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A Review of Passive Acoustics Monitoring Results in the Coastal Waters off Western Taiwan for the Past Decade

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ABSTRACT

The Taiwanese government has been actively promoting green energy development, particularly in the western region, focusing on areas such as Miaoli and Changhua, which are prime locations for offshore wind power projects. Comprehensive environmental impact assessments (EIAs), which include passive acoustic monitoring, are essential both before and during offshore wind farm development to mitigate auditory effects on marine organisms. This precaution is especially crucial due to the presence of the critically endangered Taiwanese humpback dolphins (*Sousa chinensis taiwanensis*) in the western waters. This study reviews relevant literature on passive acoustic monitoring near wind farms in Miaoli and Changhua between 2013 and 2022 to elucidate the temporal and spatial variability of marine organisms, including fish and cetaceans, and the impacts on the underwater soundscape and ecosystems. The literature review unveils how dolphins' respond to vessel transits, reducing their call rates and simplifying frequency patterns during ship construction. Long-term passive acoustic data analysis highlights heightened fish call activity in Miaoli and Changhua wind farm areas during sea surface temperature rises and new moon phases. These extensive passive monitoring initiatives not only foster harmonious coexistence of offshore wind farm development and underwater ecosystems, but also inform the formulation of precise regulatory frameworks, ecological conservation measures, and technical recommendations for future endeavors.

Keywords: Underwater soundscape, passive acoustic monitoring (PAM), long-term monitoring, wind farm.

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1 INTRODUCTION

Taiwan is situated at the convergence of two tectonic plates. In its northeastern waters, the Philippine Sea plate subducts northward under the Ryukyu arc, while in the south, the Eurasian plate subducts under the Luzon arc (Sibuet & Hsu, 2004), creating intricate seafloor topography. The eastern seabed drops to depths of 1,000 meters within 10 kilometers offshore, and is characterized by troughs, forearc basins, ridges, and ocean basins. The western continental shelf, including the Taiwan Strait, generally has depths of under 70 meters, with plains, sandbars, shoals, and sand dunes prevailing. To the south, depths range up to 1,200 meters, encompassing canyons, ridges, and submarine volcanoes. This complex topography significantly influences ocean currents, with three major water masses impacting Taiwan's waters: the mainland coastal current, the Kuroshio tributary, and the South China Sea Warm Current, particularly in the western region. The area experiences diverse seasonal currents, characterized by high coastal humidity and temperatures driven by monsoon winds (Belkin & Lee, 2014). Taiwan's marine biodiversity thrives due to its varied marine topography and hydrological conditions.

Early visual and photographic surveys were constrained by weather, walrus presence, water depth, and distance, impeding repeated assessments of organisms in specific habitats over time, hindering accurate marine biodiversity descriptions (Mooney et al., 2020). Nowadays, cost-effective passive acoustic instruments enable wide-band and long-term ocean observations, offering insights into spatiotemporal changes, including earthquakes, climate, biology, and anthropogenic activities in specific sea areas, as well as environmental changes like pile driving or dredging (Browning et al., 2017; Duarte et al., 2021; Gibb et al., 2019). To monitor earthquake and tsunami activities in Taiwan's eastern waters, the Central Weather Bureau launched the "Marine Cable Hosted Observatory (MACHO)" off the coast of Toucheng, Yilan, in 2011(Chen et al., 2012; Hsu et al., 2007). Equipped with a passive acoustic recorder and sound velocity profiler, the system allows for long-term observation of local marine mammals (Fang et al., 2012; Lin et al., 2021; Lin et al., 2015b), earthquakes (Fang, et al., 2014), and data on the physical environment, such as temperature and salinity changes, of the Kuroshio tributary (Chen et al., 2012).

In the western waters of Taiwan, spurred by the government's "Sustainable Energy Policy Framework-Saving Energy and Reducing CO_2 Emissions Action Plan" in September 2008, efforts to achieve the "Thousand Onshore and Offshore WP Turbines" program by 2011 have led to the development of a new generation of wind turbines. Subsequently, in July 2012, the Ministry of Economic Affairs (MOEA) introduced the Offshore Wind Power Demonstration Incentive Program, with the goal of increasing the share of renewable energy in electricity generation to 20% and offshore wind power generation to 5GW by 2025. Following the initiation of the Offshore Wind Power Demonstration Incentive Program, developers have commenced the construction of offshore wind turbines off Miaoli and Changhua in western Taiwan (Gao et al., 2021); (Liu & Ho, 2016). These endeavors necessitate comprehensive environmental impact assessments, including passive acoustic monitoring (Mooney et al., 2020) throughout the construction and operational phases of the wind turbines. Passive acoustic monitoring is employed to monitor the frequency of noise generated by working vessels (Guan et al., 2015) (Hu et al., 2022), high-intensity pile driving noise, and underwater vibrations during operation (Dahl et al., 2014; Popper, 2003; Popper & Hastings, 2009; Siddagangaiah et al., 2021). In this study, we conducted a review of passive acoustic monitoring data from 2013 to 2022 in wind farms near Miaoli and Changhua. Our analysis focused on elucidating the temporal and spatial variability of fish and cetaceans, as well as changes in the impacts on the underwater soundscape and ecosystems.

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2 UNDERWATER ACOUSTIC DATA COLLECTION AND COMPILATION

The Taiwanese government has segmented the offshore wind power development into three distinct phases. The first phase (2015-2020) focused on the demonstration of wind farms, involving environmental assessments conducted at the Formosa Offshore Wind Farm (FOW) site (FOW1) near Miaoli and the Taipower (TP) site (TP1) off the coast of Changhua. The second phase (2021-2025) is designated as the Potential Sites phase, with a total generation capacity of 5.5GW, with primary development and environmental assessment concentrated in the Changhua Offshore Wind Farm (refer to Figure 1 on the right). The third phase (2026-2035) is also designated as Potential Sites, with a projected total generation capacity of 15GW. This phase entails large-scale block development, with wind farms distributed across water depths ranging from 40 to 70 meters. Please refer to Figure 1 for the distribution of wind farms and the current development progress.

