



# Fish chorus contributions to Australian underwater soundscapes

Lauren Amy Hawkins (1) and Miles J. G. Parsons (2,3)

- (1) Department of Biodiversity, Conservation and Attractions, Kensington, Western Australia  
(2) Australian Institute for Marine Science, Crawley, Western Australia  
(3) Centre for Marine Science and Technology, Curtin University, Bentley, Western Australia

## ABSTRACT

Aggregations of vocalising fish characterise and often dominate Australian underwater soundscapes. These continuous calling events are known as fish choruses and are produced in association with particular life functions of the respective fish source species. Over 300 fish choruses have been detected across Australian marine and estuarine waters and have subsequently been described in the Australian Fish Chorus Catalogue (AFCC). However, a comprehensive analysis of the spatiotemporal distribution of the AFCC choruses and the number of unique fish chorus types recorded within the catalogue has not yet been conducted. In this study, publicly accessible AFCC records were analysed to examine broad-scale patterns in the spatial, temporal, and spectral characteristics of Australian fish choruses. A combination of manual identification and clustering analysis was also applied to AFCC spectral records to estimate the number of fish chorus types recorded in the catalogue. Australian fish choruses were widely distributed across a myriad of aquatic habitat types with significant variation evident in the temporal distribution and spectral characteristics of these choruses. This study estimated that over 100 unique fish chorus types have been identified within the AFCC. Several fish chorus types demonstrated potentially significant geographic distributions, warranting future ground-truthing efforts to identify the source species. This study demonstrates the value of regional sound libraries as foundations for addressing large-scale ecological questions. The AFCC provides a scalable framework for passive acoustic monitoring that can support biodiversity assessments, habitat mapping, and conservation planning.

## 1 INTRODUCTION

Fish choruses are a widespread biophonic phenomenon in underwater ecosystems (Hawkins et al. 2025b), occurring when numerous individuals vocalise simultaneously over extended periods, elevating sound levels within characteristic frequency bands (Cato 1978; McCauley 2001). These choruses have been linked to life functions such as feeding, spawning, and aggregation (Hawkins et al. 2025b). Passive acoustic monitoring (PAM) provides a powerful, non-invasive method for studying these events, offering insights into fish distribution, habitat use, and reproductive dynamics, and informing management of fish populations and their habitats (Stratoudakis et al. 2024). However, most existing studies have focused on specific regions or species, leaving broad-scale patterns in fish chorus distribution, habitat associations, and acoustic diversity largely unexplored.

To address this gap, the Australian Fish Chorus Catalogue (AFCC) was developed as a publicly accessible national inventory of fish chorus contributions to Australian underwater soundscapes (Hawkins et al. 2024a). This study presents a synthesis of the AFCC dataset, examining large-scale spatial, temporal, and spectral patterns across more than 300 documented fish choruses collected across 83 recording sites in marine and estuarine waters. This work provides a foundational resource for future research aimed at understanding the ecological and environmental factors influencing fish acoustic behaviour. It also highlights the value of sound libraries in supporting biodiversity monitoring, ecological research, and marine resource management using passive acoustic data.

## 2 METHODS

The AFCC is a publicly accessible data repository hosted on the Australian Ocean Data Network (AODN). The repository contains audible and spectral examples, deployment metadata, individual spectral measurements from 24-hour recordings, and monthly distribution records for 301 fish choruses (Hawkins et al. 2024a). A detailed description of the AFCC, including data acquisition and fish chorus identification methods, is provided in Hawkins et al. (2024a) and is not repeated here. In this study, AFCC records were analysed to investigate large-scale

ecological patterns in the spatiotemporal distribution and spectral characteristics of Australian fish choruses, and to undertake classification of fish chorus types.

Spatial patterns of fish chorusing in Australian waters were examined by measuring the number of distinct chorus types detected per site over its respective recording period, henceforth referred to as fish chorus richness. Fish chorus richness was then compared across climate regions, benthic substrate types, and geomorphic feature types. Coordinates for each AFCC site were retrieved from the AFCC deployment information table ("AFCC\_deployment\_information.pdf") and were then classified by climate region—tropical (<25°S), subtropical (25–30°S), and temperate (>30°S). Sites were also categorised by benthic substrate type using the CAMRIS benthic substrate map (CSIRO, 2015), and by geomorphic feature type using the Geomorphic Features 2006 dataset (Heap & Harris, 2006), with an additional "estuary" classification included. It is important to note that this analysis did not account for variation in the duration of site-specific recording periods. Since fish chorus production can be highly seasonal (e.g., Parsons et al. 2016), sites with less than one full year of data are unlikely to capture the true extent of the diversity of chorus types present. Of the 83 AFCC recording sites, only 30 had at least one year of continuous acoustic data (Hawkins et al. 2024b, "AFCC\_seasonal\_presence.csv"). Therefore, fish chorus richness estimates of the remaining sites—those with shorter recording durations—should be interpreted as conservative, likely an underestimation of the true fish chorus richness of the respective site due to limited temporal coverage.

