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Migration and spawning strategies of hilsa shad (*Tenualosa ilisha*, Clupeidae) in the Ayeyarwady River revealed by otolith chemistry

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ABSTRACT

Hilsa shad (*Tenualosa ilisha*) is an ecologically and economically important fish species in the Indo-Pacific region, yet its migration and spawning behaviour remains poorly in Myanmar. This study investigates hilsa migration and spawning strategies in the Ayeyarwady River using otolith chemistry, including elemental ratios (Sr:Ca, Ba:Ca, Mg:Ca, Mn:Ca) and ^{87}Sr:^{86}Sr isotope signatures. Otoliths from 101 juvenile and adult hilsa collected across the Ayeyarwady River Basin showed that 94 % of hilsa exhibited life histories consistent with anadromy (spawning in freshwater rivers but growing up in the ocean). However, a small subset (6 %) displayed alternative reproductive strategies, likely spawning in higher salinity environments (such as estuarine or coastal areas) without entering rivers. Additionally, hilsa may migrate over 1500 km to the Upper Ayeyarwady from the sea. Additionally, otoliths of juvenile hilsa collected in the Chindwin River, exhibited consistently low Sr:Ca ratios along the core-to-edge profiles, indicating prolonged freshwater residency post-hatching (up to six months). Findings from this study illustrate the predominance of an anadromous life history and the existence of an alternative reproductive strategy, which are essential for adaptive management and conservation of hilsa in Myanmar. Given the species' trans-boundary distribution and importance in the Indo-Pacific region, effective fishery management requires strengthening regional cooperation to promote sustainable hilsa fisheries in the region.

1. Introduction

Hilsa shad (*Tenualosa ilisha*), hereafter referred to as hilsa, occurs widely across the Indo-Pacific region in oceanic and coastal environments (e.g., Persian Gulf, Arabian Sea, Bay of Bengal, Andaman Sea) and rivers in Bangladesh, Myanmar, India, Iran, Iraq, Pakistan and small parts of Southeast Asia (Al-Baz and Grove, 1995; Bhaumik, 2015; Froese and Pauly, 2025). The species is an important source of food and income for millions of people in the region (Baran et al., 2018; Dutta et al., 2021; Hossain et al., 2018). Most of the global annual harvest of hilsa (586,917 tonnes in 2022) is from Bangladesh, while other countries in the region share much smaller percentages of the catch (FAO, 2025; Sahoo et al., 2018). In Myanmar, hilsa accounted for over 2 % of total fish yield, with 9059 tonnes exported and generating over US$27 million in revenue (Akester et al., 2024; DoF, 2023). Of this, the inland capture fishery yield increased slightly (DoF, 2023). However, the fishery faces multiple

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threats in the region, such as overfishing, pollution, habitat destruction and connectivity loss (BOBLME, 2015; Conallin et al., 2019; Rashid et al., 2021).

Hilsa migrate from the sea to rivers and vice versa to complete their life cycle. They grow at sea but migrate to freshwater rivers to spawn (anadromous species). In Myanmar, this species is recorded from the sea to over 1000 km upstream in the Ayeyarwady River (BOBLME, 2015; Conallin et al., 2019). Hence, the species is highly vulnerable to fishing pressure and barriers due to its long-distance migration. Hilsa may exhibit complex migration patterns like other tropical fish species (Hauser et al., 2019; Vu et al., 2022), therefore, understanding its migration strategies is essential for effective management, not only for Myanmar, but also for the Indo-Pacific region. Otolith (ear-bone) chemistry is one of the best tools for investigating fish movements and spawning (Loury et al., 2021), as elements from the ambient environment are constantly absorbed in otoliths in layers, the different elemental concentrations in each otolith layer reflect fish movements and habitat use (Campana, 1999; Zimmerman, 2005).

Although hilsa was previously believed to be strictly anadromous (living in the ocean, but spawning in rivers), spawning grounds of this species have been also reported in river deltas, including estuaries and coastal waters in the Indo-Pacific region (Blaber et al., 2003; Hossain et al., 2018). Most hilsa migrate from the sea to rivers for spawning except for a small subset of the population that remains in marine waters and spawns in estuaries without entering rivers (Hossain et al., 2016; Merayo et al., 2020). This strategy is partly confirmed by otolith chemistry for Bangladesh hilsa (Blaber et al., 2003; Koochaknejad et al., 2024). Such a spawning strategy for Myanmar hilsa has not been