Following the announcement of the Offshore Wind Power Demonstration Incentive Program by the Taiwanese government in 2012, the Miaoli Demonstration Wind Farm underwent environmental assessment in 2013. Subsequently, the construction of the meteorological observation tower was completed in 2015, and the two demonstration wind turbines were erected in 2016 (refer to the right figure in Figure 1). The first phase of operations commenced in 2017, and following the successful completion of the second phase of the Environmental Impact Assessment (EIA) by the end of 2019, the second phase of operations began. As per government regulations mandating a comprehensive EIA for demonstration wind farms, including pre-construction, construction, and operation stages, this study incorporates passive acoustic data from the Miaoli demonstration wind farm (refer to the upper panel of Figure 3). The measurement period spans the pre-construction EIA phase (2013-2015), construction phase (2015-2019), and operational phase (2017-2022). Additionally, passive acoustic monitoring locations for the demonstration wind farm (refer to the upper-left figure in Figure 2) adhere to government regulations, situated within the neighboring protected area (northern point or MLn, 3.6 km away from the MLs point) and within the predetermined wind farm (southern MLs location, 660 meters away from the wind farm) for comparison purposes. For comprehensive measurement of pile driving and operation noise, pile driving noise was assessed at a distance of 750 meters from the wind turbine foundation piles, while operation noise was monitored at a distance of 10 meters from the wind turbine foundation piles, as referenced in Figure 3 above. The aforementioned data are integrated into the passive acoustic data presented in Figure 3 below (markers #21 and #28).

The Changhua Demonstration Wind Farm underwent environmental assessment in 2015, completed the construction of the marine meteorological observation tower in 2016, and finalized the installation of 21 demonstration wind turbines by 2021 (please refer to Figure 1). Operations commenced in 2021, and as such, the passive acoustic data from the Changhua Demonstration Wind Farm has been incorporated into this study (refer to the lower figure of Figure 3). The measurement period encompasses the pre-construction environmental assessment phase (2013-2016), construction phase (2016-2021), and operational phase (2021-2022). Passive acoustic monitoring points (refer to the lower-left figure in Figure 2) mirror those of the Miaoli demonstration wind farm, with one measurement point in the north and another in the south. The CHn point in the north (5.5 km offshore and 11.5 km from the CHs point) is situated near the protected area, while the CHs point in the south is selected for its proximity to the protected area and adjacency to the wind farm (1.2 km from the wind farm).

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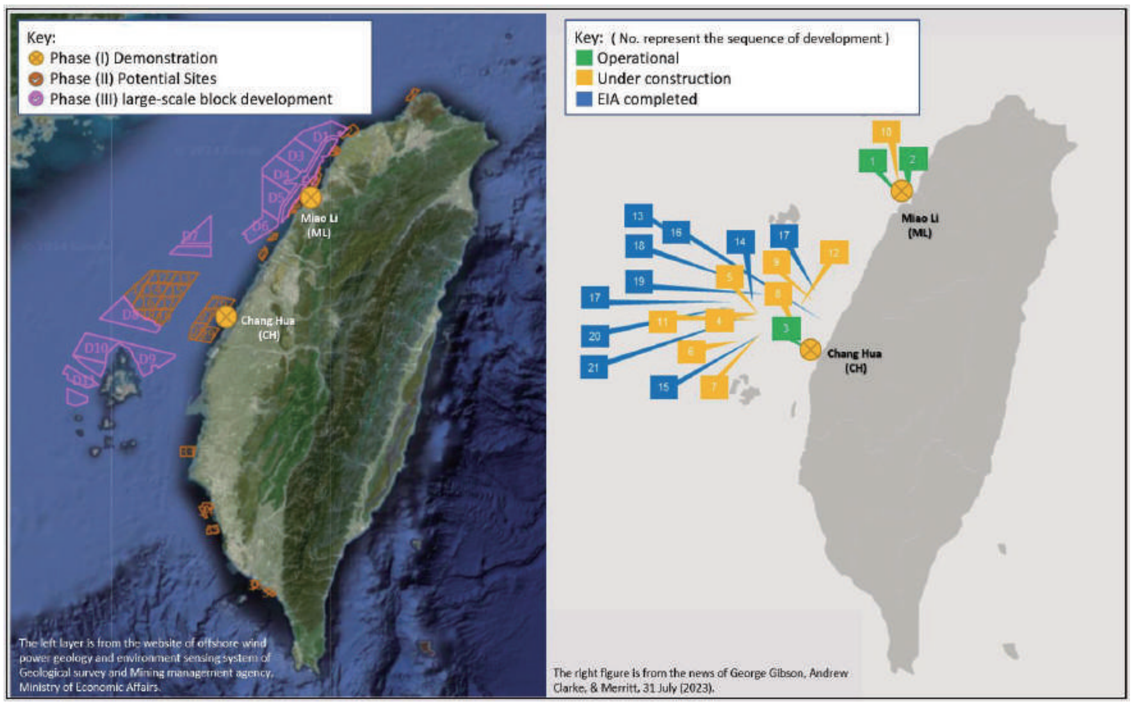

Figure 1. Mapping offshore wind farm locations across three development phases (Left) and current progress status of each wind farm (Right). (Norton Rose Fulbright, 2023, July 31)

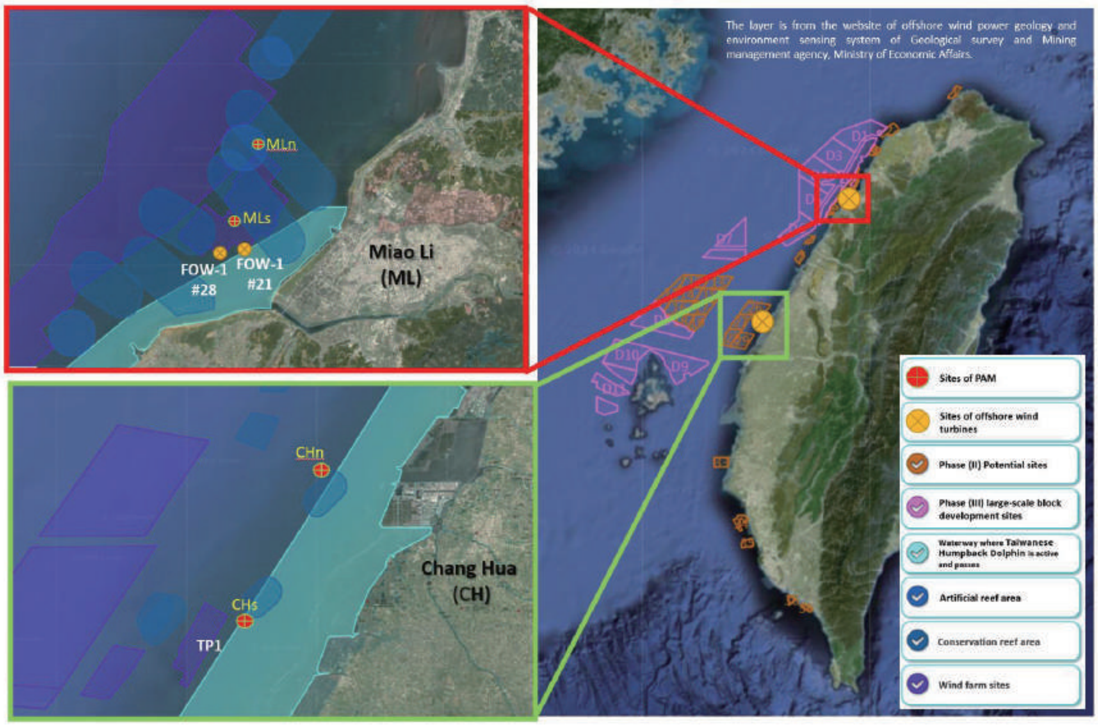

Figure 2. Geographic location of Phase (I) wind farms in Miaoli and Changhua, alongside PAM deployment sites, protective reefs, and Taiwanese Humpback Dolphin (THD) corridors.

