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MESSAGE FROM THE VICE-CHANCELLOR

It is with great honor and enthusiasm that I extend my warmest greetings on the occasion of the publication of the second volume of the Journal of Earth and Ocean Science, an esteemed academic initiative proudly facilitated by Faculty of Earth and Ocean Science, Bangladesh Maritime University. As the Vice Chancellor, I take immense pride in observing the continued advancement and scholarly contributions of our institution in the domains of earth and ocean sciences.

Bangladesh Maritime University has consistently been at the forefront of academic excellence and innovation, and this journal stands as a testament to our unwavering commitment to the pursuit of knowledge and the resolution of global scientific challenges through rigorous research and intellectual inquiry. The articles featured in this issue encompass a wide spectrum of topics and perspectives, demonstrating the dedication and expertise of our esteemed faculty, researchers, and contributors.

I extend my sincere appreciation to the editorial team for their meticulous efforts in upholding the quality and relevance of each published work. Their steadfast commitment to maintaining the highest standards of academic integrity is commendable and instrumental in the journal's success.

As we advance, I encourage our faculty, researchers, and students to actively engage with the Journal of Earth and Ocean Science, as their scholarly contributions not only enhance our academic community but also play a vital role in the broader advancement of these scientific disciplines.

I express my deep gratitude to all authors for their valuable research contributions, to the reviewers for their insightful assessments, and to the editorial team for their unwavering dedication to excellence. Through our collective efforts, we will continue to elevate Bangladesh Maritime University as a center of innovation and intellectual discourse.

I eagerly anticipate the continued success and impact of the Journal of Earth and Ocean Science and look forward to the significant contributions that will shape the future of research in this field.



Rear Admiral Dr. Khandakar Akhter Hossain, NUP, ndc, psc, PhD
Vice-Chancellor
Bangladesh Maritime University

EDITOR'S NOTE

It is a privilege to introduce the second volume of the Journal of Earth and Ocean Science, an annual scholarly publication by the Faculty of Earth and Ocean Science at Bangladesh Maritime University. As the Chief Editor, I am pleased to present a collection of research articles that highlight recent advancements in our field.

This journal provides a valuable avenue for academics, scientists, and professionals to share their research and innovative ideas in earth and ocean sciences. Our goal is to encourage high-caliber research that contributes to knowledge and addresses contemporary challenges.

Since launching our inaugural issue, we have worked diligently to establish this journal as a credible academic resource. This second edition builds on that foundation, featuring carefully selected articles that meet rigorous scholarly standards. Every submission has been subject to thorough peer review, ensuring the highest level of academic integrity.

I extend my sincere appreciation to the authors for contributing their research, the reviewers for their expertise in maintaining quality, and the editorial team for their dedication to the journal's success. Your efforts are invaluable in maintaining its credibility and impact.

As we move forward, we aim to expand our scope, encourage interdisciplinary research, and explore new topics of significance. I encourage researchers from Bangladesh Maritime University and beyond to consider this journal as a platform to showcase their work.

Thank you for your continued support. Together, we will strive to advance the Journal of Earth and Ocean Science as a leading publication in the field.



Commodore A K M M Sherafullah (H), NGP, BCGMS, psc, BN
Dean
Faculty of Earth and Ocean Science
Chief Editor, Journal of Earth and Ocean Science

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ANALYSIS OF PRESENT GLOBAL SHIP RECYCLING INDUSTRY STATUS AND FUTURE OF LOCAL YARDS

Rear Admiral Khandakar Akhter Hossain¹

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Abstract

Ships are usually dismantled and recycled at the End-of-Life (EOL), and that is recognized as a sustainable practice globally. Thousands of obsolete ships are recycled annually, making ship recycling a significant and economically viable industry from an environmental perspective. In Bangladesh, ship recycling has evolved from informal, beach-based operations to a globally significant sector. Currently, the country accounts for over 45% of global ship recycling tonnage, making it one of the top ship recycling hubs in the world, alongside India and Pakistan. What began with the dismantling of stranded ships has evolved into a profitable industry, making a significant contribution to the national economy. The sector employs a large number of semi-skilled laborers, particularly in poverty-prone coastal areas. It also supplies essential raw materials, such as scrap steel, to local industries. However, the sector faces challenges in terms of coastal zone management, including environmental degradation, weak law enforcement, and concerns regarding occupational health and safety. While fully green ship recycling—aligned with stringent European standards—remains expensive, a more viable and environmentally responsible model is possible by upgrading existing beaching methods commonly used in South Asia. Findings highlight significant shortcomings in adherence to the Hong Kong Convention-2009 (HKC), with only approximately 40% of operational ship recycling yards currently certified. Deficiencies were also noted in areas such as workplace safety, environmental protection measures, and institutional oversight. A comparative analysis reveals that India has successfully modernized around 120 HKC-compliant yards, supported by substantial governmental and donor investments, while Pakistan is actively upgrading its Gadani facilities through a large-scale financial initiative. This analytical study provides a comprehensive assessment of the local and global ship recycling industry, as well as a prediction of the future status of Bangladesh's local yards and the entire sector.

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1. Introduction

Ship recycling is a crucial global industry that promotes environmental sustainability and resource recovery by dismantling End-of-Life (EOL) ships to extract valuable materials such as steel, machinery, and equipment. Each year, thousands of ocean-going ships—including tankers, bulk carriers, and container vessels—are dismantled, with South Asia responsible for nearly 90% of global ship recycling due to favorable geography and

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comparatively low labor costs. Among the leading countries in this sector, Bangladesh has emerged as a key player. The coastline of Chattogram, particularly the Fauzdarhat area, serves as the nation's primary hub for ship recycling operations. Since the industry's unplanned inception in 1965, ship recycling in Bangladesh has grown into a billion-dollar enterprise. It now supplies more than 60% of the country's raw materials for steel production and domestic shipbuilding. The industry provides direct employment to over 200,000 workers and supports the livelihoods of approximately one million people indirectly, making it a vital source of income in economically vulnerable regions. Despite its substantial economic contributions, the sector faces growing criticism for its continued use of the beaching method—a cost-effective but environmentally controversial approach. This study also aims to analyze the quantity and types of reusable and waste materials generated by the ship recycling process in Bangladesh, based on field-level data. It will further assess how these materials are distributed and managed in terms of reuse, recycling, and dumping.

Over the last three decades, ship recycling activities have mainly taken place in South Asian countries, including Bangladesh, India, China, and Pakistan, where vessels are typically beached and dismantled using labor-intensive methods and moderate safety precautions. These countries have played a crucial role in global ship recycling, handling the majority of EOL vessels with considerable efficiency, albeit often in a less professional or regulated manner. In fact, over the last twenty years, recycling yards in Bangladesh, India, and Pakistan have accounted for nearly 90% of global ship recycling by tonnage. The growing need for ship recycling has led to improved regulatory oversight at both national and international levels. Despite this, the beaching method remains prevalent in South and Southeast Asia due to favorable tidal conditions and geographic advantages. In contrast, the dry-dock method of ship recycling is considered the safest and most environmentally sound process which is primarily practiced in developed countries, such as those in the EU and the USA. However, it is significantly more expensive to construct and operate. Some countries, such as Turkey and China, have adopted a middle-ground approach using the alongside or pier breaking method rather than beaching. Among these, Aliaga in Turkey and specific locations within the European Union are leading advocates for high-standard, environmentally friendly ship recycling practices, openly opposing the traditional beaching or slipway techniques. EOL ships are usually beached for recycling and deconstruction in South Asian nations, including Bangladesh, India, and Pakistan, taking advantage of the region's favorable tidal conditions. These countries have played a significant role in environmental preservation by efficiently recycling obsolete and decommissioned vessels—many of which, as history suggests, were once discarded in deep seas. At present, over 40% of the global EOL gross tonnage (GT) is recycled annually on the beaches of Bangladesh alone. This sector employs approximately 200,000 workers and contributes approximately USD 1 billion to the national economy. It is estimated that nearly 20,000 ships worldwide (over 500 GT and approximately 30 years of age) are approaching the end of their service life and will soon require recycling through a reverse engineering process.

The regulatory backdrop for ship recycling is undergoing significant transformation, driven by frameworks such as the European Union Ship Recycling Regulation (EU SRR) and the HKC 2009 for the Safe and Environmentally Sound Recycling of Ships () globally. These regulations impose stricter environmental and safety standards, posing operational challenges for traditional ship recycling yards in South Asia. While countries like India and Turkey have successfully upgraded a substantial number of yards to meet HKC and EU compliance requirements, Bangladesh has made slower progress. Only a limited number of yards in the country have attained green certification. In response, Bangladesh passed the Ship Recycling Act in 2018 and set a national target to bring all operational yards into compliance with HKC-2009 standards by 2025. Although this goal has not been fully achieved, notable advancements have been made in infrastructure development, regulatory compliance, and institutional oversight—particularly through the Shipbuilding and Ship Recycling Board (SBSRB) under the Ministry of Industries. This study provides a comprehensive assessment of Bangladesh’s ship recycling industry within the broader global context. It examines the industry's historical development, current regulatory challenges, comparative performance against other leading ship recycling nations, and its socio-economic contributions. It is an analytical and research-based investigation, and the evaluation offers critical insights into the current state of the local and global ship recycling sector, forecasts its future trajectory, as well as the way forward.