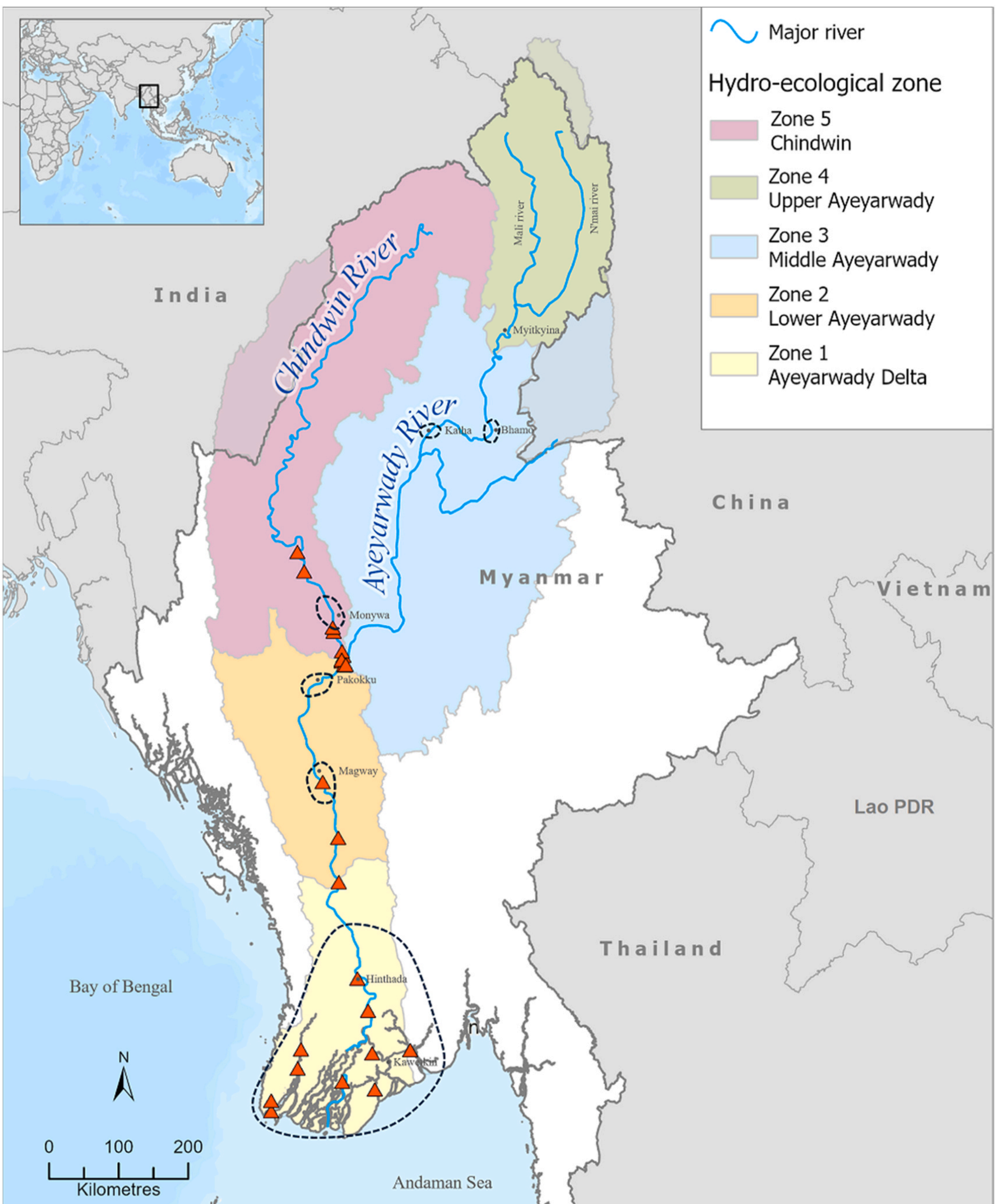

Fig. 1. Sampling sites (▲) for hilsa in the Ayeyarwady River Basin. Map showing spawning areas of hilsa (dotted circles), adapted from BOBLME (2015).

confirmed in the Ayeyarwady River Basin (ARB).

Knowledge of hilsa migration and spawning behaviour is limited in Myanmar, where the number of publications on hilsa is low compared to other countries in the region, such as Bangladesh and India (Bandara and Wijewardene, 2023). The objective of this study was to investigate migration and spawning strategies of hilsa in the ARB by quantifying multi-elemental ratios in otoliths (Sr:Ca, Ba:Ca, Mg:Ca, Mn:Ca) combined with isotopic signatures (^{87}Sr:^{86}Sr). This integrated method provides insights on habitat use and life history diversity of hilsa. To achieve this objective, we hypothesised that all hilsa migrate from the sea to rivers to spawn in the ARB. Findings from the study are expected to contribute to better management and conservation of hilsa, not only in Myanmar but also in other countries in the Indo-Pacific region.

2. Methods

2.1. Study area

The ARB covers 413,710 km^2 in Myanmar (91 %) and small areas in China and India (WLE, 2022). The Ayeyarwady River originates from the confluence of the N'mai and Mali rivers in northern Myanmar and flows approximately 2170 km to the Andaman Sea, annually discharging around 400 km^3 (Ketelsen et al., 2017), with hydrology that varies greatly between seasons (Vu et al., 2025). The Chindwin River is the largest tributary in the ARB, joining the Ayeyarwady main channel about 800 km from the sea (Fig. 1). The ARB is divided into five hydro-ecological zones, each characterized by internally similar hydrology, geomorphology, and ecology, but differing significantly from the other zones along the river continuum. The river supports fisheries and agriculture, which are vital for food security and income for millions of people. However, the ARB faces multiple stressors, including deforestation, industrial and agricultural pollution, and the impacts of climate change (Conallin et al., 2019).