Seasonal patterns in chorus activity were analysed using the AFCC seasonal presence-absence summary file ("AFCC\_seasonal\_presence.csv"), which records monthly detections ("1"), non-detections ("0"), and instances of masking or missing data ("2" or "3" respectively) for each chorus type (Hawkins et al. 2024a). To quantify seasonal presence across climate regions, the percentage of monthly detections – henceforth termed percentage presence - was calculated using the following equation:

$$P = \frac{FC_p}{FC_t} \times 100$$

Where  $P$  is percentage presence of AFCC fish chorus types for a given month within a specific climate region.  $FC_p$  is the number of AFCC fish chorus type detections recorded that month in that region as per the presence-absence summary file.  $FC_t$  is the total number of AFCC fish chorus types that could have been detected (i.e., the total number of AFCC fish chorus types detected in that region in the AFCC, accounting for all valid detection opportunities including both non-detections ("0") and detections ("1"), Hawkins et al. 2024a). For example, if 12 different AFCC fish chorus types are known to occur in tropical regions, and 2 of them were detected in February, but 3 could not be detected due to ambient noise masking and/or lack of recordings, then  $FC_p = 2$  and  $FC_t = 9$ , yielding a percentage presence of 22.2%.

Patterns in the spectral characteristics of the AFCC fish choruses were investigated by summarising and visualising spectral measurements of a subset of spectral parameters provided in the AFCC measurement excel sheet, "AFCC\_measurement\_spreadsheet.csv" (Hawkins et al. 2024a). These parameters included minimum frequency, maximum frequency, peak frequency, centre frequency, root-mean-square bandwidth (the difference between the high and low frequencies of the square root of the second moment of the signal's squared amplitude spectrum), root-mean-square low frequency (the low frequency of the square root of the second moment of the signal's squared amplitude spectrum), root-mean-square high frequency (the high frequency of the square root of the second moment of the signal's squared amplitude spectrum), and 90% energy bandwidth (frequency range that contains 90% of the total energy of the signal) (Erbe et al. 2022; Hawkins et al. 2024a). The AFCC measurement file provides a singular representative measurement of these spectral parameters for most of the AFCC fish choruses calculated over one 24-h recording period when masking from ambient sound sources was minimised (Hawkins et al. 2024a).

The AFCC fish choruses were classified in one of ten broad categories of call types via one-operator manual scrutiny of chorus-specific spectrographic and audio records held within the AFCC repository (Hawkins et al. 2024a): down-sweeps; up-sweeps; low-frequency pulse series; mid-frequency pulse series; high-frequency pulse series; tonals; tonal up-sweeps; tonal down-sweeps; other call types; and unknown call types. These categories have previously been defined and applied to Australian fish choruses by Hawkins et al. (2023), developed from established call descriptions by Parsons et al. (2016), Di Iorio et al. (2018), Desiderà, et al. (2019), and Raick et al. (2023).

A combination of manual identification and clustering analyses was applied to the above-mentioned subset of AFCC spectral records to classify the AFCC choruses to type and estimate the number of unique fish chorus types recorded in the AFCC. Fish choruses often exhibit species-specific spectral characteristics and/or temporal patterns (Parsons et al. 2013; Stratoudakis et al. 2024). Consequently, it was assumed that AFCC fish choruses which demonstrated similar spectral characteristics could be produced by the same or closely related fish species. Mixed-Type data clustering analysis was undertaken in RStudio using the *clustMixType* software package

(Szepannek 2018). Clustering analysis was applied to chorus-specific data including call-type, and measures of minimum frequency, maximum frequency, peak frequency, centre frequency, root-mean-square bandwidth, root-mean-square low frequency, root-mean-square high frequency, and 90% energy bandwidth. AFCC fish choruses classified with an unknown call type were excluded from this analysis. The clusters were then manually reviewed and revised as necessary using the AFCC audible and spectrographic records as a reference.