2. Literature Review and Methodology

2.1 Evolution and Global Dynamics of Ship Recycling

In the post-industrial era, ship recycling has emerged as a crucial global industry, driven by growing demand for raw materials and the necessity for economically viable disposal of EOL vessels. Over the past two decades, the industry has become highly concentrated in five countries—Bangladesh, India, Pakistan, China, and Turkey—with nearly 90% of global EOL vessels processed in South Asia alone [1, 4, 5, 51]. This regional dominance is primarily driven by favorable geographic conditions, low labor costs, and limited environmental oversight [7, 26, 56]. In contrast to the prevailing practices in South Asia, Turkey, and China have adopted slipway-based and dry-dock recycling methods. Though more expensive, these approaches offer significantly improved worker safety and environmental protection, reflecting a broader transition toward compliance-based ship recycling models [21, 58]. The European Union’s Ship Recycling Regulation (EU SRR) exemplifies this shift, mandating that EU-flagged vessels be dismantled only in facilities listed on the European List, thereby prohibiting the use of beaching techniques [10, 49]. Despite growing regulatory efforts, traditional beaching remains the predominant method in South Asia, especially in Bangladesh, which accounted for the largest share of scrapped vessels in 2023, according to data from the NGO Ship Recycling [54, 58]. In this method, vessels are run aground at high tide and dismantled manually—a process that, although cost-effective, results in the direct release of hazardous substances, such as oils, heavy metals, and asbestos, into the intertidal environment [28, 29, 57]. Although international frameworks, such as the EU SRR and the International Maritime

Organization's HKC for the Safe and Environmentally Sound Recycling of Ships, aim to standardize and certify ship recycling practices globally, most facilities in South Asia have yet to meet these compliance standards [55, 69, 70]. As the industry evolves, bridging the gap between cost-efficiency and environmental sustainability remains a pressing challenge.

2.2 Historical Development of Global and Local Ship Recycling

According to the International Maritime Organization (IMO), ship recycling encompasses all related operations, including mooring or beaching, dismantling, material recovery, and reprocessing, as defined in IMO Resolution A.951 [69]. Often referred to as ship dismantling, this process is inherently sustainable, offering global environmental and economic benefits through the reuse of valuable materials. Historically, until the 1960s, ship recycling activities were primarily conducted in industrialized nations such as the United States, the United Kingdom, and Germany [2, 5]. However, during the 1960s and 1970s, the industry gradually shifted to semi-industrialized countries, including Spain, Turkey, and Taiwan, driven by the availability of inexpensive labor and the growth of re-rolling steel markets. By the early 1980s, the sector experienced another significant shift as ship-owners increasingly opted to dismantle EOL vessels in developing countries such as India, China, Pakistan, Bangladesh, the Philippines, and Vietnam. This relocation was primarily motivated by the desire to reduce operational costs by capitalizing on minimal safety, health, and environmental (SHE) regulations and an abundant supply of low-wage labor [9, 17, 51]. In Bangladesh, the ship recycling industry began in 1965 with the dismantling of the Greek vessel *M D Alpine*, followed by the Pakistani ship *Al Abbas* in 1974 [4, 5, 54]. These initial cases demonstrated the geographical suitability of Chattogram's coastal region, particularly its gently sloping beaches and tidal characteristics, which facilitated the manual beaching and dismantling of large vessels. This attracted growing interest from local entrepreneurs, eventually transforming the area into a major hub for ship recycling. Today, Bangladesh's ship recycling sector has evolved into a vital component of the national economy, with a 20-kilometer-long industrial corridor along the Chattogram coast dedicated to dismantling activities [7, 8, 11]. Approximately 40 operational yards are currently active in the region, each exhibiting varying levels of regulatory compliance and adherence to international standards [13].

Table 1: Summarize fact and figure of 26 sample EOL ships.

Sl No	Ship Category/ Type	Sample Ships No	Range of LDT	Manufacture/Build Year
1	Bulk Carrier	6	11834 to 21592	1978 to 1986
2	Tanker	5	11182 to 29324	1981 to 1989
3	Cargo	5	5008 to 18302	1984-1990
4	Container	5	6698 to 16053	1977 to 1992
5	Other Ships (Refrigerator, Ore Carrier, Passenger, LNG/LPG, Motor, Floating Restaurant, etc)	5	5625 to 25997	1966 to 1981

2.3 Methodology for On-ground Data Collection and Calculation of Reusable and Waste Material

In this research work author has taken an effort to depict the actual distribution channel of reusable and waste material produced from local industry of Bangladesh by analyzing on ground data [9 and 22]; which has collected by physical involvement of the author in a period of seven years (2011 to 2017). Data of the ship recycling activity were collected from actual ship recycling industry located in Chittagong and provided by the different stake holders as well as Bangladesh Ship Breakers Association (BSBA). The inventory of reusable and hazardous wastes materials from recycled ships was derived and compiled on the basis of collected data by author. Results have based on original on ground data and take considerable help/guideline from the methodology followed in available literature and research paper. Primary and basic data about output of material/component and hazardous material of different types of recycled ships has collected from the industry by physical involvement of the author [13]. However, nuclear waste and other releases, such as emissions to atmospheric pollutants and diffuse emissions of pollutants to the water [22 and 27], were not included in the scope of this research work. Total 26 in number of different types/category as well as sizes of recycled ships has been considered as sample to calculate the average annual amount of reusable materials output and which has shown in table 1. For this research work, 5 bulk ships, 5 tanker, 6 container carrier, 5 cargo ships and 5 other different types of ships has been selected. For a single ship, it takes six to eleven months to complete an inventory of different materials and item output from the obsolete ship by involving long times with the sector. The fact and figure of those 26 sample EOL ships have been shown in **table 1** below. This is the first time in Bangladesh such broad data sampling analysis has been taken place.

2.4 Other Primary and Secondary Data Collection

The data, analysis and findings of this study reveal a nuanced yet critical trajectory for Bangladesh's ship recycling industry as it navigates the post-HKC enforcement era. Drawing on both on ground or primary data from over 500 different stakeholders, long experience/relation of researcher (last 20 years) with this industry and secondary data analysis from global ship scrapping records (2014–2024), journal, literature, media, and the study triangulates industry readiness, competitiveness, and future opportunities. The research begins with the collection of secondary data from diverse sources to establish the foundational context. Data were gathered from:

- a. Government and institutional reports (e.g., Ministry of Industries, BSRB, DoE)
- b. International organizations (IMO, UNCTAD, NGO Ship-breaking Platform)
- c. Academic journal articles, books, and policy briefs
- d. Industry and yard-level records where available (e.g., tonnage, vessel numbers, steel output)

- e. Media reports and grey literature
- f. Practical involvement and filed work since last 20 years

Statistical data on ship-breaking volumes, employment figures, scrap steel production, accident rates, and environmental violations were collated to analyze industry trends and compliance issues over the past two decades.

3. Analysis of Present Status of Global Ship Recycling Industry

In table 2 (given below), the annual global shares by nations of ship scrapping by country from 2014 to 2024 are shown. Each year’s row sums to 100 percent, and the five principal destinations—Bangladesh, China, India, Pakistan, and Türkiye—are shown as their respective proportions of the world total. Notably, Bangladesh’s share grows from 20% in 2014 to a peak of 55% in 2019 before stabilizing around 43–45% by 2024. China’s share conversely declines from 24% in 2014 to near zero after 2018. India fluctuates between roughly 22% to 34%, and ending with its highest point of 34% in 2024 and maintaining upward trend. Pakistan hovers around 18% to 21% percent up to 2018, and suddenly drops to 3% in 2019, partially rebounds, and then gain back to 7% by 2023–2024. Türkiye maintains a small but consistent presence, varying between 3% and 9% since last decade.