2.2. Otolith collection and preparation

In the ARB, hilsa are known to ascend into the upper Ayeyarwady and Chindwin, a distance of approximately 1000 km from the sea (Bhaumik, 2015; Conallin et al., 2019). Hence, we conducted field trips to sample hilsa across the ARB (Fig. 1), covering known or suspected migration routes and spawning areas (Zalun and Monyo in Hinthada Township), collecting fish in the Ayeyarwady Delta, Lower Ayeyarwady River and Chindwin River during the field trips (Fig. 1 and Table 1). A total of 101 hilsa shad (total lengths from 8 cm (3 g) juveniles to 51 cm (1423 g) adults) was obtained from either local fishers or markets during 2018–2019 in the ARB. Total length (cm) and body weight (g) were measured for each hilsa before extracting otoliths (sagittate) in the field. Otoliths were then cleaned, set in resin, sectioned, polished and prepared for elemental analysis as described by Vu et al. (2022).

Table 1
Sample sizes, fish lengths, and weights (mean, standard deviation, and range) of hilsa collected for otolith chemistry in the Ayeyarwady River Basin. See Appendix 1 for detailed information on each individual fish.

Hydro-ecological zone	Number of hilsa	Total length (cm)	Weight (g)
1. Ayeyarwady Delta	49	40 ± 5 (30–51)	764 ± 283 (288–1423)
2. Lower Ayeyarwady River	27	36 ± 10 (22–49)	524 ± 410 (75–1228)
3. Chindwin River*	25	27 ± 10 (8–49)	219 ± 192 (3–847)

* Including five hilsa juveniles (8 – 14 cm in total length, sampled in the Chindwin, 791 km from the sea).

2.3. Elemental analysis of otoliths

Three analytical techniques were used in our study. First, concentrations of five elements (Mg, Mn, Ca, Sr, Ba) were measured along the core-to-edge transects (28 µm spot size at 3 µm/s scanning speed) for all hilsa otoliths using a LPF Pro 200 193 nm excimer laser ablation (LA) with an iCAP RQ Q-inductively coupled plasma mass spectrometry (ICPMS) (Stoot et al., 2024). Second, six hilsa found with high Sr at the core from the first technique were selected to further quantify ^{87}Sr:^{86}Sr along the core-to-edge transects (50 µm spot size at 5 µm/s scanning speed) using a LA system with an ATLEX-I-LR 193 laser and a Sapphire multi-collector-inductively coupled plasma mass spectrometry (MC-LA-ICPMS) (Stuart et al., 2024). Third, concentrations of Ca and Sr were mapped across entire otolith sections (two-dimensional maps) for six randomly selected hilsa otoliths using synchrotron x-ray fluorescence microscopy (SXFM, 2 µm spot size, 10 µm step size, and 200 µm/s scan velocity) with a Maia detector with aluminum foil taped to the front window of the detector array to attenuate the dominant fluorescence signal from Ca in the bone (Vu et al., 2024). These elements and isotopes selected in our study are commonly used to understand fish movements for otolith chemistry studies (Campana, 1999; Carlson et al., 2017).

2.4. Data analysis

Otolith data analysed from the LA-ICPMS and MC-LA-ICPMS were processed by Iolite software while data from the SXFM were processed with GeoPIXE and ArcMap software, as described in detail by Stoot et al. (2024); Stuart et al. (2024); Vu et al. (2024). Ratios of element:Ca were smoothed using a 5-point moving average for LA-ICPMS and MC-LA-ICPMS data. The Fulton index was used to infer spawning seasons indirectly (Fulton, 1904): higher K values indicate pre-spawning (accumulation of somatic energy reserves that will later support gonad development); a decline in K values indicates spawning (energy diverted into gonadal tissue and reproductive activity); and lower K values indicate post-spawning (energy reserves depleted).

3. Results

3.1. Body condition

The Fulton index varied between seasons, peaking in both February and August before significantly declining afterwards. The temporal pattern in body condition (Fig. 2) indicates two spawning seasons of hilsa: a main one in July to September and an additional one in February to March.