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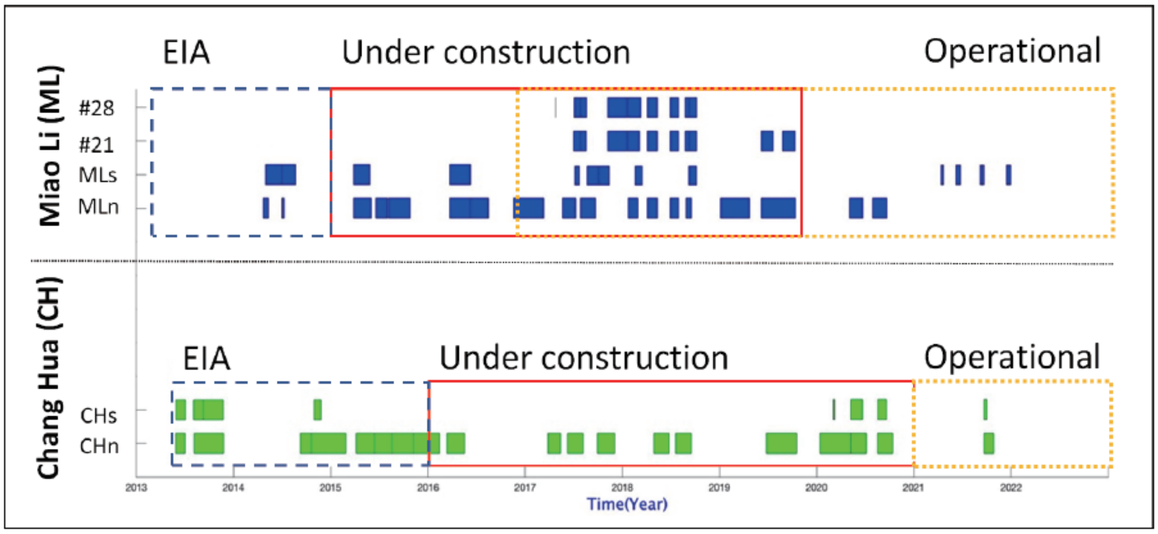

Figure 3. Operational timeline of initial phase wind farms in Miaoli (Miao Li) and Changhua (Chang Hua) and corresponding PAM data recording periods. The blue dotted line indicates the Environmental Impact Assessment (EIA) period, the red solid line denotes the construction phase, and the orange dotted line represents the operational phase.

The selection of passive acoustic monitoring sites considers multiple factors, including the proximity of protected areas to capture local organism sounds, the distance from wind farms to monitor wind farm noise, and the water depth at which instruments are deployed, taking into account the presence of whales and dolphins commonly found in the nearshore areas of the Taiwan Strait. Based on the 2023 stranding annual report by the Marine Animal Rescue Network and the Ocean Conservation Administration, which identifies approximately 18 cetacean species stranded in Taiwan's waters (refer to Figure 4), including Kinmen-Matsu-Penghu waters (Maine Animal Rescue Network, 2023), it was noted that *Sousa chinensis taiwanensis,* an endemic subspecies, has been reported stranded in Taiwan. This endemic subspecies is classified as Critically Endangered (CR) according to the IUCN Red List of Threatened Species (Chen & Lee, 2023; Jefferson & Smith, 2016; Wang et al., 2016). Given its distribution area's proximity to the Miaoli and Changhua demonstration wind farms, as illustrated by the blue-green THD activity range in Figure 2, it is essential to consider this species' habitat requirements.

According to Austin & Matthews (2024), Taiwanese humpback dolphin inhabits inshore waters less than 20 meters deep (Austin & Matthews, 2024). Therefore, passive acoustic monitoring site deployment in Miaoli is based on selecting water depths where Taiwanese humpback dolphins are more likely to be found. Consequently, the water depth at the Miaoli passive acoustic monitoring site was approximately 20 meters, while at the Changhua passive acoustic monitoring site, it was about 18 meters.

According to the ISO 18406 standard, instrument deployment for pile driving noise measurement can be categorized into surface deployment, bottom-mounted deployment, and bottom-mounted deployment with acoustic release (ISO 18406, 2017). Among these, bottom-mounted deployment is deemed superior to surface deployment. Surface deployment aims to minimize the effect of surface wave action and interference from surface vessels by placing the water listener far from the pressure-release water-air surface (ISO 18406, 2017). However, if particular attention is required for noise impact from species near or on the seafloor, or if pile driving generates surface waves on the seafloor around the piles, bottom-anchored instrumentation is recommended for measurements (Bundesamt für Seeschifffahrt und Hydrographie, 2011; Robinson et al., 2014).

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Additionally, in waters with strong currents or tidal currents, current movement may displace the cable under the hydrophone, causing cable noise due to resonance (Robinson et al., 2014). Therefore, in the Miaoli and Changhua wind farms studied here, measurement instruments were deployed in a bottom-anchor type with a sand anchor, and the underwater microphones were positioned at a height of 2 meters from the seafloor (refer to Figure 5).

The passive acoustic monitoring instruments utilized in the Miaoli and Changhua wind farms were manufactured by Wildlife Acoustics, employing underwater listeners for continuous recording, with each audio file lasting 60 minutes and recorded in WAV format. The sensitivity of the matched underwater microphone ranged from -164 to -165 dB re:1 v/μPa (Siddagangaiah et al., 2024; Siddagangaiah et al., 2022a; Siddagangaiah et al., 2022b), calibrated using a pistonphone (Chandapillai, 2016) before and after each sea trip in accordance with the NIEA P210.21B measurement method (NIEA P210.21B, 2019). Additionally, during measurements, a temperature-depth meter was installed next to the passive acoustic monitoring instrument, with a sampling frequency of once per minute, to simultaneously monitor temperature changes.