Table 2: Market share of major ship recycling countries from 2014-2024 (UNTCAD)

Year	World	Bangladesh	China	India	Pakistan	Türkiye
2014	100%	20%	24%	31%	18%	4%
2015	100%	34%	19%	22%	19%	4%
2016	100%	32%	12%	32%	19%	3%
2017	100%	29%	16%	29%	18%	6%
2018	100%	45%	2%	25%	21%	4%
2019	100%	55%	3%	27%	3%	9%
2020	100%	40%	1%	29%	18%	9%
2021	100%	54%	1%	16%	18%	7%
2022	100%	36%	3%	32%	18%	7%
2023	100%	45%	0%	32%	7%	7%
2024	100%	43%	1%	34%	7%	7%

In figure 1 which has been shown below plot ship recycling shares over time, tracing the rise, fall, and relative stability of each country’s ship recycling activity. The golden line for Bangladesh shows a dramatic upward trajectory through 2019, a brief dip during 2020, and a strong rebound thereafter. The orange line for China slopes steadily downward, flattening near the horizontal axis after 2018. India’s red line undulates yet trends upward by 2024 and India is going to lead the market from 2025. Pakistan’s violet line reveals volatility—especially the sharp 2019 dip, but their recent preparation will bring back to the competition. However, Türkiye’s sky-blue line remains low and steady,

reflecting its niche role. Over the ten-year period, global ship recycling shifted decisively toward South Asia. Bangladesh emerged as the clear leader, leveraging low labor cost with abundance, coastal condition, high tide margin/difference and cheap land costs plus extensive beaching infrastructure. Its share more than doubled between 2014 and 2019, only moderating slightly in the years that followed. India maintained a solid second position, expanding its share after 2020 as it began investing in on-shore dismantling facilities, high HKC compliance certifications.

Again, in contrast, China's retreat from beaching—driven by stringent environmental regulations and a pivot to on-land, high-tech recycling—saw its share collapse from nearly a quarter of global tonnage to virtually none. Pakistan's performance fluctuated with local policy changes and yard capacity constraints and recent big investment plan, while Türkiye carved out a stable but small niche by specializing in European and IMO-compliant vessel recycling. The ratification and enforcement of the HKC-2009 have played a critical role. China's post-2018, yard closures directly reflect its push to meet HKC standards, which prohibit hazardous beaching practices. Bangladesh and India have begun ratifying the Convention and piloting well-known "green yards," but their continued reliance on traditional beaching means future compliance pressure could erode market share unless further investments are made. Meanwhile, Türkiye has capitalized on the Convention by marketing its regulated facilities to European flag states seeking safe, environmentally sound recycling.

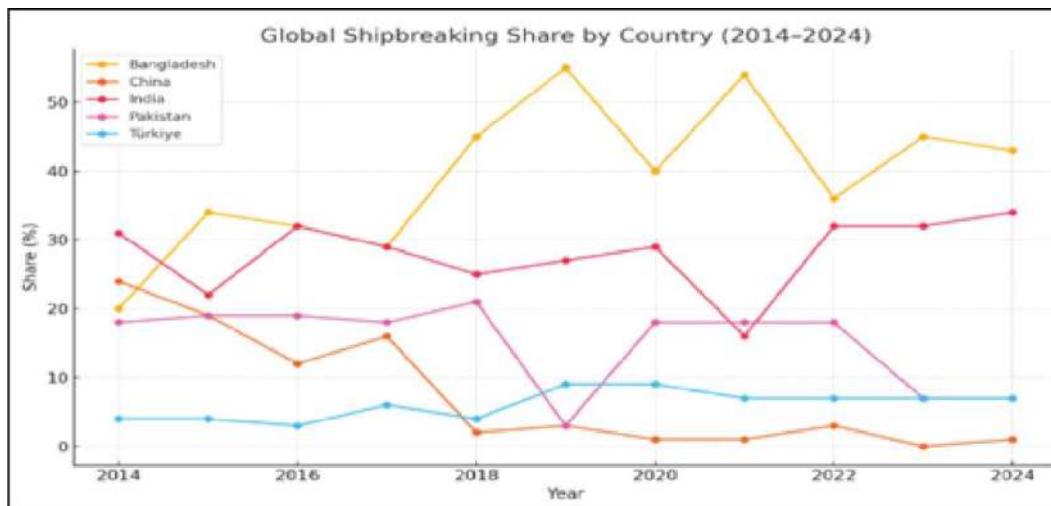


Figure 1: Market share of major ship recycling countries since last decade

China's policy shift away from beaching illustrates the power of regulatory drivers: after 2018, its share fell below 3% as domestic legislation forced the closure of open-beach yards, and tonnage was redirected toward newly built on-land facilities or to foreign markets. Bangladesh and India filled the resulting gap, growing their shares substantially. Pakistan's inconsistent policy enforcement and limited yard upgrades

resulted in a sharp 2019 downturn and subsequent volatility, underscoring the importance of regulatory stability. In South Asia, the trend is clear: countries that adapt by investing in compliant infrastructure will capture the bulk of future global tonnage. Bangladesh's competitive advantages rest on very low labor and land costs, a highly experienced, young and available workforce accustomed to beaching operations, and an ecosystem of ancillary industries—steel re-rolling mills, spare-parts trading, and transport services.

However, environmental and worker-safety pressures under the IMO and HKC are mounting, and domestic regulations are poised to tighten. In the short term, Bangladesh is likely to sustain a 40–45% share, given its existing capacity. Over the next five to ten years, however, strategic investment in on-shore “green yards”—with modular hazardous-waste treatment, mechanized dismantling, and formal safety training along with sufficient capital government investment and incentive like RMG are essential to maintain leadership as full HKC enforcement takes effect. Looking ahead, Bangladesh can solidify its position by developing value-added recycling services—advanced material recovery, more mechanical and safe dismantling, proper disposal of toxic residues, and certified green-yard operations. Government investment and incentives for yard modernization, combined with industry partnerships and targeted training programs, will help bridge the HKC compliance gap. Research to model the cost–benefit of green upgrades and to forecast tonnage flows under scenario analyses of HKC ratification can guide policy and investment decisions. By proactively addressing environmental and safety challenges, Bangladesh is well positioned not only to retain its market share but also to set a new standard for sustainable ship recycling in the region.

4. Reusable Material Output from Local Recycling Yards

Ship recycling yields an extensive range of reusable materials, often comprising hundreds to thousands of distinct items per vessel. In this study, the author undertook the challenging task of preparing a comprehensive inventory of materials and components from 26 EOL ships. Given the restrictive nature of the industry and the scale of data involved, the process required sustained effort over a period of seven years. To facilitate this data-intensive undertaking, the researcher assembled a dedicated team consisting of six data entry personnel and two supervisory managers. The reusable materials extracted from the selected sample of ships were categorized into four main groups in accordance with the guidelines set forth in the HKC for the Safe and Environmentally Sound Recycling of Ships [23, 25]. This categorization was further refined using principles of ship design and construction, drawing on the researcher's professional expertise as a naval architect. The classification scheme was also informed by existing academic and technical literature [1, 2, 3, 5–8, 12, 21, 22, 29]. Data collection was conducted through manual tallies and digital entry using Microsoft Excel spreadsheets. The categories of reusable materials identified from EOL ships are as follows:

- **Metal Items:** Includes heavy and light steel plates, brass, copper, MS pipes, nickel, galvanized iron, stainless steel sheets, aluminum, zinc, chains, anchors, shaft plates, cast iron, and various ferrous and non-ferrous scraps.
- **Machinery, Equipment, and Accessories:** Comprises main engines, generators, gearboxes, propellers, rudders, pumps, condensers, radiators, heat exchangers, air conditioning units, fire safety equipment, lifeboats, kitchen accessories, and personal protective equipment.
- **Electrical and Electronic Items:** Encompasses electrical cables, transformers, motors, navigation and communication systems (e.g., radar, GPS), televisions, washing machines, computer equipment, and assorted electrical tools and spare parts.
- **Outfit and Other Reusable Components:** Includes doors, hatches, port windows, cranes, winches, capstans, valves for various fluid systems, ladders, furniture, and sanitary fittings.

Based on the compiled dataset, the study estimates that the annual output of reusable materials from the ship recycling sector in Bangladesh ranged between 1,833,461 metric tons (MT) and 1,989,252 MT in the year 2018. Material quantification and flow analysis were performed using a combination of manual calculations and software tools, including Microsoft Excel and the Material Flow Analysis (MFA) software STAN [21, 22, 28, 29, 31]. Comparative analysis revealed that manual calculations deviated by a maximum of 0.4% from STAN-generated results, while results obtained via Excel showed no observable variation [26, 27, 30]. **Table 3** presents the average output of reusable materials (in MT per year) for different ship types, while **Figure 2** illustrates the relationship between Light Displacement Tonnage (LDT) and reusable material output across ship categories. The detailed compilation, data visualization, and result interpretation for the 26 sampled ships were performed using advanced Excel programming and broadsheet models [31, 57]. Furthermore, **Figure 4** provides a model of the material distribution channel—including both reusable materials and waste—for a typical container ship processed at a local ship recycling yard in Bangladesh [32].

Table 3: Reusable material factor and amount of materials output per year in MT in 2018 [22].