3.2. Otolith chemistry

Two-dimensional Sr:Ca ratios varied across hilsa otoliths, but

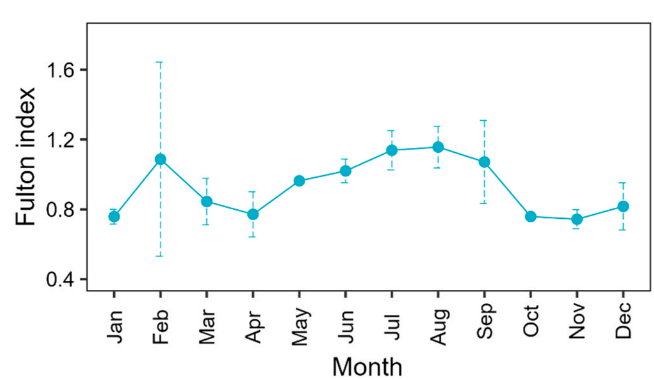

Fig. 2. Body condition of hilsa in the Ayeyarwady River (mean ± standard deviation).

patterns of these ratios among hilsa otoliths were relatively similar: low Sr:Ca at the otolith core and edge, and high Sr:Ca in between (Figs. 3 and 4). Most hilsa otoliths had Sr:Ca ratios of < 2.5 at the core ($n = 95$, 94 %, group 1) but six fish otoliths (Da12, Hi2, La3, Ma9, ML26, and PP4, see Appendix 1 for more details) had core ratios ≥ 2.5 ($n = 6$, 6 %, group 2). These hilsa in group 2 were sampled in the Ayeyarwady Delta (zone 1, Fig. 1). Otoliths from group 2 were further examined by quantifying ^{87}Sr:^{86}Sr ratios from the core-to-edge. The results show that ^{87}Sr:^{86}Sr ratios were consistently low at the core (mean: 0.7097). Additionally, ^{87}Sr:^{86}Sr ratios were consistently low along the core-to-edge profile of four hilsa (Da12, Ma9, ML26, and PP4), while these ratios of two hilsa (Hi2 and La3) varied significantly along the core-to-edge profiles (ranging from 0.7065 to 0.7234) (Fig. 4).

Trends in Sr:Ca core-edge profiles were opposite to those of Ba:Ca, while Mg:Ca and Mn:Ca core-edge profiles varied greatly (Fig. 4). Sr:Ca were low at the otolith core, then increased markedly before declining at the otolith edge. By contrast, Ba:Ca peaked at the otolith core and then declined significantly until the edge. The distance from the core to where Sr:Ca significantly increased varied among hilsa (Fig. 3), and ranged from 51 to 627 µm (mean: 328 ± 124 µm, hilsa in group 1).

Ratios of element:Ca varied at the otolith cores among hilsa (Fig. 4), reflecting the elemental concentrations of each hilsa's spawning grounds. For Sr:Ca at the core, these ratios ranged from 0.50 to 4.90 (mean: 1.57 ± 0.71). Ratios of most hilsa otoliths (75 %) varied from 1.0 to 2.0 while there were small subsets of hilsa with either lower (13 %) or higher (12 %) Sr:Ca ratios at the core. For Mg:Ca at the core, ratios ranged from 0.02 to 0.18 (0.06 ± 0.03; mean and standard deviation), most hilsa (96 %) had ratios < 0.1, while there were few hilsa with ratios > 0.1. For Mn:Ca at the core, these ratios ranged from 0.01 to 0.17 (mean: 0.02 ± 0.03).

4. Discussion

Although our otolith chemistry data confirmed that hilsa are predominantly anadromous in the ARB, a small percentage of the population likely spawned in estuaries or coastal waters (higher salinity environments), indicating some plasticity in this species' migration and spawning strategies. Consequently, our hypothesis was rejected because not all hilsa migrated from the sea to rivers for spawning: a small sub-set of hilsa (6 %) likely spawned in estuary or coastal areas of the ARB.

4.1. Migration and spawning

Hilsa were recorded throughout the ARB, with confirmed presence up to 1000 km from the sea. Otolith chemistry data from this study suggests that some individuals may migrate even further, potentially over 1500 km, to reach the Middle and Upper Ayeyarwady (see Fig. 1, zone 3 and 4 and Fig. 5). This is supported by elevated ^{87}Sr:^{86}Sr ratios in otoliths, which peaked at 0.7234 along core-to-edge transects, exceeding the water chemistry signature recorded in Myitkyina township (ranging 0.7128–0.7185), located 1500 km from the sea up the main stem of the Ayeyarwady river (Chapman et al., 2015; Vu et al., 2025). These findings imply that hilsa may migrate beyond Myitkyina before returning to the ocean. Local fishers also reported that hilsa juveniles (10–15 cm) are regularly caught in tributaries and leasable fisheries around Bhamo, approximately 120 km downstream of Myitkyina. Additionally, ripe female hilsa were observed near Katha (potential spawning grounds), about 200 km downstream of Myitkyina, during our field surveys. Such long-distance migrations are not unique to hilsa; similar patterns have been documented in catfishes (*Pangasius pangasius* and *Pangasius* sp.) in the Ayeyarwady River (Vu et al. n.d., under review) and many other fish species on other tropical rivers (Deinet et al., 2024, 2020). Our findings confirm the extensive migratory behaviour of hilsa and highlight the importance of maintaining longitudinal connectivity in the river system.