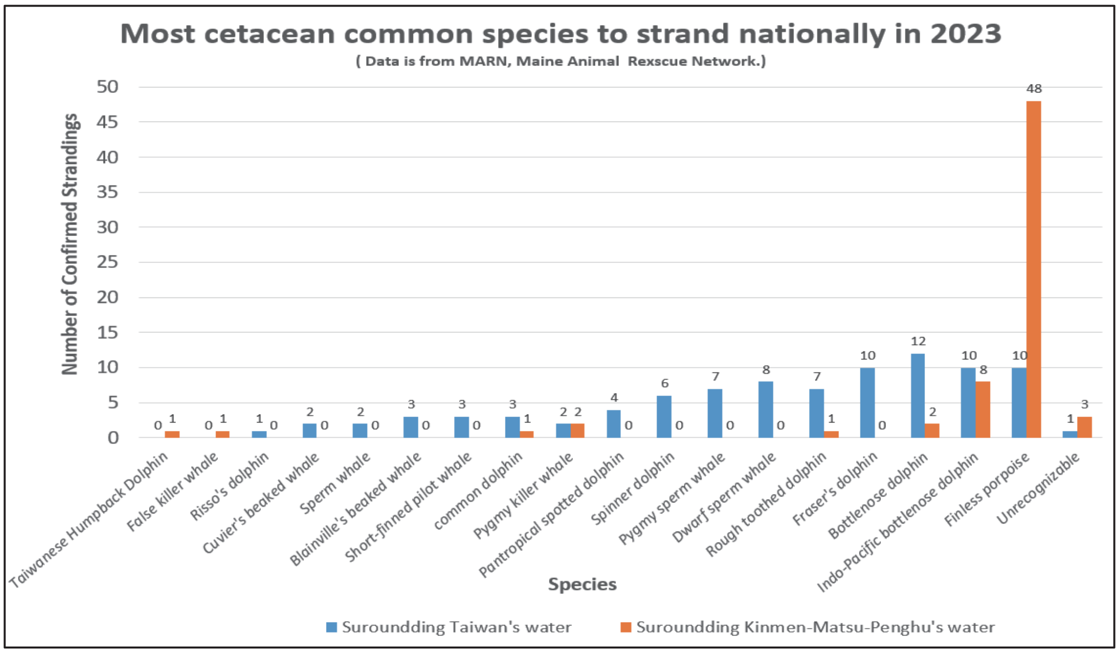

Figure 4. Most cetacean common species to strand nationally in 2023 (Maine Animal Rescue Network, 2023).

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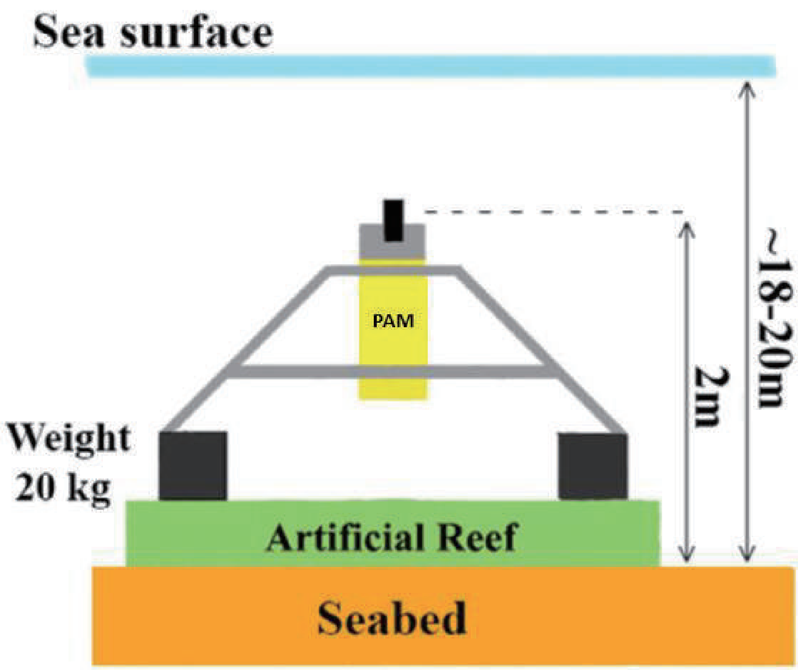

Figure 5. Diagram of bottom-mounted passive acoustic monitoring system (Siddagangaiah et al., 2022b).

3 EXPLORING BIOPHONY IN THE SOUNDSCAPE

Raimbault et al. (2005) and Dubois et al. (2006) advocate the use of the term "soundscape" to delineate the spatial arrangement of sound, aiming to circumvent the inherent limitations associated with the term "noise" and promote a more nuanced understanding of the acoustic environment. The underwater soundscape encompasses three main components: anthrophony, biophony, and geophony. Anthrophony comprises sounds generated by human activities such as ship noises, pile driving noise, naval sonar signals, geophysical surveys, underwater communications, and other marine engineering-related activities. Biophony encompasses sounds produced by marine organisms, including cetaceans, dolphins, fish, and other fauna. Geophony encompasses sounds arising from natural phenomena such as winds, waves, rain, ice, earthquakes, and volcanic eruptions.

Merchant et al. (2013; 2015) utilized metrics such as sound pressure level (SPL) or power spectral density (PSD), which offer spectral information, and sound exposure level (SEL), which integrates a temporal dimension, to analyze diverse types of sound sources detected by passive acoustic monitoring (PAM). Sertlek et al. (2016) argued that it is not feasible to ascertain the proportion of each source within a specific volume, whereas Ainslie et al. countered this, demonstrating that the proportion of each source within a specified time frame can indeed be measured (Ainslie et al., 2018). They showed that it is possible to determine the percentage of time occupied by each source over a specified observation period (e.g., temporal window duration of 60 seconds), enabling qualitative quantification of soundscape metrics for anthrophony, biophony, and geophony.

This section delves into the soundscape metrics of anthrophony, biophony, and geophony from 2013 onwards, specifically focusing on the underwater soundscape of the wind farms in Miaoli and Changhua from 2013 to 2022, which includes whale and dolphin vocalizations and fish choruses.

3.1 Cetacean soundscape

Cetaceans utilize whistles for various purposes including socialization, foraging, and reproduction (Dungan et al., 2016; Hu et al., 2022). They also use broadband echoes to localize clicks for navigation, prey, and object recognition (Lin et al., 2013a, 2015a). Whistles and clicks serve as signature signals for individual identification (Cheng et al., 2017). The recognition of dolphin whistles and clicks can be achieved using PAMGuide, a visual analysis tool widely employed in the biological community (Hu et al., 2022; Rodríguez et al., 2021), in conjunction with auditory (visual and aural) recognition. Additionally, dolphin sound detectors such as entropy detectors (Erbe & King, 2008), bandpass energy detectors (Erbe & King, 2008), edge detectors (Gillespie, 2004), and local-max detectors (Zimmer, 2011) can be utilized for recognizing whistles and clicks. Lin (2013b) developed an enhanced version of the local-max detector without contour extraction and introduced noise-filtering procedures for detecting whale whistles in the waters surrounding Taiwan.