### 3 RESULTS

#### 3.1 Spatial distribution

The AFCC fish choruses were distributed in marine waters all around the continent in addition to several estuaries. Most recording locations analysed in the AFCC were located across tropical waters of Australia, predominantly restricted to the western side of the continent due to sampling effort (Figure 1a). The number of tropical recording locations was almost double the number of temperate recording locations, while the number of subtropical recording locations included in the AFCC were very few (Figure 1b). The reduced area available for recordings to be collected in the subtropical region in comparison to the tropical and temperate regions likely contributes to the lack of available recordings in this climate region. On average, tropical recording locations demonstrated the highest per site richness of fish chorus detections, while the temperate recording sites demonstrated the lowest (Figure 1c). The range of fish chorus richness detected at the tropical recording locations was also more variable in comparison to the subtropical and temperate recording sites (Figure 1c).

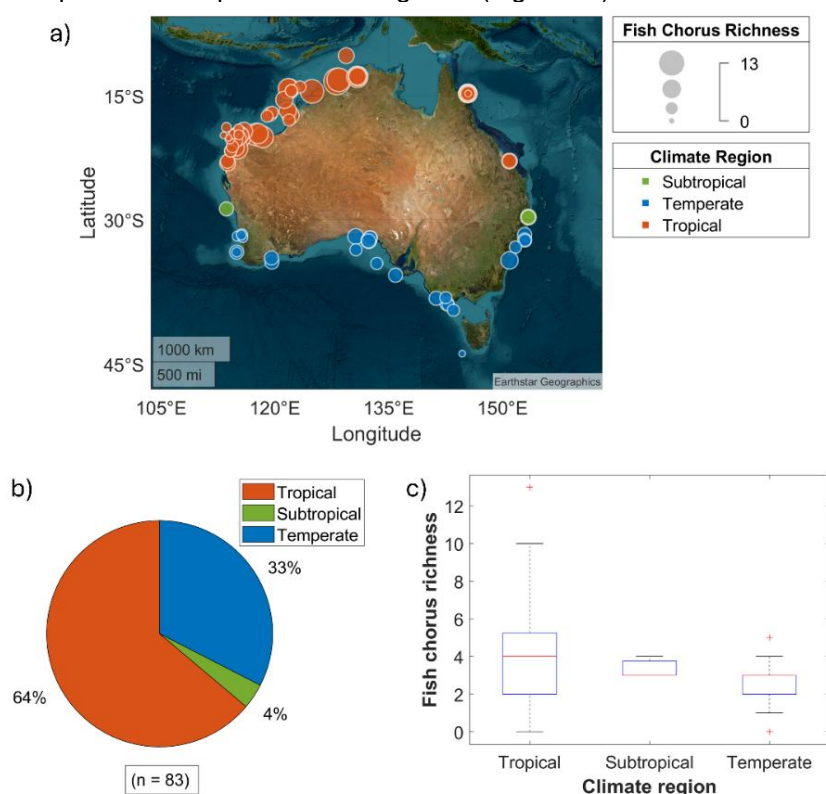


Figure 1: The a) spatial distribution and richness of AFCC fish chorus detections across the estuarine and marine waters of Australia, the b) distribution of recording sites across climate regions, and c) fish chorus richness in relation to the climate regions of Australia.

The AFCC fish choruses were detected across 5 of 8 types of seafloor sediment. These types included: calcareous gravel, sand, and silt (CGSS), calcareous ooze (CO), mud and calcareous clay (MC), mud and sand (MS), and sand, silt, and gravel with less than 50% mud (SSG). The CGSS and SSG benthic substrate types demonstrated the highest fish chorus richness, while MC demonstrated the lowest (Figure 2a). CGSS also demonstrated the greatest representation of acoustic recordings, with 4 - 5 times more recordings collected in this habitat type compared to the other four benthic substrate types (Figure 2b). Please note, there were no AFCC recording sites located within the other three benthic substrate types (biosiliceous marl and calcareous, pelagic clay, and volcanic sand and grit). AFCC recordings were distributed across 11 of Australia's 21 geomorphic feature types (Figure 2d), with the highest representation of recordings located in Shelf habitats (Figure 2d). Fish choruses were detected across 10 out of these 11 geomorphic feature types (Figure 2c). Highest fish chorus richness was detected in the basin and estuary recording sites (Figure 2c). Lowest fish chorus richness was detected in Canyon,

Deep/hole/valley, Plateau, and Trench/trough habitats and the Ridge geomorphic feature type was the only habitat where fish choruses were not detected (Figure 2c). These five geomorphic feature types also typically demonstrated the lowest representation of acoustic recordings (1 or 2 datasets per type only). The Shelf geomorphic feature type demonstrated low to moderate fish chorus richness despite having the highest representation of the AFCC acoustic recordings by far (Figure 2d).