Hilsa is an anadromous species, with key spawning locations in rivers in Bangladesh (Meghna River), India (Hooghly-Bhagirathi rivers), and Myanmar (Ayeyarwady River) and other river systems in Iran, Iraq, Kuwait and Pakistan (Hossain et al., 2019, 2018). It is known that hilsa move widely within the Bay of Bengal (Bangladesh, India, and Myanmar) as a single pan-memetic population, but it is not known whether they return to their natal rivers. There is likely another hilsa population in the Persian Gulf (Mahmud, 2020). Therefore, hilsa populations should be managed differently between regions. Despite being typically categorized as anadromous, a small proportion of the Ayeyarwady hilsa population (around 6 % in this study) appears to spawn in estuarine or coastal areas. This finding is supported by other otolith chemistry studies in Bangladesh and Southwestern Iran (Blaber et al., 2003; Koochaknejad et al., 2024). Future studies should include sampling of hilsa in marine environments to investigate whether a sub-population exists that spawns in coastal or estuarine areas and they remain in the sea without returning to rivers. This potential life history strategy remains unconfirmed, as neither this study nor previous ones have sampled hilsa at sea. Moreover, freshwater residency after spawning varies among individuals and across geographic regions (Arai et al., 2019; Koochaknejad et al., 2024). Such plasticity may represent an adaptive strategy to environmental variability, potentially enhancing resilience to climate-induced and other hydrological changes. Estuarine

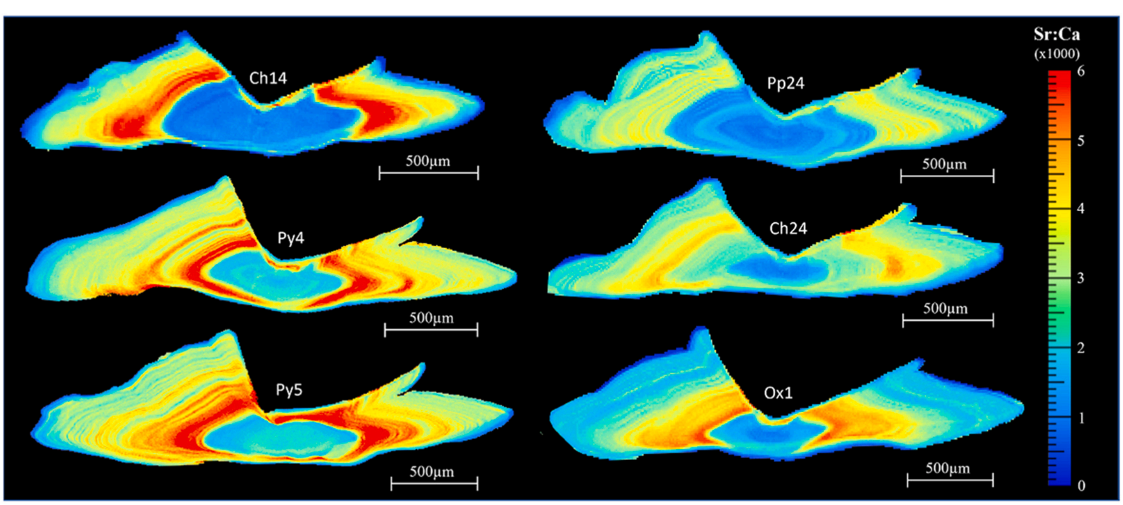

Fig. 3. Examples of two-dimensional Sr:Ca maps of hilsa's otoliths. Sample codes of each hilsa are indicated. See Appendix 1 for detailed information on each individual fish.