Hu (2022) analyzed data from the operational period of turbine No. 28 in the Changhua Demonstration Wind Farm, located near turbine FOW-1 (#28) (refer to Figure 2, with the measurement location approximately 10 m near turbine #28), covering the period from May 1 to July 31, 2017. Referencing Figure 3, the data time of turbine #28 in this period is indicated by the orange dotted line, corresponding to the operational period of the turbine. Taiwanese humpback dolphin (*Sousa chinensis taiwanensis*) whistles were classified into seven types based on visual and auditory criteria, denoted as Type 1 to Type 7. Simple types exhibiting no obvious curvilinear changes, such as flat, ascending, or descending shapes, include Type 2, Type 3, Type 4, Type 5, and Type 6. As illustrated in Figure 6, simple types without apparent curvilinear changes, including flat, ascending, or descending shapes, encompass Type 2, Type 3, and Type 5. Complex types characterized by curvilinear changes, such as U-shaped, J-shaped, and tangent shapes, comprise Type 1, Type 4, Type 6, and Type 7 (Hu et al., 2022).

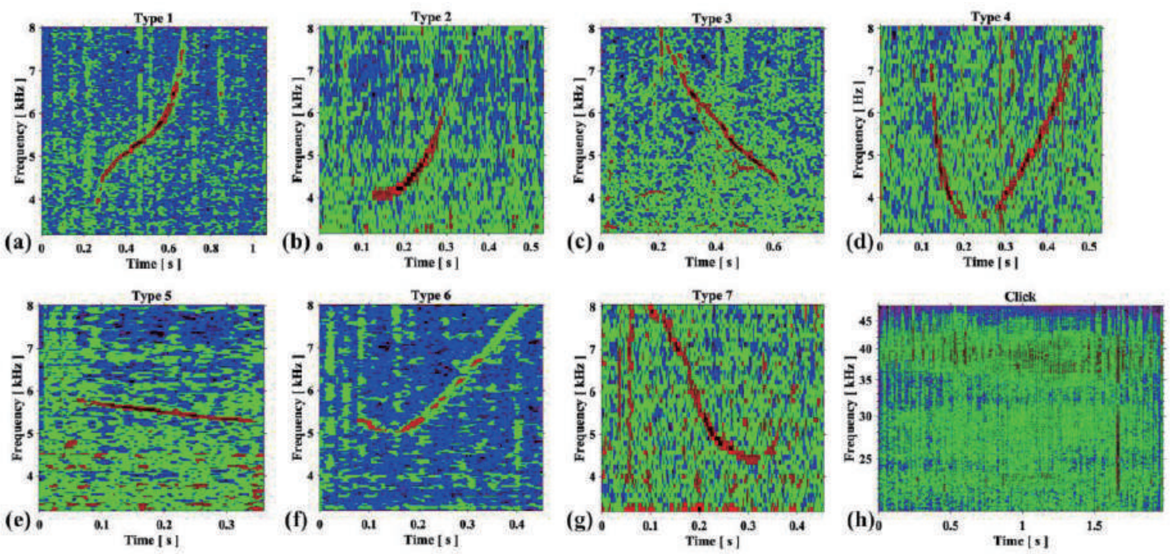

Figure 6. Spectrograms of whistling tract types produced by Taiwanese humpback dolphins in the Changhua Demonstration Wind Farm (a-g) whistles and (h) clicks (Hu et al., 2022).

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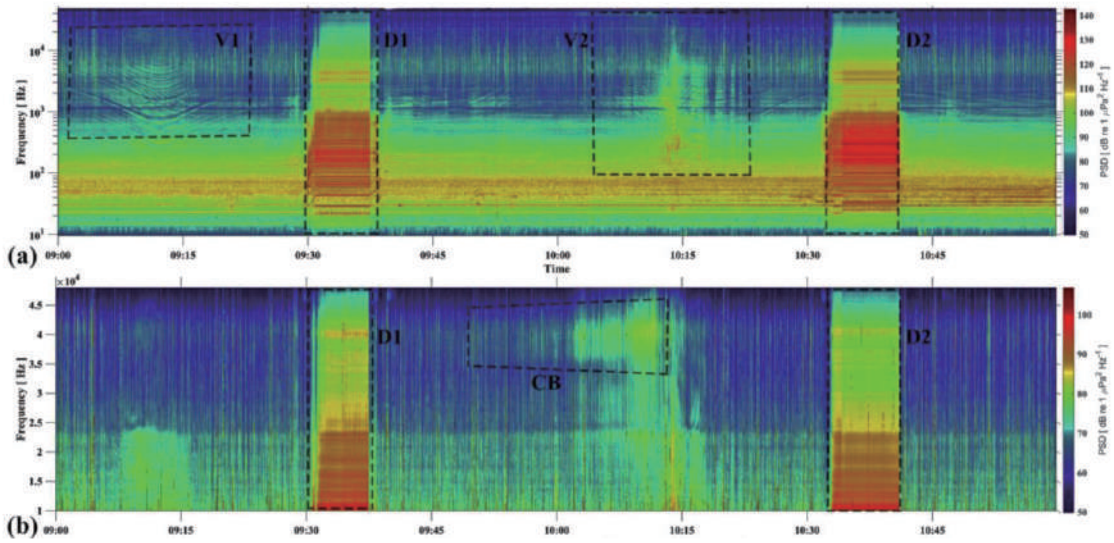

Figure 7. PAM recordings from the Changhua Demonstration Wind Farm on May 10, 2017: (a) Logarithmic scale spectrograms (10-48 kHz) illustrating ship noise (V1 and V2) and dredging construction (D1 and D2). (b) Linear scale spectrograms (10-48 kHz) displaying click bursts (CB) emitted by dolphins (Hu et al., 2022).