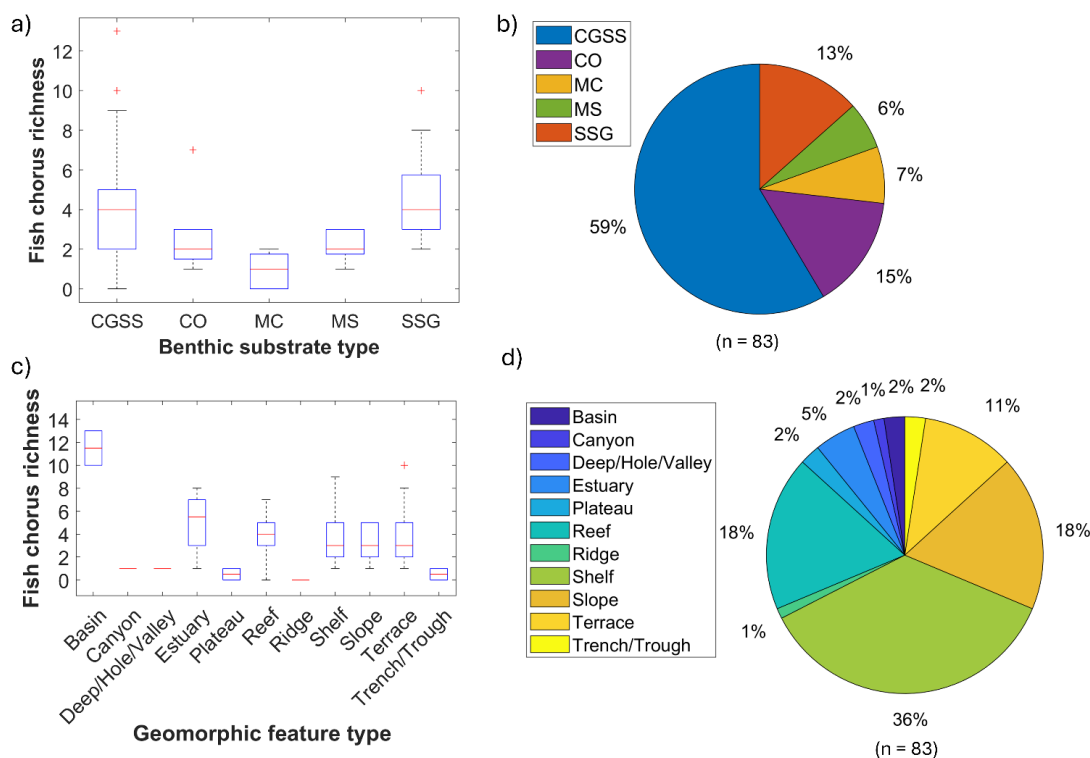


Figure 2: The distribution of fish chorus richness across a) benthic substrate type and c) geomorphic feature type and the proportion of recording sites classified across b) benthic substrate type and d) geomorphic feature type.

### 3.2 Temporal distribution

Patterns in fish chorus presence varied across climate region. At tropical recording sites, fish chorus presence increased from September to May, peaking over the early and late wet season (Figure 3). In comparison, fish chorus presence peaked over in late winter and early summer at the temperate recording sites (Figure 3) and at the subtropical recording sites, their presence increased across summer, autumn, and winter, peaking in April and May (Figure 3).