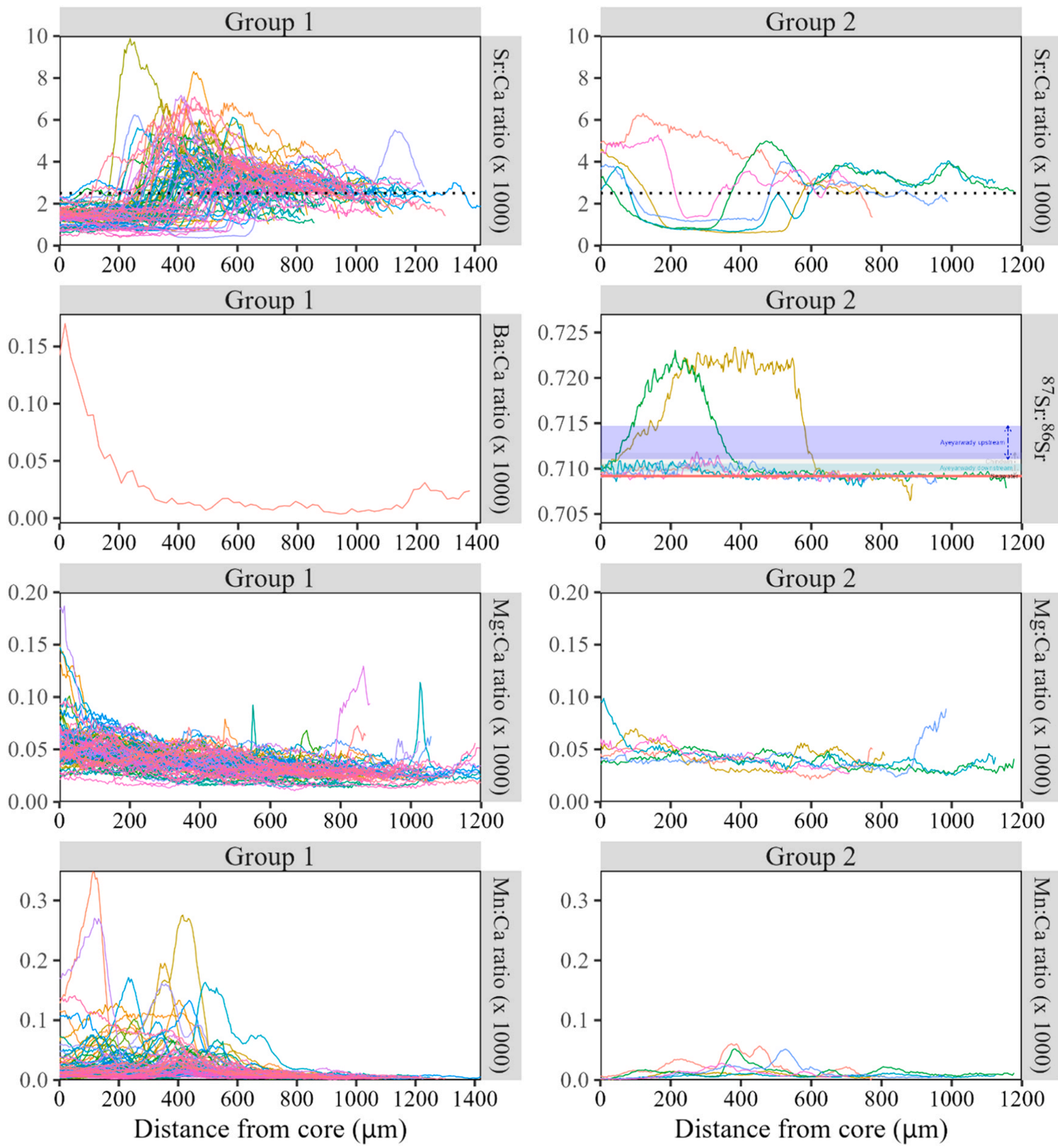

Fig. 4. Variations of element:Ca ratios along the core-to-edge profiles of hilsa otoliths, divided into two groups: group 1 where Sr:Ca ratios at the core < 2.5; and group 2 where Sr:Ca ratios at the core ≥ 2.5. The ^{87}Sr:^{86}Sr plot shows horizontal colour bands for water signatures (^{87}Sr:^{86}Sr) for key regions of the Ayeyarwady River (90 % of confidence limits) such as seawater, Ayeyarwady downstream and upstream, and Chindwin, data from Vu et al. (2025). Data for Ba were excluded due to technical issues, but one hilsa otolith was re-analysed for Ba and used in this study.

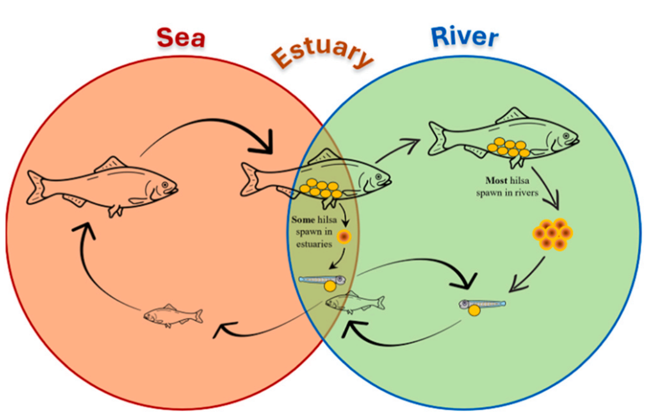

Fig. 5. A conceptual diagram of the life cycle of hilsa.

and coastal spawning could be advantageous if rivers have severely altered flow regimes or experience habitat fragmentation, suggesting that these estuarine and coastal habitats are ecologically critical and should be prioritised for protection. In addition to conservation of these diverse spawning habitats, it is also essential to maintain hilsa population connectivity and gene flows.

Spawning seasons of hilsa vary across the Indo-Pacific region. Hilsa females are usually sexually mature at 31 – 33 cm in total length (about 2 years old) (Hossain et al., 2019; Rahman, 2001); the smallest female maturing hilsa was found at 17 cm in length and 43 g in weight (about 1 year old) in the Tetulia River, Bangladesh (Mahmud, 2020). Hilsa spawn all year round, but focus on two periods: June – October and February – April in Bangladesh (Hossain et al., 2018); October – November and February – March in India (Ray et al., 2022); and July – September and February – March in Myanmar (this study). These seasonal spawning differences are likely influenced by local hydrological regimes and climatic conditions (Bhaumik et al., 2011; Rahman and Cowx, 2006). Understanding these regional temporal dynamics is vitally important for implementing effective seasonal fishing restrictions and habitat protection measures, according to each country's ecological context. A substantial hilsa harvest comes from inland (i.e. fish migrating up river to spawn) (Hossain et al., 2019), hence, some countries have imposed seasonal fishing bans to improve hilsa populations in the Indo-Pacific region (BOBLME, 2015; Hossain et al., 2019). Coordinated regional management strategies that align with these spawning windows can enhance reproductive success and support the long-term viability of hilsa populations regionally. Both unsustainable fisheries practices (e.g., overfishing) and other factors (e.g., artificial barriers to fish migration) can contribute to the decline of hilsa fisheries. Therefore, the fisheries sector should collaborate with related sectors (e.g. agriculture and hydropower) to minimise potential impacts on hilsa populations.