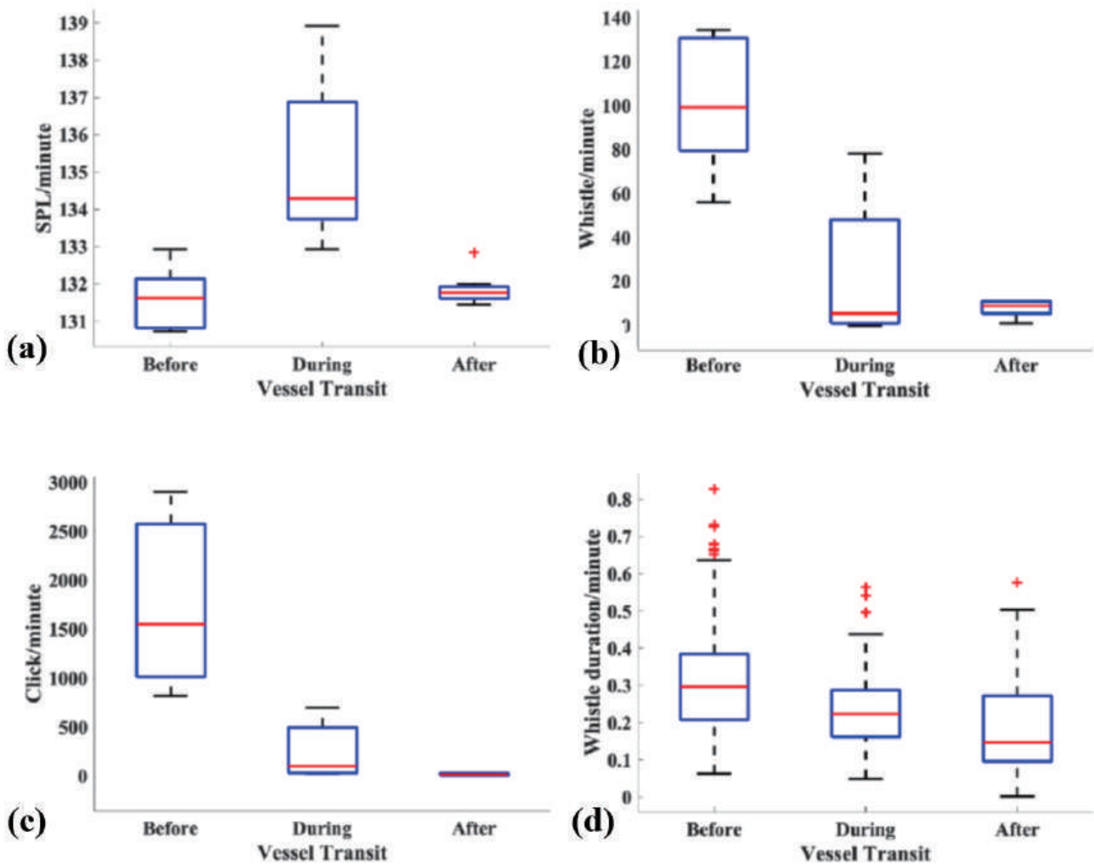

Figure 8. Dolphin whistle and click activity variation in response to passing ships (Data recorded at the Changhua Demonstration Wind Farm on May 10, 2017) (a) Sound pressure level (SPL); (b) whistles; (c) clicks; (d) whistle duration (Hu et al., 2022).

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During the operational period of turbines No. 28 and No. 21, as well as the construction period of other turbines, passive acoustic sound files captured ship noise, marine engineering noise, and vocalizations of whales and dolphins, as depicted in Figure 7. Ship noise and dredging operations at marine works are labeled as V1, V2, D1, and D2, respectively, while the click burst of dolphins is labeled as CB (Hu et al., 2022).

Given that the energy of dredging noise typically falls below 1 kHz, it is less likely to overlap with the vocal frequency bands of dolphins (Todd et al., 2015) or Taiwanese humpback dolphins. Therefore, this study exclusively examines the impact of vessel noise on the Taiwanese humpback dolphin based on seven identified noise characteristics. Figure 8 illustrates the comparison of changes in the number of whistles and clicks of dolphins as vessels pass by.

Each box plot's central red mark represents the median, while the top and bottom edges indicate the 25th and 75th percentiles. The whiskers denote the maximum and minimum values, with anomalous values indicated by "+". Analysis of the graphs reveals an increase in the sound pressure level of cetacean calls and a decrease in the number of whistles and clicks, as well as the duration of whistles, during vessel passages. This suggests that dolphins respond to vessel passages by reducing their call rate and producing shorter calls with simpler frequency patterns.

3.2 Fish soundscape

Choral singing among fish is a prevalent phenomenon observed in passive acoustic sound files, serving various behavioral functions such as social cohesion (Van Oosterom et al., 2016), territorial defense (Buscaino et al., 2015), foraging (Versluis et al., 2000), and spawning activity (Buscaino et al., 2016; Ladich & Fine, 2006; Siddagangaiah et al., 2021). These choruses exhibit cyclical patterns, influenced by lunar phases such as full or new moons (Buscaino et al., 2016; Ladich & Fine, 2006; Siddagangaiah et al., 2021).

Due to physiological constraints, fish possess a limited contraction rate of sonic swim bladder muscles, restricting the vocal frequency band to primary energy levels below 1000 Hz (Ladich & Fine, 2006).

Ecologists utilize concepts such as nonlinear dynamics, predictability, complexity, and regularity (Dakos, 2020) to analyze ecosystems (Siddagangaiah et al., 2022a). These concepts can also be applied to passive acoustic sound files for analyzing their complexity, regularity, predictability, and dynamics (Siddagangaiah et al., 2021). Rosso et al. (2007) developed the complexity-entropy (C-H) method, employing statistical complexity (C) and permutation entropy (H), to distinguish between noise and chaos. This method, which quantifies complexity indices, has been practically applied to the Miaoli and Changhua demonstration wind farms for detecting fish choruses (Siddagangaiah et al., 2019). It enables the tracking of fish choruses even amidst noisy ship transportation (Siddagangaiah et al., 2021).

In a study conducted by Mok's team (2009) in the coastal waters of estuaries in Taiwan, vocal fish species belonging to the Sciaenidae family, such as the blackspotted croaker (*Protonibea diacanthus*), Japanese croaker, and big-snout croaker, were identified. These fish exhibit vocal characteristics consisting of pulses (Mok et al., 2009), as illustrated in Figure 9. In the present study, conducted at the Miaoli Demonstration Wind Farm between 2016 and 2017, the call spectra of two distinct types of fish with differing pulse patterns were identified. Please refer to Figure 10 for details. Type 1 exhibited a peak frequency of 1.8 kHz, enabling continuous singing for durations of 5-9 hours. Conversely, Type 2 displayed peak frequencies of 0.7 kHz and 1.7 kHz, allowing for singing periods of 1.5-3 hours.

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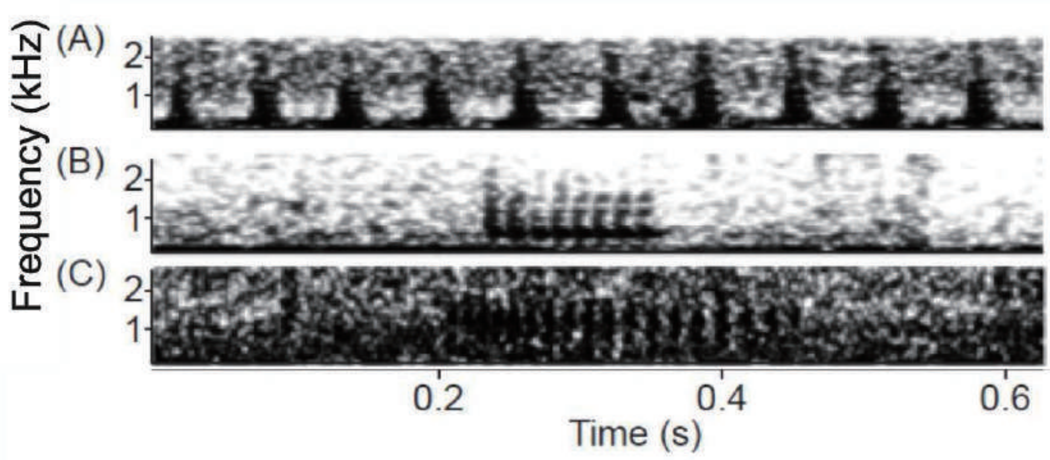