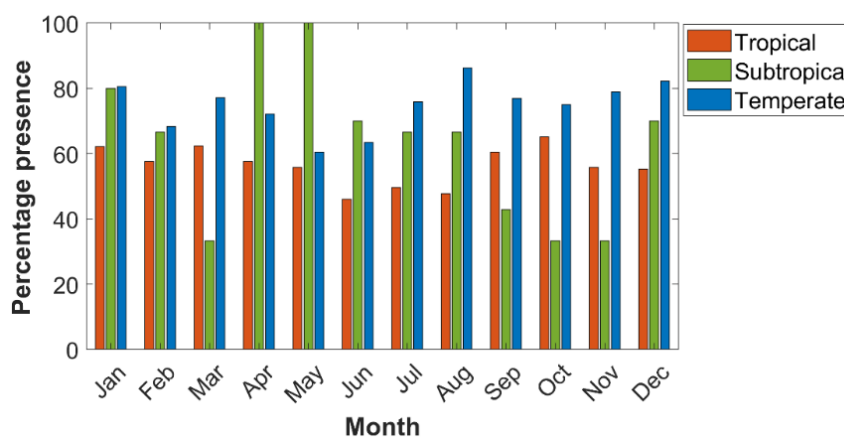


Figure 3: Percentage fish chorus presence across the tropical, subtropical, and temperate regions of Australia.

### 3.3 Spectral characteristics

The AFCC fish choruses exhibited a diverse range of spectral characteristics. Most choruses displayed minimum frequencies below 300 Hz (Figure 4). In contrast, maximum frequencies were more varied, with the top two 100-Hz frequency bands that contained the most choruses with a maximum frequency within the respective band, occurring at 700 – 800 Hz and 2900 - 3000 Hz (Figure 4). Peak frequencies were also typically low, with a significantly higher number of choruses demonstrating peak frequencies between 200 and 300 Hz (Figure 4). Distribution of AFCC fish choruses across centre frequency, root-mean-square bandwidth, root-mean-square low frequency, root-mean-square high frequency, and 90% energy bandwidth were also lower frequency skewed (Figure 4). Variation was observed in centre frequencies, root-mean-square low frequencies, and root-mean-square high frequencies.

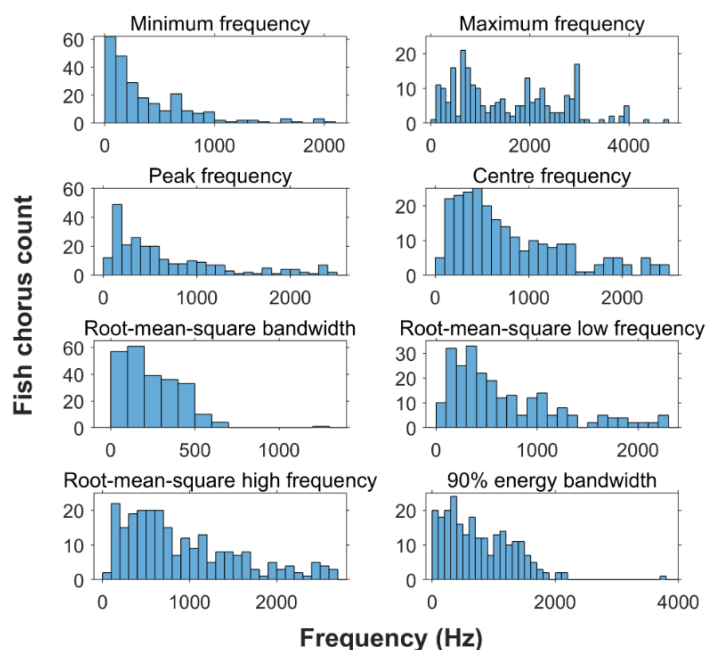


Figure 4: The spectral characteristics of the AFCC fish choruses.

### 3.4 Fish chorus classification

The AFCC fish choruses predominantly were comprised of tonals (TN), high-frequency pulse series (HFP), and low-frequency pulse series (LFP) call types (Figure 5). Tonal up-sweeps (TNU), tonal down-sweeps (TND), mid-frequency pulse series (MFP), and other (OT) chorus call types were also detected, albeit in lower numbers (Figure 5). Due to several factors, 20 AFCC fish choruses could not be identified to call type and were subsequently classified as unknown (UNK, Figure 5). In several cases, the Nyquist frequency of the respective hydrophone did not encompass the full frequency range of the chorus, in other cases, individual vocalisations could not be delineated from the cacophony of the respective fish choruses.

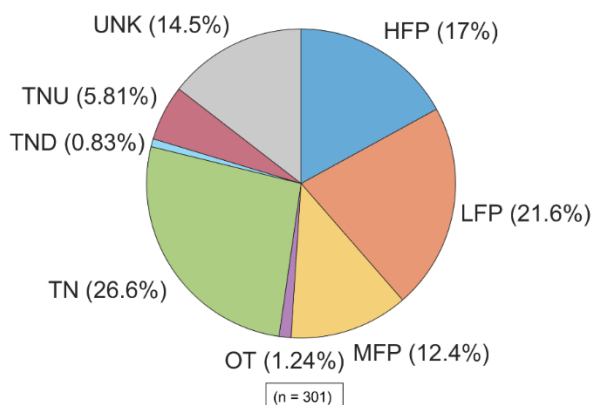


Figure 5: Distribution of the 301 AFCC fish choruses across call type.