Sl. No	Type of Ship	Average LDT per year	Reusable Factor (%)	Material	Average Reusable Material per year (MT)
1	Cargo	111,486	0.67	Min.	74,696
			0.78	Max.	86,959
2	Bulk Carrier	1,094,566	0.94	Min.	1,028,892
			0.98	Max.	1,072,675
3	Tanker	579,542	0.95	Min.	550,565
			0.97	Max.	562,156
4	Container	186,583	0.8	Min.	149,266
			0.87	Max.	162,327
5	Other	120,169	0.25	Min.	30,042
			0.8	Max.	96,135
6	Total	2,092,346		Min.	1,833,461
				Max.	1,980,252

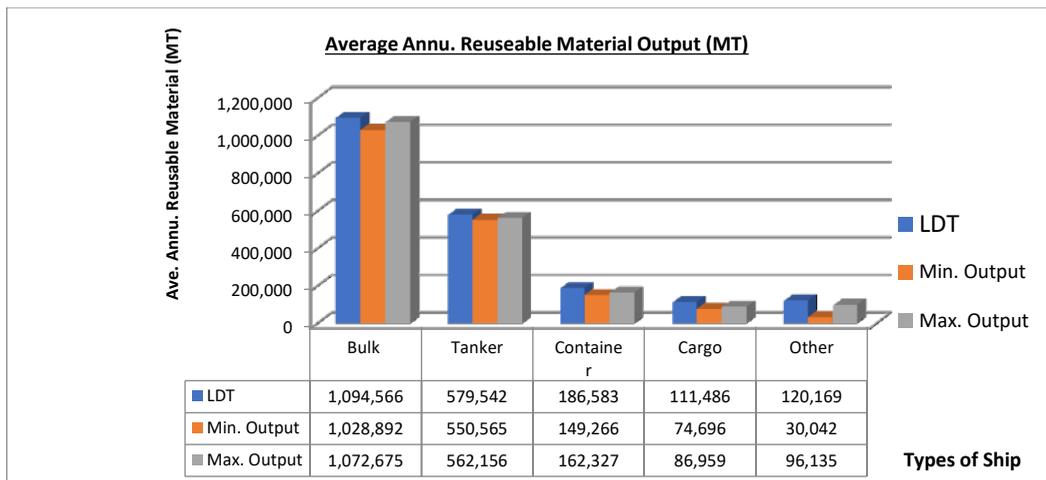


Figure 2: Average annual LDT against average annual reusable material output in MT [21]

5. Waste Output from Local Recycling yards

According to the *Bangladesh Environment Conservation Act, 1995*, hazardous waste is defined as any substance which, by its inherent physical, chemical, reactive, toxic, flammable, or corrosive properties—either alone or in combination with other substances—poses a threat to human health or the environment. These wastes are broadly categorized into two types: (i) organic hazardous materials such as polymers, which can potentially be chemically treated or incinerated; and (ii) inorganic materials such as heavy metals and asbestos, which typically require containment or specialized disposal. In this study, the researcher classified hazardous wastes generated from ship recycling yards in Bangladesh into six distinct categories. The classification was informed by the guidelines of the HKC for the Safe and Environmentally Sound Recycling of Ships [23, 25], naval architectural principles, and insights from relevant literature [1, 2, 5–8, 12, 13, 21, 22, 57]. This categorization facilitated efficient data compilation, weight estimation, and waste management planning. The groups are defined as follows:

- **Group A – Asbestos and Asbestos-Containing Waste:** Includes asbestos insulation, glass wool, ceramic wool, damping materials, and other insulation-related substances.
- **Group B – Landfill Waste:** Includes cementitious residues, ceramic dust, iron rust and scale, ash (including incinerator ash), cathode ray tube glass particles, zinc residues, and other solid wastes suitable for landfill.
- **Group C – Incinerable Waste:** Consists of paint residues, coatings, pharmaceuticals, PVC, PCBs, PCTs, PBBs, polybrominated analogues, oil sludge, plastic, textiles, polyurethane foams (PUF), welding fumes, and other combustible or chemically treatable substances.
- **Group D – Bilge and Liquid Waste:** Comprises bilge water, fuel and lubricating oils, organic solvents (halogenated and non-halogenated), hydraulic oils, volatile organic compounds, outdated chemicals, microbial sediments, and pesticide/insecticide residues.

- **Group E – Heavy Metal Waste:** Includes toxic metals such as lead, mercury, and cadmium, commonly found in batteries, anodes, electrical fittings, thermometers, soldering equipment, motor components, cable insulations, and communication devices.
- **Group F – Ozone-Depleting and Explosive Substances:** Contains compressed gas cylinders, fire suppression liquids, and materials with ozone-depleting potential, such as CFCs, halon, and Aqueous Film Forming Foam (AFFF).

For the quantification of waste output and determination of associated factors, a combination of manual calculation and digital tools was employed. Microsoft Excel and the MFA software STAN were used to compute and cross-verify results [21, 28, 29]. It was observed that results from manual computation varied by no more than 0.4% compared to those generated by STAN, while outputs from Microsoft Excel showed full consistency with manual estimates [22, 26, 30]. **Figure 3** illustrates the average annual quantity of hazardous waste (in MT) generated from different categories and sizes of EOL ships recycled in Bangladesh. **Table 4** presents detailed annual data (both minimum and maximum values) for each waste category, derived from the sample of 26 obsolete vessels dismantled in 2018. All data in this study were collected, compiled, and analyzed by the author over a seven-year period through direct field engagement with the ship recycling industry. Data processing and graphical analysis were conducted using structured Microsoft Excel broadsheets and custom programming modules [30, 31].

Table 4: Annual average amount waste produced in MT from different EOL ships [20, 54]

Sl. No	Type of Ship	Average LDT per year (MT)	Total Waste (Land-filled, Incinerated, and Bilge Waste)							
			Average Land-filled Waste Per Year (MT)		Average Incinerated Waste Per Year (MT)		Average Bilge Waste Per Year (MT)		Total Average Hazardous Waste Per Year (MT)	
1	Bulk	1,094,566	3042	Min.	2,188	Min.	2360	Min.	7590	Min.
			4078	Max.	2,861	Max.	3073	Max.	10012	Max.
2	Tanker	579,542	2244	Min.	1,357	Min.	2087	Min.	5688	Min.
			3030	Max.	1,854	Max.	2852	Max.	7736	Max.
3	Container	186,583	718	Min.	524	Min.	374	Min.	1616	Min.
			808	Max.	574	Max.	410	Max.	1792	Max.
4	Cargo	111,486	582	Min.	260	Min.	208	Min.	1050	Min.
			648	Max.	290	Max.	232	Max.	1170	Max.
5	Other	120,169	580	Min.	299	Min.	400	Min.	1279	Min.
			849	Max.	562	Max.	583	Max.	1994	Max.
Total		2,092,346	7166	Min.	4,628	Min.	5429	Min.	17223	Min.
			9413	Max.	6,141	Max.	7150	Max.	22704	Max.

6. Disposal and Management of Waste

Extensive field investigations and repeated visits to ship recycling yards in Bangladesh have revealed that approximately 97% of glass wool and other insulation materials recovered from EOL ships are recycled and re-enter the market through local contractors. These materials are resold as insulation products to various sectors, including shipbuilding and repair, construction, small-scale industries, and cold storage facilities. Only an estimated 3% of such insulation waste is directed to Treatment, Storage, and Disposal Facilities (TSDF), primarily when the materials are damaged or contaminated beyond reuse. This high recovery rate is attributed to the generally intact condition of insulation materials upon removal and their consistent demand in the domestic market. For instance, in Bangladesh, second-hand glass wool insulation fetches an average price of USD 110 per MT, while in neighboring India the average price is approximately USD 100 per MT [13, 19, 20, 22]. These figures underscore the economic viability of insulation material recovery in South Asia’s ship recycling industry. Interestingly, other forms of ship-borne waste—including bilge water, sludge, spent chemicals, solvents, and even damaged furniture—are frequently sold to local entities. These substances are often repurposed for use in brick kilns, informal housing construction, or small-scale industrial processes. The informal reuse of these materials, while economically beneficial, raises questions about safe handling practices and potential environmental risks. The removal of insulation, flooring, and tiling—sub-processes commonly performed during pre-cutting—may result in minimal environmental release, especially when the recovered materials are in good condition and removed using low-impact techniques. For example, in India, intact insulation panels are directly purchased by resellers to serve the insulation needs of cold storage operators and similar industries [14, 19, 21]. Furthermore, there exists a robust secondary processing ecosystem surrounding the ship recycling yards in Bangladesh. A wide array of firms specializes in refurbishing and reintroducing salvaged materials—including machinery, furniture, electrical components, and metals—back into industrial use [5, 11, 20, 22]. The diverse and dynamic material flows generated through the ship recycling process highlight a complex circular economy network that is shaped by market demand, material condition, and the recycling methods employed.