Figure 9. Spectrogram of fish chorus recorded by Mok's team in coastal waters of Taiwan in 2009. (A) Blackspotted croaker; (B) Japanese croaker and (C) big-snout croaker sounds (Mok et al., 2009)

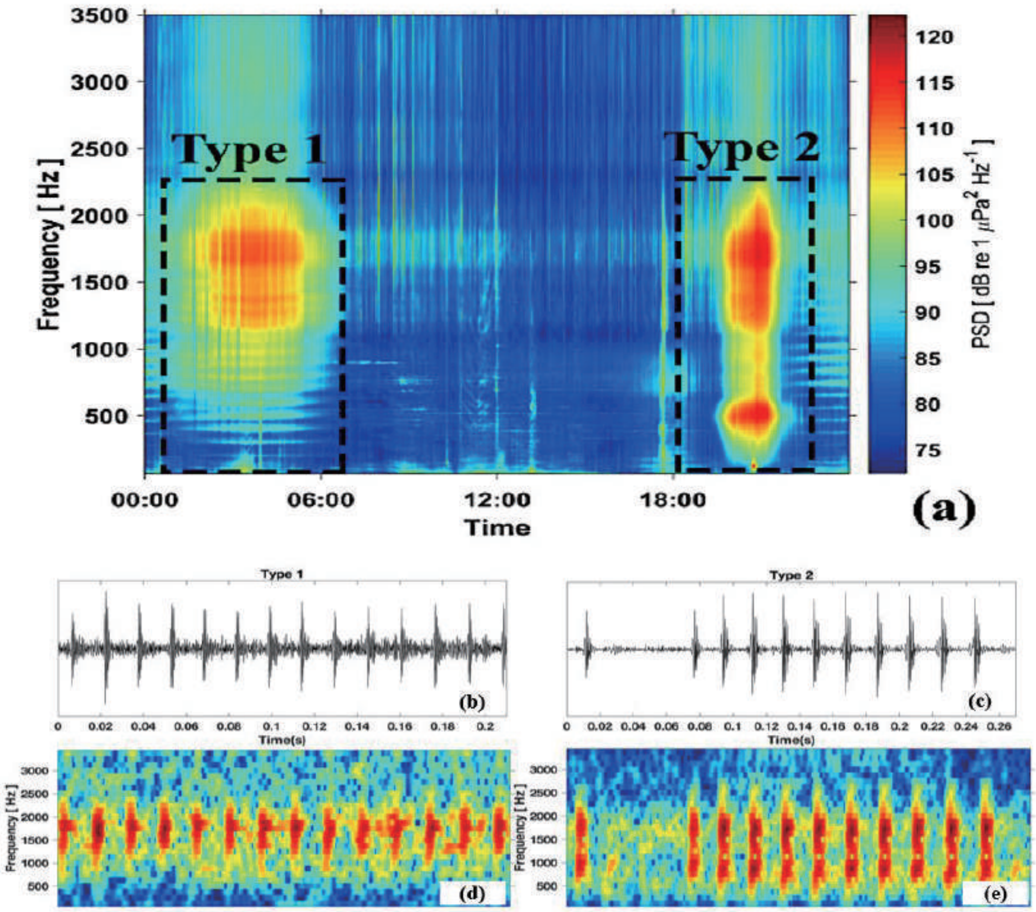

Figure 10. Spectrum of two different fish chorus found in the Miaoli Demonstration Wind Farm. (a) Spectrogram of Type 1 and Type 2; (b) waveform of Types 1; (c) waveform of Types 2; (d) zooming the spectrogram of Type 1; (e) zooming the spectrogram of Type 2. (Siddagangaiah et al., 2022b)

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The C-H method, as outlined by Siddagangaiah et al. (2019), was employed to develop an automated acoustic indicator for extracting fish calls from the PAM recording data in both the Miaoli Demonstration Wind Farm (Site MLn) and the Changhua Demonstration Wind Farm (Site CHn), as depicted in Figure 2. This analysis covers the period from 2016 to 2017. Subsequently, analyzing the variation of sound pressure level during a 24-hour cycle from 2016 to 2017, based on the detected fish call events, revealed two distinct peaks occurring near dawn and dusk, as illustrated in Figure 11.

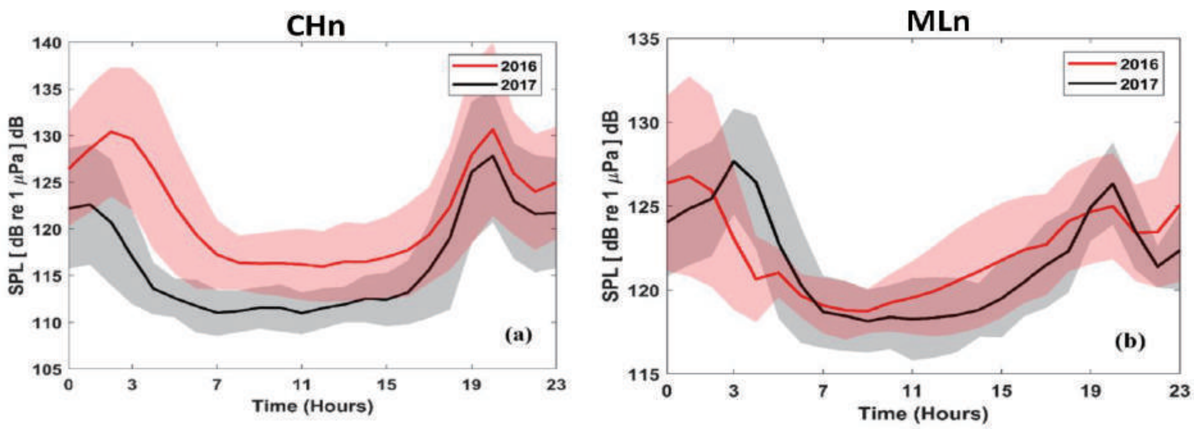

Figure 11. Diagram depicting the overall regular nocturnal fish chorusing behavior observed over 30 days at average SPL in the hourly 500 to 2500 Hz frequency band in Site CHn and MLn (Siddagangaiah et al., 2019).