An estimated 109 unique fish chorus types were identified from the AFCC fish chorus records based on clustering and subsequent manual review (Figure 6a). In addition, 20 AFCC fish choruses were unable to be attributed to type. Several fish chorus types demonstrated a broad geographic distribution across the marine waters of Australia (Figure 6b). For example, Type 2 was detected across 14 locations along the north-west shelf of Western Australia and the Timor Sea, Type 34 was detected at 12 locations along the southern Australian continental shelf from Bremer Bay in Western Australia to north-east coast of New South Wales, and Type 39 was detected across 11 reef sites along the north-west and north-east coasts of Australia (Figure 6b).

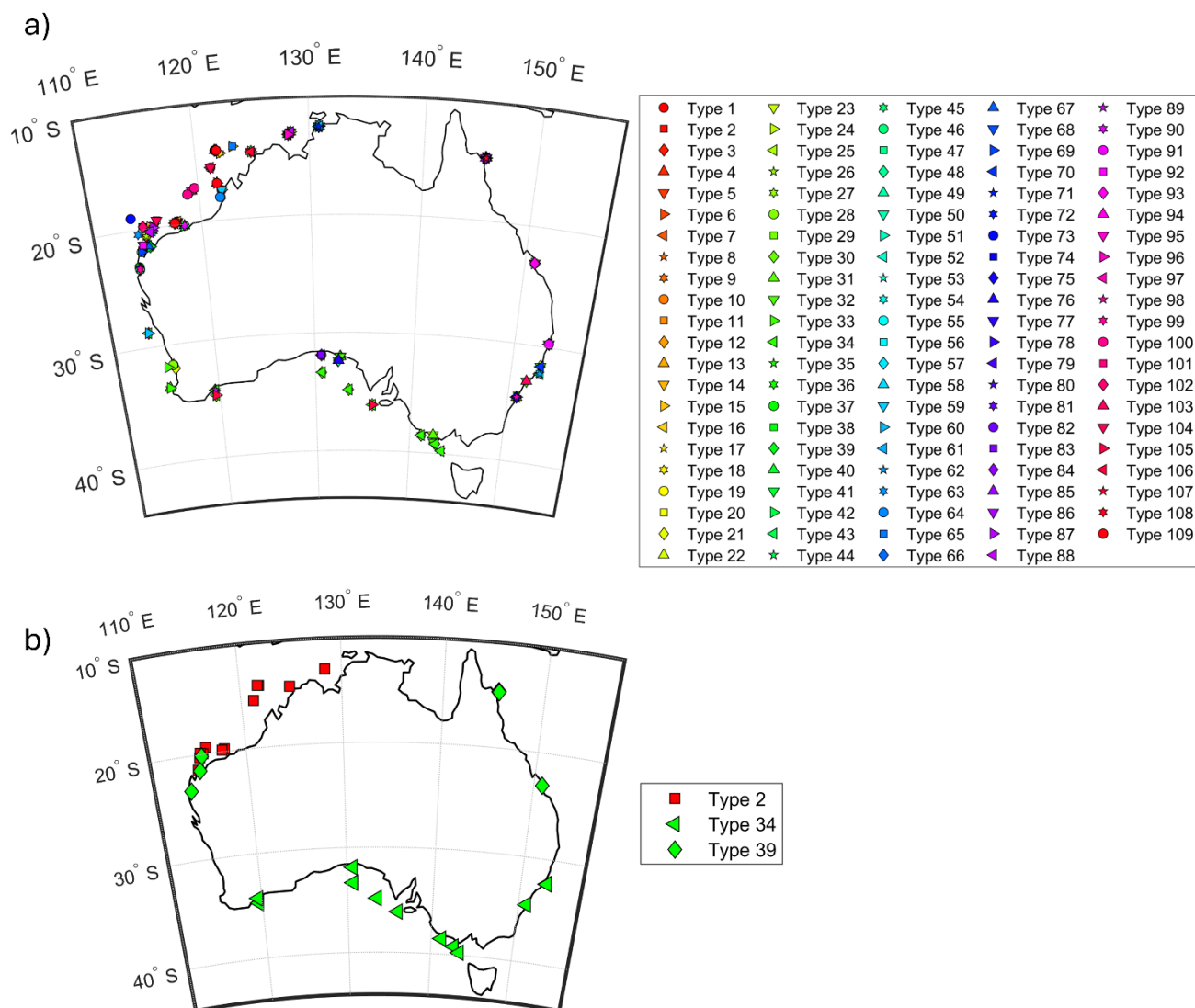


Figure 6: Geographic distribution of a) the estimated 109 AFCC fish chorus types and b) examples of the broad geographic distribution of AFCC fish chorus types 2, 34, and 39 along the north-west shelf of Western Australia and the Timor Sea, the southern Australian continental shelf from Bremer Bay in Western Australia to north-east coast of New South Wales, and the north-west and north-east coasts of Australia respectively. Please note for a) that more than one fish chorus type was detected at several AFCC recording locations; therefore, it was difficult to separate chorus types visually here and for b) several recording sites of each chorus type were located too close to each other to separate visually on this map.

#### 4 DISCUSSION

Detections of AFCC fish choruses were widespread across Australian marine waters, with several also recorded in estuarine environments. This broad distribution highlights fish choruses as a common and ecologically significant component of Australia's underwater soundscapes, likely reflecting patterns of fish community activity and habitat use. Fish choruses were detected across five sediment types and eleven geomorphic features, with the highest richness observed in estuaries and basins—suggesting that habitat heterogeneity may support greater

acoustic diversity, as noted by Hawkins et al. (2023). Seafloor and geomorphic complexity are known to influence fish species' richness and distribution through factors such as current dynamics, prey availability, reproductive opportunities, and predator avoidance (Scharf, Manderson and Fabrizio 2006; Borland et al. 2021). However, representation across habitat types was uneven, with fewer than 2% of AFCC recording sites located in estuaries and basins. Targeted research in these underrepresented habitats is needed to better understand how environmental conditions shape fish chorus richness and to support the use of PAM in identifying critical foraging or spawning habitats.