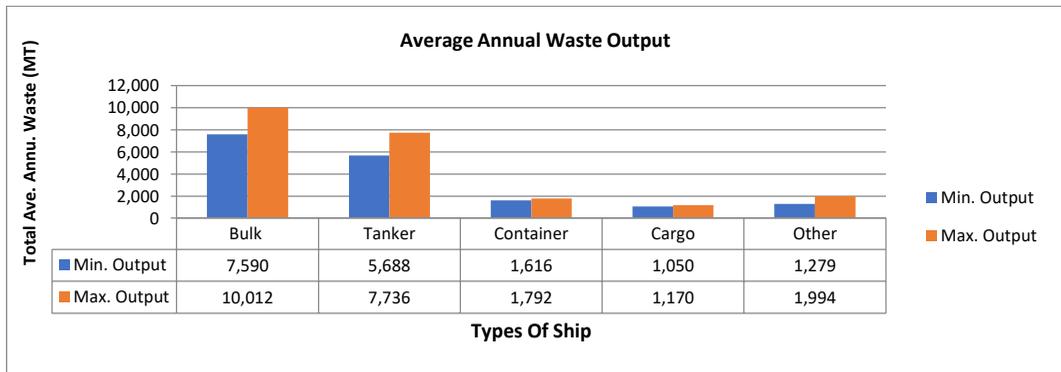


Figure 3: Total average annual HazMat or Waste produced in MT [22, 58]

MFA serves as a valuable analytical tool for visualizing, planning, and comparing various scenarios related to the recycling of EOL ships. It enables stakeholders to trace the movement of materials throughout the recycling process, identify critical points of reuse or disposal, and optimize the distribution of recovered substances and components. A comparative analysis of second-hand markets in two major ship recycling hubs—Alang (India) and Chattogram (Bangladesh)—highlights significant economic activity around the resale of materials recovered from dismantled vessels. For instance, in Alang, legally traded items include electrical cables (USD 1–2 per kg), electric motors (USD 1 per kg), glass wool insulation sheets (USD 0.02 per kg), sludge (USD 0.02 per kg), waste oil (USD 8–15 per barrel), and scrap machinery (USD 1 per kg) [59]. In comparison, the second-hand market in Chattogram reflects slightly higher prices across most categories: electrical cables (USD 1.2–2.2 per kg), electric motors (USD 1.2 per kg), glass wool insulation sheets (USD 0.2 per kg), sludge (USD 0.2 per kg), waste oil (USD 10–16 per barrel), and scrap machinery (USD 1.2 per kg) [18, 21]. These pricing variations are influenced by local demand dynamics, supply chains, and industrial needs, and further demonstrate the economic potential of systematically recovered ship components. A schematic model illustrating the distribution channel of reusable and waste materials from a typical recycled container ship at a local ship recycling yard in Bangladesh is provided in **Figure 3**. This model depicts the pathways through which recovered materials are sorted, processed, sold, or disposed of—offering insight into the circular economy network operating around ship recycling activities in the region. During the research period from 2012 to 2018, the author conducted regular field visits to ship recycling yards in Chattogram, Bangladesh. These visits enabled detailed observations of operational practices and data collection methods. In the earlier stages of the research, it was evident that record-keeping and documentation regarding reusable and hazardous materials were largely informal. Reporting was primarily based on visual estimations, lacking systematic weighing, tracking, and control mechanisms.

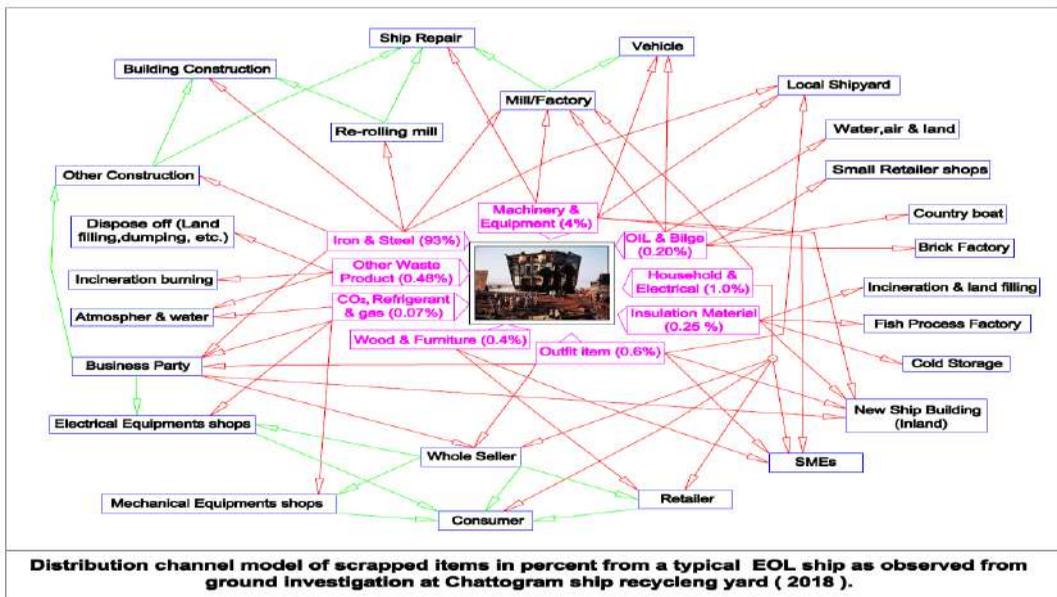


Figure 4: Distribution channel of reusable and waste material of a typical ship [32]

In recent years, however, the industry has undergone substantial improvement in multiple critical areas. Notable progress has been made in the handling of hazardous materials, with more structured approaches to safe storage and disposal. Practices related to work in confined spaces and at elevated heights have become more regulated and safety-conscious. Fire prevention and control measures have been introduced more widely across yards, and the use of personal protective equipment (PPE) is now enforced. Cutting and paint-removal activities are increasingly carried out on hard-standing floors to minimize environmental contamination. Worker facilities such as rest areas, recreational spaces, showers, and accommodation have been significantly upgraded, improving overall welfare conditions. Additionally, emergency evacuation procedures and rescue protocols have been developed and implemented in many yards. There has been a marked improvement in asbestos management practices, including the proper removal, handling, and disposal of asbestos-containing materials. Hazardous waste is now better inventoried and stored, and preventive environmental measures are being implemented alongside regular awareness-building initiatives. Health and welfare planning for workers has gained attention, with more emphasis on long-term well-being and security. Importantly, many recycling yards have begun to employ naval architects and technical professionals to oversee operations, and there is growing investment in worker training and education to ensure compliance with modern technological standards and international regulatory frameworks. As a result of these advancements, thirteen local recycling yards have successfully achieved certification under the HKC for the Safe and Environmentally Sound Recycling of Ships. Another six yards are currently undergoing the certification process and are expected to meet HKC standards within the year. It is projected that by the end of the next calendar year, more than thirty operational recycling yards in Bangladesh will be HKC-certified. Nevertheless, to sustain its top position in the global ship recycling market, Bangladesh will need to increase this number to at least forty active HKC-certified yards. Meeting this target poses a significant challenge that demands proactive engagement from both the government and industry stakeholders. Continued improvements in infrastructure, regulatory enforcement, environmental management, and human resource development will be essential to ensuring long-term sustainability and competitiveness in the global market.

7. Comparison of Reusable and Waste Material Factor with other Countries

A comparative analysis of key indicators—namely waste generation and material reuse factors—between Bangladesh and other prominent ship recycling nations provides valuable insight into the performance and efficiency of different ship recycling clusters. Table 5 presents the waste and reusable factors derived from a comprehensive field survey conducted at Alang Port, India. The survey covered 241 ships dismantled over a three-year period (2011–2013) and included various ship types. The analysis was based on ship weight expressed in terms of LDT and included quantification of significant waste fractions, such as bilge water, landfillable wastes, and incinerable wastes produced throughout the recycling and disassembly process. Among the six major ship

types surveyed, general cargo vessels, bulk carriers, and container ships demonstrated notable structural and operational similarities, particularly with respect to the spatial distribution of waste materials within the ship body. These ship types, commonly dismantled during the observed period at Alang, India were found to have comparable waste characteristics, thereby enabling a consistent basis for estimating “emission or waste factors,” which were expressed in kilograms per LDT (kg/LDT). Correspondingly, the “reusable factor,” indicating the proportion of recoverable materials from EOL ships, was expressed as a percentage of total LDT. To assess performance differentials between Alang (India) and Chattogram (Bangladesh), the values of waste and reusable factors obtained through sample-based analysis have been compiled and compared in Table 5 and Table 6. This comparison highlights differences in operational efficiency, material recovery, and waste management practices between the two recycling clusters. Further, the relationship between average reusable material output, waste generation, and asbestos content per LDT for ships dismantled in Bangladesh is graphically represented in Figure 5. This visualization offers a clearer understanding of trends across ship types and supports data-driven insights into the material flow and environmental impact of ship recycling activities in the region.