Hilsa likely remain in fresh water for a certain period of time after spawning in river, before returning to the sea. For example, five hilsa juveniles (79 – 144 mm in total length) were collected in Chindwin River and hilsa juveniles were also observed in the Upper Ayeyarwady (Bhamo). Ratios of Sr:Ca along the otolith core-edge profiles (mean: 1.74 ± 0.14; range: 1.38–2.13) remained consistently low for all five hilsa juveniles, indicating that they were born and had developed entirely in fresh water without exposure to brackish or marine environments. Based on length-age relationships (Milton and Chenery, 2003; Rahman and Cowx, 2006), a juvenile hilsa with a total length of 144 mm is estimated to be 3.9 – 5.7 months old. It appears that duration of freshwater residency varies among individuals and across geographic regions. In Myanmar (this study) and Bangladesh (Milton and Chenery, 2003), early life stages remain in river systems up to six months longer than in other countries. Meanwhile, some studies found that hilsa larvae drift or migrate to the ocean soon after hatching in Malaysian and Iranian rivers, as indicated by elevated Sr:Ca ratios beyond the core (Arai et al., 2019; Koochaknejad et al., 2024).

4.2. *Trans-boundary fishery management*

Given their wide distribution across the waters of multiple countries (Myanmar, Bangladesh, and India), trans-boundary fishery management for hilsa is crucial for regional coordination and conservation to sustain hilsa fisheries in the region. Some regional fisheries advisory bodies have been established in the Indo-Pacific region to manage shared fish stocks (SriHari et al., 2025). For example, the Bay of Bengal Programme Inter-Governmental Organisation (BOBP, 2025) was formed in 2003 to provide both technical and management advice for marine fisheries in four countries (Bangladesh, India, Maldives, Sri Lanka). Similarly, the Regional Fisheries Management Advisory Committee was set up in 2012 to manage shared hilsa stocks in the Bay of Bengal (Bangladesh, India, and Myanmar). Although regional plans have been established to manage the hilsa fishery in the Bay of Bengal (Hossain et al., 2019), legal authority and financial challenges hamper enforcement and research in the region. For example, the hilsa fishery provides important sources of food and income for millions of local people, but this species is over-exploited, particularly in Bangladesh and Myanmar (Akester et al., 2024; Fernandes et al., 2015). Most hilsa landed are reported as small and medium-sized fish (<2 years old) (BOBLME, 2010). Since management strategies for hilsa fisheries vary between countries, regional cooperation is crucial for effective management of the trans-boundary migratory hilsa.

Protecting spawning and nursery habitats during spawning seasons is critical for any fish stock and the fisheries dependent upon them. Our study shows that two spawning seasons (July–September and February–March) are evident in the ARB. Extended freshwater residency of juveniles (up to six months) underscores the need to protect nursery habitats in upstream areas: a strategy that has successfully improvedA study indicated that hilsa catches following the establishment of protected areas in Bangladesh and Myanmar (Islam et al., 2016). This is important because fishery management and conservation measures for hilsa vary between countries (Hossain et al., 2019), thus fishing regulations (capture sizes and closed seasons that align with hilsa spawning periods in each country) and establishment of sanctuaries for spawning and nursery areas need to be adapted to specific countries due to differences in spawning seasons among countries in the region. Consequently, effective management for the trans-boundary migratory hilsa requires collaborative efforts from multiple stakeholders in different countries to ensure sustainable fishing practices and conservation. Although regional cooperation programs have been established in the Indo-Pacific region, coordinated collection and sharing of scientific data should be strengthened to promote the hilsa fisheries and ensure the long-term viability of this important fishery.

Protecting hilsa migration routes is especially important to sustain the population. Hilsa is a long-distance migratory species requiring unimpeded hydrological connection between spawning areas in rivers and the sea. Hilsa migrate from the sea to the Ayeyarwady River to spawn along the main stem, up to 1500 km from the sea (Fig. 1). The Ayeyarwady delta (e.g., Kawetkin, and Hinthada) is the most important spawning ground, additional breeding zones are also reported further upstream, such as the Lower Ayeyarwady (e.g., Magway and Pakokku), the Middle Ayeyarwady (e.g., Bhamo and Katha), and Chindwin River (e.g., Monywa) (BOBLME, 2015). In addition, our findings indicate that a subset (6 %) of hilsa spawns in estuaries. Therefore, management of spawning grounds should include estuarine and coastal habitats, not just riverine zones. Hilsa is believed to be a batch spawner (release eggs in multiple times over a spawning season), they spawn from the delta to further upstream of the Ayeyarwady River. We found a strong relationship between the Fulton index and capture location of hilsa (Pearson correlation $= -0.80$).