A latitudinal gradient in fish chorus richness was evident, with tropical regions exhibiting the highest site-level richness and temperate regions the lowest. This pattern aligns with previous findings (Hawkins et al. 2023), and mirrors established trends in fish species richness and abundance (Macpherson & Duarte, 1994; Diamond & Roy, 2023). These results support the potential of using fish chorus richness and spatial distribution as proxies for biodiversity, offering a non-invasive tool to contribute to conservation planning and ecosystem assessment (Pinna et al. 2023; Yousefi, Jouladeh-Roudbar and Kafash 2024). The greater variability observed in tropical regions may reflect dynamic ecological processes, such as broader species assemblages, diverse reproductive strategies, or fluctuating environmental conditions (Parravicini et al. 2013). However, lower sampling effort in subtropical and temperate regions may have influenced these patterns. Expanding acoustic monitoring in these areas will help clarify the differences observed in this study. Understanding how fish chorus activity varies across climate regions is essential for applying PAM in long-term ecological monitoring and management.

Seasonal patterns in fish chorus presence were distinct across climate regions. Tropical sites showed peaks during the austral wet season, subtropical sites peaked in April and May, and temperate sites exhibited bimodal peaks in late winter and summer. These patterns likely correspond to region-specific spawning or feeding behaviours influenced by local oceanographic conditions such as temperature, salinity, productivity, and tides (Hawkins et al. 2025b). For instance, primary productivity peaks during the wet season in tropical waters (McKinnon et al. 2017), supporting spawning activity (Schweigert et al. 2013), while temperate upwelling events typically occur between November and May (Huang & Wang, 2019), aligning with increased chorus activity (Hawkins et al. 2025a). These findings reinforce the value of PAM for phenological studies and detecting climate-driven shifts in biological activity. Continued monitoring could provide early warning signals of ecological change, particularly in response to ocean warming or habitat degradation. However, the effectiveness of this approach depends on identifying the species responsible for each chorus (Stratoudakis et al. 2024), highlighting the need for spectral characterisation and ground-truthing to source species (Parsons et al., 2022; Looby et al., 2023).