Table 5: Comparison of reusable material and waste factors (in Kg per LDT) of different types of ships recycled in the ship dismantling yards in Alang Port in the State of Gujarat, India during the year 2011 to 2013 [21, 27]

Sr. No.	Ship type	Total Landfillable wastes	Total incinerable wastes	Bilge water	Cumulative weight of wastes	Reusable material factor in %
		kg/LDT	kg/LDT	kg/LDT	kg/LDT	w/w %
1	General Cargo, Bulk Carrier & Container Ships	16.5-20.0	2.7-3.0	2.1-2.4	21.3-25.4	92
2	Oil & Chemical Tanker	11-16.6	2.5-3.3	4.2-4.5	17.7-24.4	94
3	Refrigerator Ship	40.0-152.0	1.7-10.0	13.8-14.8	55.5-176.8	81
4	Passenger Ship	17.6-36.6	0.8-1.2	1.3-1.47	19.7-39.2	72

Table 6: Estimated data of waste factors and reusable factor has compared between Alang Port, India and Chittagong, Bangladesh.

Sr. No.	Ship type	Cumulative weight of wastes (for India)	Reusable material factor in % (for India)	Cumulative weight of wastes (for Bangladesh)	Reusable material factor in % (for Bangladesh)
		kg/LDT	w/w %	kg/LDT	kg/LDT
1	General Cargo, Bulk Carrier & Container Ships	21.3-25.4	92	10.1- 13.5	93
2	Oil & Chemical Tanker	17.7-24.4	94	11.2-14.1	95
3	Refrigerator Ship	55.5-176.8	81	-	-
4	Passenger Ship	19.7-39.2	63	14.1-17.2	62

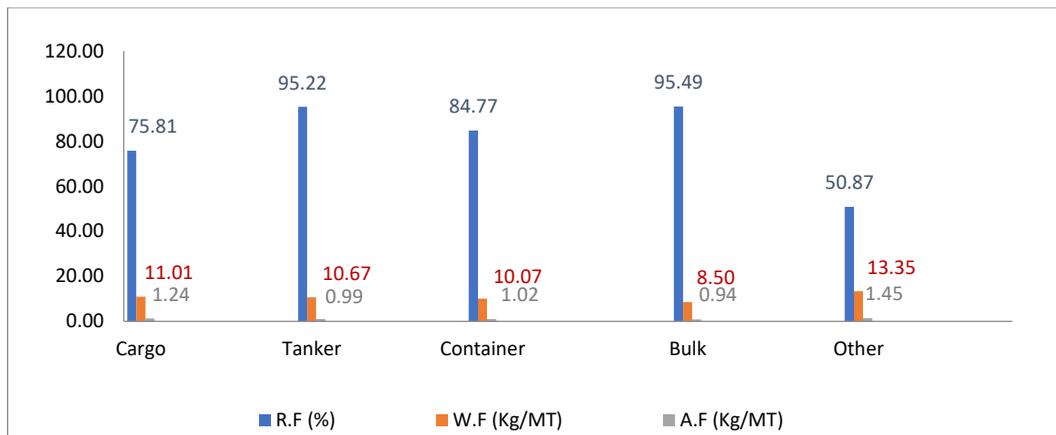


Figure 5: Relation among average reusable, waste and asbestos factor with LDT of EOL ships for Bangladesh [21, 52, 58]

8. Future Challenges for Local Ship Recycling Industry of Bangladesh

In 2018, the Bangladeshi government passed the Bangladesh Ship Recycling Act, which requires ship-breaking and recycling yard operators to implement safe and eco-friendly recycling practices in accordance with the HKC-2009. Out of the approximately (40+) active/operational recycling yards, only 13 yards (*and hope that another 7 are going to HKC certified soon*) have obtained the Green Passport (HKC certificate). Due to the expenses involved (huge capital investment), the majority of non-compliance yards are hesitant to implement the green ship recycling criteria (HKC 2009 requirement). Currently, more than forty yards are attempting to meet those requirements. Ship recycling yards ought to be in a desperate attempt to improve and meet HKC requirements. However, the high cost of building green yards made local recycling owners hesitant/timid. It would take at least Taka 200 to 300 million (around 2.5 million USD for single yards) to modernize one ship recycling yard, and it would cost about Tata 12 billion (around 100 million USD for whole industry) to upgrade the entire recycling industry/sector in order to have all of these facilities and stay competitive and resilient in business/sector globally [43, 44, 58]. In contrast, Bangladesh's recycling competitors, like India, are far ahead of us and have already complied with the HKC standard. China and Turkey have already made their ship recycling facilities green in accordance with the guidelines set forth by the HKC, which was adopted in 2009. By the end of 2026, Bangladesh aimed to convert all local ship recycling yards into environmentally friendly establishments. However, given the state of affairs and the mindset of the local yard owners, there are questions whether this goal might not be met this year. Additionally, the government had established numerous deadlines for reforming the local recycling sector. There are diversified challenges for SBRI in Bangladesh.

According to a research by the Bangladesh Ship Breakers and Recyclers Association (BSBRA), the appreciation or crisis of the USD and LC concerns caused a fall in the import of scrap vessels in 2023–2024. In this running year

very few vessels have imported, showing a significant commercial deficit. The UNCTAD analysis claims that because of the difficult environment brought about by the global geopolitical and financial circumstances, maritime trade, global tariff crisis in 2025 has increase the risk further and more uncertain than it was within 2021–2024. Nonetheless, the present growth rate is 1.4% (2026–2030), and it is anticipated that this significant growth will either stay the same or maybe rise by 2% in the upcoming years. This is a little slower than what was observed in the decades prior [61, 69, 75]. Demand was rising in the post-pandemic globe, which was driving up shipping costs. This has made it more difficult for owners of outdated or EOL ships to dispose of them in recycling facilities. Additionally, new shipbuilding orders were being placed found declining trend. As a result of price of EOL ship is increasing and this upward trend may continue further [58, 69]. Global businesses have been greatly impacted by the current geopolitical environment, which includes the COVID-19 pandemic, the Israel-Iran war, and the ongoing consequences of the Ukraine-Russia conflict and global tariff dilemma. A difficult environment for international business, particularly the ship recycling industry, has been brought about by rising inflation and widespread uncertainty [57, 65, 71]. In order to achieve their goals and compete with other international companies (India, Pakistan, and Turkey), local ship recycling yards need to adopt a more corporate culture and modify their mindset. Local yards can succeed commercially and maintain their competitiveness in the global recycling market by adopting appropriate tactics and practices and drawing inspiration from highly efficient industrial nations [56, 58]. According to ILO and IMO laws, local recycling yards must take the required actions to ensure health, hygiene, and safety standards [49, 57, 76]. Local recycling yards need to establish a Ship Recycling Facilities Plan (SRFP) and other safety and technical requirement in order to comply with HKC regulations as early possible. It will be more difficult and complicated to continue operating local recycling business in the future if local yards don't get ready to ratify HKC and some form of EU RRC as soon as possible [51, 52, 58].

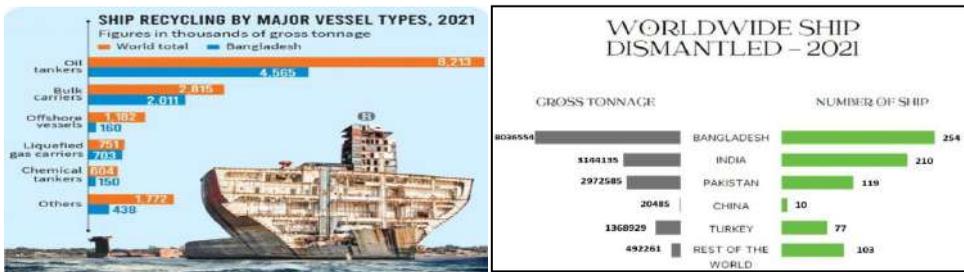


Figure 7: Global ship recycling comparison and statistics by major vessel types in 2021 [22, 51]

9. Analysis and Future of Global and Local Ship Recycling Industry

The study and analysis show that Bangladesh has taken visible steps toward regulatory modernization, including HKC ratification in 2023 and the initiation of facility audits, SRFP (Ship Recycling Facility Plan) development, and draft legislative reforms aligned with IMO conventions. However, around 60% of yards are either non-compliant or uncertain about HKC obligations. The readiness gap between paper compliance and practical enforcement is evident in the weak institutional frameworks for monitoring, certification, and penalization. By contrast, India's formal adoption of the Recycling of Ships Act, 2019, and the operational/active around 120 HKC-compliant yards, gives it a comparative edge in attracting EU-flagged and environmentally conscious ship-owners. Labor conditions remain one of the most contentious and revealing domains. Few local yards HKC-compliant yards have significantly improved workplace safety, over 30% of respondents reported a lack of PPE, inadequate emergency training, and exposure to hazardous materials without containment. This is consistent with academic critiques of the industry, which highlight that informal labor recruitment and limited oversight continue to dominate yard practices [34, 38]. Bangladesh's poor track record on environmental and health compliance—especially in non-HKC yards—could become a reputational risk, affecting future trade and access to OECD and EU ship disposal contracts [23, 57, 60, 76]. Compared to India's structured workforce training and Pakistan's recent commitments to build hospitals and training centers in Gadani, Bangladesh's social investments remain fragmented and donor-driven rather than systemic.