The activities and behaviors of marine organisms are intricately linked to their natural environment. However, the complex interplay of various external factors necessitates an individual analysis of each environmental factor's correlation with marine organisms' activities. Through an analysis of data collected in Changhua in 2017, it was observed that fish chorusing demonstrates a close relationship with sea surface temperatures across different seasons, as depicted in Figure 12. The correlation coefficients (R values) between the seasonal temperature trend (Figure 12, top) and the sound pressure level (SPL) trend (Figure 12, bottom) indicate a strong association between different temperatures and SPL levels. Specifically, the R value in spring is 0.98, in summer it is 0.97, and in autumn-winter it is 0.96. This suggests that as sea surface temperatures rise, the frequency of fish chorusing also increases (Siddagangaiah et al., 2021).

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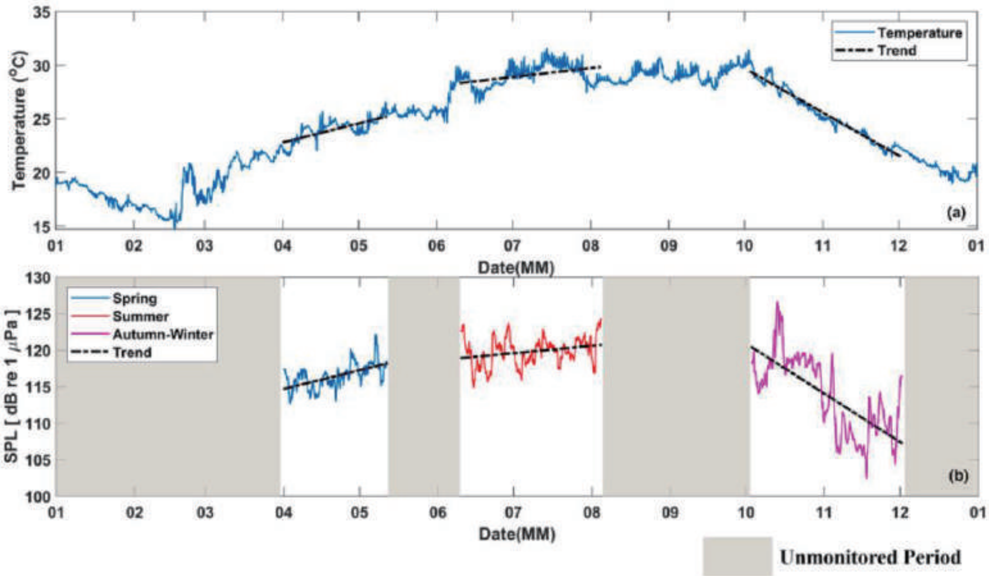

Figure 12. (Top) Diagram of sea surface temperature changes throughout 2017. (Bottom) Diagram of seasonal SPL changes in 2017. The black dotted line represents the corresponding temperature and SPL changing trends. (Siddagangaiah et al., 2021)

Lunar cycles and tides also exert an influence on fish chorusing activity, as depicted in Figure 13. The tidal patterns observed in the Changhua area are characterized by semi-diurnal tides. During full moon and new moon periods, there is a correlation between the rise in tidal height and the intensification of fish chorusing, with an associated R value of 0.6 (Siddagangaiah et al., 2021). When either a full moon or new moon (black circle) occurs, the water level during high tide is elevated, leading to an increase in the sound pressure level (SPL) of fish chorusing. This heightened intensity is particularly notable during the new moon phase, suggesting that fish may display increased activity levels during this lunar cycle.

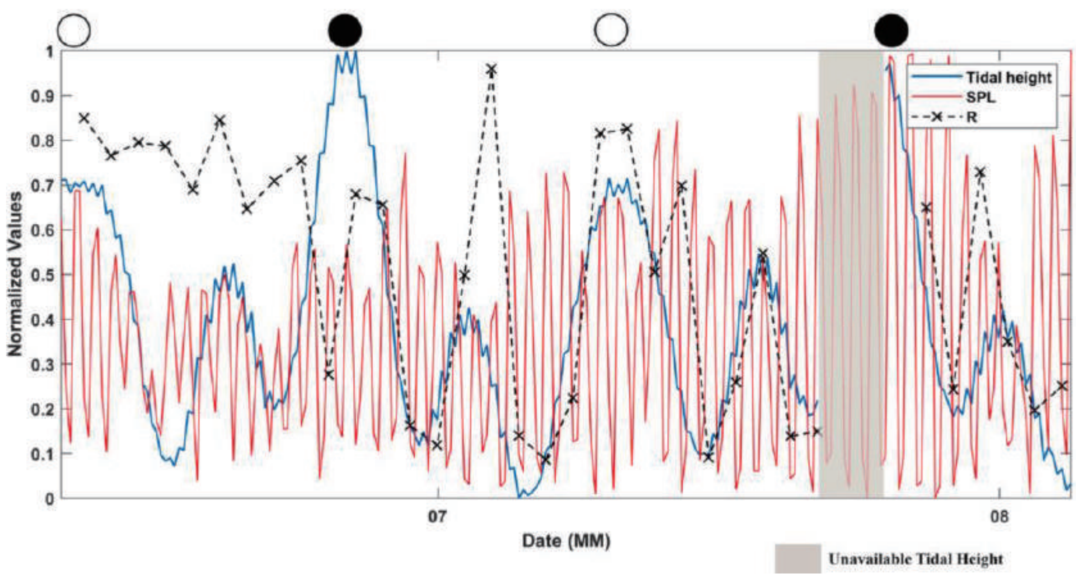

Figure 13. Normalized values of tide height and peak values of SPL of fish chorusing in summer 2017. The corresponding Pearson correlation coefficient R (calculated every 36 hours) is shown by the dotted black line; the white circle is the full moon and the black circle is the new moon. (Siddagangaiah et al., 2021)

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4 CONCLUSIONS

In conclusion, our analysis of nearly a decade of passive acoustic monitoring data in the western waters of Taiwan not only reveals significant correlations within the biophony component of the soundscape via an automated acoustic indicator, but also identifies heightened fish calls associated with rises in sea surface temperature and during new moon phases across seasons. Additionally, our findings highlight the crucial importance of conducting comprehensive underwater acoustic surveys before, during, and after the construction and operational phases of offshore wind farms, mitigating the impact of vessel traffic on Taiwanese humpback dolphin encounters. Despite historical challenges in conducting sea experiments due to adverse weather conditions, leading to limited acoustic data availability, especially during winter and in offshore regions, passive acoustic monitoring remains an invaluable tool for evaluating the spatial and temporal distribution and variability of cetaceans and fishes. As emphasized by Cotter (2008), the underwater soundscape is instrumental in providing essential information to fish and other marine organisms. Furthermore, passive acoustic measure ments serve as indispensable assets in marine biology and fisheries research (Cotter, 2008), facilitating the observation of dynamic ecosystem changes and enabling the establishment of baseline data for future assessments (Ahonen et al., 2017).

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