Australian fish choruses exhibited notable acoustic diversity and spectral complexity. Two distinct peaks in maximum frequencies were observed, likely reflective of contributions from different fish families or functional groups using sound for communication. These spectral patterns may reflect species-specific communication strategies and variation in local acoustic environments. Low minimum, peak, and centre frequencies were common with most choruses demonstrating a peak frequency between 200 and 300 Hz. Most choruses also had 90% of their energy below 2 kHz, with a concentration between 300 and 400 Hz. These results typically aligned with known calling ranges of many soniferous fish, within the commonly associated frequency band for fish calls (200-800 Hz, Azofeifa-Solano et al. 2025). However, the high proportion of choruses demonstrating minimum, centre, peak, and maximum frequencies below this bandwidth has implications for the use of this frequency band in PAM studies in Australian waters to detect and monitor fish sonic contributions to underwater soundscapes. A greater understanding of how these spectral characteristics are distributed across climate regions and between specific habitat types will contribute to the improvement of project- or location-specific PAM applications for Australian fish species. Low-frequency sound production also indicates the vulnerability of these soniferous fish species to masking from broadband or low-frequency noise including contributions from anthropogenic sources such as vessels, seismic surveys, and construction. These anthropogenic sounds overlap with the frequency ranges of Australian fish choruses, potentially masking the diverse call types and affecting acoustic communication.

The AFCC fish choruses revealed a diverse array of call types. Tonal, High-frequency pulse series, and Low-frequency pulse series were the most prevalent call types detected. Less common types such as Tonal up-sweeps and Mid-frequency pulse series were also detected, reflecting a broad acoustic repertoire among Australian soniferous fish species. This repertoire has likely been shaped by variations in species composition, behavioural context, and habitat use across recording sites. These call types may also provide insights into sound production mechanisms, with many consistent with swim bladder- and sonic muscle-driven vocalisations (Fine & Parmentier, 2015). Combining this information with chorus-specific spectral characteristics can assist with ground-truthing fish chorus source species. It is also important to acknowledge that some choruses may originate from other soniferous marine fauna, such as invertebrates (e.g., Radford et al. 2008; Soars et al. 2016) rather than fish. Ground-truthing efforts will be essential to resolve these uncertainties and accurately attribute chorus sources to species or functional groups. Until species-specific identifications can be made, chorus call types can serve as proxies for species-specific contributions, helping to characterise vocal communities and inform ecological assessments (e.g., Hawkins et al. 2023).

This study identified an estimated 109 fish chorus types occurring in the marine and estuarine waters of Australia. These results demonstrate a high level of soniferous fish diversity. Such diversity implies either a high richness of vocal fish taxa or complex sound production behaviours within taxa, consistent with previous findings that fish choruses can be species-specific and shaped by anatomical and behavioural variation (Hawkins et al. 2025b). Several chorus types were broadly distributed across regions, suggesting either wide-ranging species distributions or convergent acoustic behaviours among different taxa. These patterns reinforce the utility of PAM as a non-invasive tool for mapping biodiversity, identifying habitats of ecological importance, and detecting fish species or populations of conservation concern. Importantly, the spectral and temporal characteristics of fish choruses offer a foundation for species-level identification. While many fish chorus sources remain unknown, cataloguing distinct chorus types provides a practical framework for ground-truthing choruses to species. Until such associations are resolved, chorus types can act as acoustic proxies for species-specific contributions, enabling researchers to track ecological patterns and inform conservation strategies at scale and over significant temporal extents (Stratoudakis et al. 2024; Hawkins et al. 2025b).

The AFCC represents a foundational resource for advancing marine conservation and ecosystem management. By providing a comprehensive inventory of fish chorus types, their spatial and temporal distributions, and associated acoustic characteristics, the AFCC enables researchers and managers to monitor biodiversity patterns, detect ecological shifts, and identify habitats of conservation significance with minimal disturbance to marine life. Its potential utility extends beyond species detections supporting long-term ecological assessments, informing marine spatial planning, and guiding mitigation strategies for anthropogenic noise impacts. As passive acoustic monitoring becomes increasingly integrated into marine management frameworks, the AFCC offers a scalable, data-rich platform for tracking the health and resilience of fish communities across Australia's diverse aquatic environments.

## 5 CONCLUSION

The AFCC provides a foundational view of Australia's underwater acoustic biodiversity, revealing broad spatial, seasonal, and spectral patterns. The data contained in this repository is available to support fishery management, conservation planning, and long-term monitoring of ecosystem health. Future research is needed to ground-truth the fish chorus type classifications presented here and to begin the processes of attributing these choruses to specific fish species to improve species-specific outcomes in PAM applications for conservation and management.

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