Sl No	Name	HKC Status
1	PHP Ship Breaking and Recycling Industries Ltd	Compliant
2	M/S S N Corporation Unit-2	Compliant
3	Kabir Steel Ltd	Compliant
4	KR Ship Recycling Yard	Compliant
5	Arab Ship Breaking and Recycling Ltd	Compliant
6	MAK Corporation	Compliant
7	H M Shipping Lines Ltd	Compliant
8	M/S S N Corporation Unit-1	Compliant
9	M/S S N Corporation Unit-3	Compliant
10	M/S Ferdous Steel Ship Recycling Industries	Compliant
12	KR Steel Ltd	Compliant
13	NB Steel	Compliant
14	Janata Steel Ltd	SRFP approved, receive provisional DASR soon
15	Asadi Steel Enterprise	SRFP approved, receive provisional DASR soon
16	BOB Recyclers	SRFP approved, receive provisional DASR soon
17	Taher & Co. Ltd	SRFP approved, receive provisional DASR soon

Figure 8: Present HKC status of local recycling yards.

India's technological advancement (with shore cranes, dry-dock recycling, concrete hard-standing), its legislative certainty, and large investment inflows collectively challenge Bangladesh's historic volume leadership. Pakistan's Rs12 billion (~USD 42 million) modernization plan for Gadani—though just beginning—signals a geopolitical pivot that could dilute Bangladesh's regional dominance if not matched with countermeasures. Bangladesh's export of ship recycling services is still heavily dependent on low-cost labor and favorable geography. But these advantages are rapidly diminishing as environmental, labor, and governance factors become critical selection criteria for ship-owners under ESG mandates. Failure to realign with global best practices may not only lead to a drop in market share but also attract sanctions or exclusion from "green" ship disposal networks. Bangladesh should finalize and enforce the draft *Ship Recycling Act* that fully integrates HKC provisions and aligns with Basel, Rotterdam, and Stockholm conventions. This law should mandate facility authorization, hazardous material inventory tracking, waste disposal compliance, and environmental impact audits. We may create a dedicated **Ship Recycling Regulatory Authority (SRRA)** with representatives from the Ministry of Industries, Ministry of Environment, Ministry of Shipping, Department of Labor, BUET, Bangladesh Maritime University or BMU (as academic advisor), etc. to coordinate oversight, inspections, and certifications. **We can** make it compulsory for all yards to submit approved **Ship Recycling Facility Plans (SRFPs)** and obtain HKC certification within a fixed transition period (within couple of years). Regular third-party audits should be institutionalized with penalties for non-compliance.

Government may provide fiscal incentives (tax rebates, accelerated depreciation, and import duty waivers) for investments in green yard infrastructure such as impermeable floors, drainage systems, shore-based cranes, and waste treatment units. **We can establish On-site Medical and Safety Facilities which** require every major yard cluster to have **on-site clinics**, safety response units, and trained emergency personnel. Medical record tracking and regular health checkups should be part of yard licensing. We need to institutionalize a training and certification framework through the **Bangladesh Institute of Marine Technology (BIMT)** or a new **Ship Recycling Safety Academy** under BMU. All workers should be registered and receive periodic refresher training on hazardous material handling and emergency response. We need to ensure fair wages, housing, insurance, and legal aid for workers through a dedicated Ship Recycling Workers Welfare Board. Monitor labor rights with cooperation from labor unions and NGOs. We may use multilateral funding (e.g., from IMO, World Bank, ADB, JICA) and national budget allocations to create a blended financing mechanism supporting local recycling yards upgrades, particularly for small and medium recyclers. **We may introduce performance-based incentives which** offer incentives (e.g., carbon credits, scrapping subsidies, export rebates) to yards demonstrating continuous improvement in safety, compliance, and environmental performance. **We may facilitate access to commercial credit to** Partner with state and private banks to develop low-interest **green loans** with technical evaluation support for upgrading recycling infrastructure.

10. Final Recommendation

Bangladesh may create a National Recycling Information System (NRIS) to develop a centralized data repository tracking vessels, tonnage, compliance status, hazardous waste movement, and workforce information with applying smart and advanced technology [44, 46, 48]. Require all yards to report monthly operations into this system. **We may conduct regular independent assessments** by partner with academic institutions and international agencies to publish **annual State of Ship Recycling Reports**, benchmarking Bangladesh against global standards and highlighting improvement areas. We need to create fund for academic and private research into alternative recycling techniques, hazardous material recovery, and environmental remediation methods suitable for Bangladesh's context. Smart and digital technology may introduce in this sector [50, 69, 76]. Work with India and Pakistan under IMO or BIMSTEC frameworks to share best practices and address cross-border environmental impacts of ship recycling. We may launch international campaigns to attract EU, Japanese, and South Korean ship-owners to Bangladesh's certified "green" yards, highlighting cost advantages and new infrastructure. This industry may promote partnerships with local industries (e.g., re-rolling mills, manufacturing, construction) to develop downstream value chains using scrap steel, recovered equipment, and refurbished ship parts. Bangladesh's ship recycling industry now faces severe competition from modernizing yards in India and Pakistan (after completion of their up-gradation plan), especially as international rules tighten. Bangladesh ratified the HKC-2009 in June 2023 [67, 71, 75], but by mid-2025 few yards (only 13) meet HKC standards. Latest industry data show India has **120** HKC certified/compliant yards, while Bangladesh has only **13** (soon to be 20) HKC compliant yards. In practice, roughly 95% of India's yards are HKC certified versus only about 40% of Bangladesh's (rest 60% not fully compliant). This gap threatens Bangladesh's market share as it was up to 2023 Bangladesh handled ~46% of global recycling tonnage whereas India handle ~33% [67, 71, 73].

Ironically, Bangladesh has developed only single dozen (13) HKC compliance green yards since decade [64]. To remain in global competition, rest of local yards (around 25 yards) need to achieve HKC certificate as soon as possible, otherwise nation will lose the race. But, the high cost of building green yards made local recycling owners still hesitant/timid. It would take at least Taka 200 to 300 million (around 2.5 million USD) to modernize single ship recycling yard, and it would cost about Tata 12 billion (around 100 million USD) to upgrade the entire recycling industry/sector in order to have all of facilities (as per HKC) and stay competitive and resilient in business/sector globally. The analysts warn Bangladesh has a potential risk and going to losing its position to Indian yards (where India has managed large donor backed "green yards") and surely India is going to capture more business in coming years ahead [64, 72]. At the same time, Pakistan, which accounts for ~16.6% of global recycling share (in 2022) has only just ratified the HKC (Dec 2023) and is scrambling to upgrade Gadani [67, 68]. It needs to

mention that Pakistan has recently initiated sizable domestic investments to modernize its ship recycling industry. In June 2025, the Pakistani government approved a fund of Rs 12 billion (~\$42 million) to transform the Gadani ship recycling yards into a “model green facility.” So, Pakistan is also going to catch the global race very soon. So, **environmental compliance** is a key challenge for Bangladesh. That is why, local recycling yards of Bangladesh need to be earned HKC certificate within short span of time and need to be upgraded rest of the incompliant yards to remain competitive, or else EOL vessels will flow increasingly toward Indian recycling yards and modernizing Pakistani yards. Now, India already mandates ‘Ready for Recycling’ certificates and strict waste management under its 2019 ‘Recycling of Ships Act’ [64, 70], while Pakistan’s government has approved major investments to build a “model green” yard at Gadani [65, 70]. As a result, local recycling yards of Bangladesh and nation as a whole have no alternative except modernization and up-gradation strategy and capital investment in this sector.