Fortunately, no dams have been built across their migration routes on the main stem of the Ayeyarwady to date. However, the construction of multiple sluice gates and tidal barrages for agricultural purposes on the lower reaches of the Ayeyarwady River Delta has disconnected key habitats for hilsa (feeding and spawning) (Conallin et al., 2019). Populations of hilsa will become land locked if their migration routes are blocked, and populations decline. It is recommended to implement seasonal sluice gate opening plans, especially during the migration seasons. Moreover, stocking strategies should be considered in the ARB to improve hilsa stocks because artificial breeding programmes for hilsa have shown promise (De et al., 2019; Sahoo et al., 2018). In addition, co-management of the resources is recommended to support management of hilsa fisheries at the local level (Islam et al., 2016) by protecting spawning grounds and conservation zones. Local fisher communities in the Ayeyarwady Delta have been encouraged to engage with government authorities in hilsa management strategies to improve the fishery.

Although regional fisheries management advisory committees were established to promote the sustainable development of hilsa fisheries in the Indo-Pacific region (BOBP, 2025; SriHari et al., 2025), given the trans-boundary nature of hilsa migrations and the socio-economic importance of this species across the region, these advisory committees on the regional hilsa fishery should be further strengthened for the regional management of the hilsa fishery and supported by country leaders and sponsors in the region. These committees should act as a multilateral platform for countries in the Indo-Pacific region to coordinate research, management, conservation, and development efforts for hilsa fisheries at a regional scale. They should facilitate joint research and monitoring programmes and regularly organise meetings and symposia to share knowledge for better management and conservation of hilsa. In this regard, the Bay of Bengal Project is currently supporting scientists to share scientific information and insights on hilsa stock structure and management.

The relevance of trans-boundary management becomes even more apparent when considering that hilsa in the Bay of Bengal form a single, shared stock moving across the Exclusive Economic Zones of Bangladesh, India and Myanmar. Acknowledging this, the three countries are now working together under a formal tripartite arrangement that promotes the exchange of scientific data and joint interpretation of stock status and trends. This effort complements the GEF–FAO Bay of Bengal Large Marine Ecosystem (BOBLME) Strategic Action Programme, which has long identified hilsa as a priority trans-boundary resource requiring coordinated action. Despite this progress, important gaps remain in our understanding of the timing, extent and pathways of hilsa migration between national waters. Addressing these uncertainties will require more consistent research, monitoring and data sharing so that management measures taken in one country align ecologically with those in neighbouring jurisdictions and support the long-term sustainability of the stock across the region.

5. Conclusion

Hilsa migrate over long-distances from the ocean to rivers for spawning, relying on free-flowing rivers to connect critical habitats, such as feeding and spawning grounds. Our findings show that 94 % of hilsa exhibit an anadromous life history, migrating from the sea to freshwater rivers to spawn, while 6 % spawn in estuarine or coastal habitats, indicating plasticity in reproductive strategies. Protecting both the spawning areas and populations is essential for the resilience and sustainability of hilsa in the region. This will require targeted conservation measures, such as seasonal fishing closures aligned with spawning periods, and establishment of conservation zones along migratory pathways. We recommend that future research should include sampling in marine environments to determine whether a sub-population exists that spawns in coastal or estuarine areas and remains entirely at sea to understand fully the diversity of hilsa life histories. To safeguard hilsa fisheries for future generations, we urge strengthening regional fishery management and cooperation across the species' distribution in the Indo-Pacific region, including the Bay of Bengal, Arabian Sea, and Andaman Sea. Regional cooperation and enforcement of fisheries regulations should be enhanced, even though fishery bodies already exist within the area. Collaborative efforts are essential to address shared challenges such as overfishing, pollution, habitat degradation, loss of river connectivity, and the impacts of climate change.

CRediT authorship contribution statement

Lwin Maung: Writing – review & editing, Investigation. **Tun Nyi:** Writing – review & editing, Investigation. **Nyein Chan:** Writing – review & editing, Investigation, Data curation. **John Conallin:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition. **Zau Lunn:** Writing – review & editing, Writing – original draft, Investigation, Data curation. **Karin E. Limburg:** Writing – review & editing, Supervision, Methodology, Formal analysis. **Vu An Vi:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Cameron M. Kewish:** Writing – review & editing, Validation, Methodology, Formal analysis. **Michael Akester:** Writing – review & editing. **Ian G. Cowx:** Writing – review & editing, Supervision, Methodology, Formal analysis. **Lee J. Baumgartner:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: John C. Conallin reports financial support was provided by Australian Centre for International Agricultural Research. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2025.107628.

Data availability

Data will be made available on request.

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