11. Conclusion

Approximately a thousand big oceangoing vessels are disassembled and recycled annually by the global ship recycling business. South Asia is currently without a doubt the world's hub for ship recycling. Nonetheless, three South Asian locations—Chattogram (Bangladesh), Alang (India), and Gadani (Pakistan)—account for 90% of ship recycling efforts. On average, 200 different kinds of old ships are recycled every year in Bangladesh in various yards of Chattogram. Once more, based on actual data from Bangladesh's ship recycling yards, I estimate that, on average, about 2 million LDT of old ships of various sizes and types are recycled each year in various Bangladeshi yards. Over the past eight years, the author has gathered and compiled an inventory of the materials, machinery, equipment, products, and HazMat on various sizes and types of EOL ships that have been recycled at Bangladeshi local recycling yards. A total of 26 recycled ships of various sizes and types have been used as a sample to determine the average yearly production of garbage and recoverable materials. The average amount of reusable materials gathered from Bangladesh's ship recycling business each year is 1,989,252 MT (highest) and 1,833,461 MT (minimum). Once more, Bangladeshi local recycling yards create an average of 17,215 MT (minimum) and 22,702 MT (maximum) of hazardous trash every year. A few variables, such as the number of ships disassembled and the actual amount of hazardous waste in the demolished ships, affect the formation of hazardous trash. Both variables vary widely. However, there hasn't been any variation in the amount of hazardous trash in the disassembled ships as a result of those elements changing. Once more, the new ship design concept and the enforcement of laws and regulations will alter both of these aspects in the future. Bangladesh, which has a large and inexpensive labor pool, has emerged as a center for recycling EOL ships. In actuality, the ship recycling sector has significantly boosted Bangladesh's economy and is crucial to both the macro and micro economies in lowering poverty.

The ship recycling industry of Bangladesh, long regarded as a global leader in volume and cost-efficiency since last decade, but now is at a critical crossroads. As this study has shown, the enforcement of the HKC 2009 for the Safe and Environmentally Sound Recycling of Ships, coupled with rising global expectations for environmental and labor standards, is reshaping the competitive landscape in profound ways. Through a combination of primary field data (including over 500 stakeholder interviews) and secondary analysis of ship-breaking trends across South Asia and beyond, this research has critically assessed Bangladesh's readiness, performance, and future prospects. Bangladesh has made important progress—like ratifying the HKC, initiating Ship Recycling Facility Plans (SRFPs), and participating in international donor-supported programs—its progress is uneven, largely fragmented, and heavily dependent on external technical assistance. The labor and environmental dimensions present perhaps the most urgent challenges. Although some yards have embraced reforms, widespread deficiencies in workplace safety, personal protective equipment (PPE), and hazardous waste management persist. Without significant improvements, these deficiencies will continue to undermine the industry's global reputation and block access to high-value recycling contracts from OECD and EU ship-owners. Now, 50% of local yards are remained in compliant with the HKC requirements. Only 13+4 or 17 local recycling yards are HKC certified out of 40+ active/operational yards. Bangladesh's regulatory delays and unclear enforcement mechanisms reflect a critical bottleneck. Stakeholder interviews reveal skepticism about the efficacy of government audits, and many operators are waiting for clarity on whether non-compliant yards will be officially delisted. This limbo state has slowed investment and discouraged long-term planning, a challenge that may intensify post-2025 when global compliance expectations harden.

To remain in global competition, rest of local yards (around 25 yards) need to achieve HKC certificate as soon as possible, otherwise nation will lose the race. But, the high cost of building green yards made local recycling owners still hesitant/timid. It would take at least Taka 200 to 300 million (around 2.5 million USD per yard) to modernize single ship recycling yard, and it would cost about Tata 12 billion (around 100 million USD for total industry) to upgrade the entire recycling industry/sector in order to have all of facilities as per the guidance and requirement HKC and stay competitive and resilient in business/sector globally. But continue to hold the top position of global market; Bangladesh should have 40+ active/operation HKC certified yards. As of today, India got authorization 'Ready for Recycling' certificates and strict waste management under its 2019 'Recycling of Ships Act' along with Pakistan's government has approved major investments to build a "model green" yard at Gadani. As a result, local recycling yards of Bangladesh as well as whole sector have no option, rather than modernization and up-gradation strategy and capital investment in local ship recycling industry. The pathway forward for Bangladesh lies not in resisting global environmental and labor norms, but in strategically aligning with them to capture a new generation of demand for ethical and green ship recycling. The time to act is now—before the market shifts irrevocably toward better-prepared competitors. Within next year rest of the local recycling yards

should get the HKC certification. But continue to hold the top position of global market; Bangladesh should have 40+ active/operation HKC certified yards.

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References :

- [1] Jain, K. P., et al, (2015), "Quantitative assessment of material composition of end of life ships using onboard documentation," International Journal of Resources, Conservation and recycling, Vol 19, Nov 2015, accessed on 09 Aug 2025
- [2] Jain, K.P., et al, (2014), "Influence of ship design on ship recycling," Maritime Technology and Engineering, pp. 269–276, CRC Press, May 2014, accessed on 09 Aug 2025
- [3] Hossain, K. A., (2015a), "Overview of Ship Recycling Industry of Bangladesh," Journal of Environmental and Analytical Toxicology, Vol 5, Issue 5, July 2015, accessed on 09 Aug 2025
- [4] Hossain, K. A., et al, (2010a), "Ship Recycling Prospects in Bangladesh," Proceeding of MARTEC 2010; 8th International Conference of Marine Technology, BUET, Dhaka, Aug 2010 accessed on 09 Aug 2025
- [5] Hossain, K. A., et al, (2010b), "A Study of Socio Economic and Ecological Impact of Ship Recycling in Bangladesh," The Journal of NOAMI, Vol 27-1, pp. 35-47, May 2010 accessed on 09 Aug 2025
- [6] Sivaprasad K., (2010), "Development of best practices for ship recycling processes," Thesis Submitted to the Department of Ship Technology, Cochin University of Science and Technology, India, Dec 2010, accessed on 09 Aug 2025
- [7] Hossain, K. A., (2017a), "Ship recycling status of Bangladesh and annual reusable material output," Journal of Toxicology, Vol 2, Issue 2, Oct 2017, accessed on 09 Aug 2025
- [8] Hossain, K. A., (2017b), "Ship recycling practice and annual reusable material output from Bangladesh ship recycling industry," Journal of fundamentals of renewable energy and application, Vol 7, Issue 5, Sep 2017, accessed on 09 Aug 2025
- [9] Stopford, M., (2009) "Maritime Economics. Routledge", New York, USA, 2009
- [10] Hossain K A, (2024a), An Overview of Merchant Ships, ISBN-13, 979-8324932374, May 2024, Amazon, US
- [11] Hossain K A, (2024b), Warship Construction Idea, ISBN-13, 979-8327525443, June 2024, Amazon, US
- [12] Hossain, K. A., et al, (2009), "Service provides and supporting industries of shipbuilding sector on Bangladesh and its impact on overall development of shipbuilding", Proceedings of the 6th International Conference & 13th Annual Paper Meet, Dhaka, Mechanical Engineering Division; The Institute of Engineers, Bangladesh (IEB), 30-31 Dec 2009, accessed on 09 Aug 2025

- [13] Hossain, K. A., et al, (2012), "Underlying Problems of ship-recycling industry in Bangladesh and way forward", 6th International Mechanical Engineering Conference & 14th Annual Paper Meet 2012; 28-29, Sep 2012, accessed on 09 Aug 2025
- [14] Hossain, K. A., (2015b), "Future of Energy Resources", International Journal of Renewable Energy Technology Research (IJRETR); Vol. 4, No. 5, Nov 2015, accessed on 09 Aug 2025
- [15] Hossain, K. A., (2017c), "Global warming and effect to the third world countries", Journal of recent advancement of petrochemical science, Volume 7, Issue 5, Jun 19, 2017, accessed on 09 Aug 2025
- [16] Hossain K. A., (2015c), "Leadership Qualities for 21st century Leaders", Journal of Management, Social Science and Humanistic", Volume 1, Issue 2, May 2015, accessed on 09 Aug 2025
- [17] Hossain K. A., (2015d), "Essential Tips and Tactics of motivation, Journal of Management", Social Science and Humanistic, Volume 1, Issue 1, April 2015, accessed on 09 Aug 2025
- [18] Hossain, K. A., (2018a), "SWOT Analysis of China Shipbuilding Industry in the Third Eyes", Journal of recent advancement of petrochemical science, Volume 4, Issue 2, Jan 2018, accessed on 09 Aug 2025
- [19] Hossain, K. A., (2018b), "Analysis of important steering factors which give Success to Global Shipbuilding Leaders", Journal of recent advancement of petrochemical science, Volume 4, Issue 5, Jan 2018, accessed on 09 Aug 2025
- [20] Hossain, K. A., (2018c), "Calculation of Yearly output of reusable material of Ship Recycling Industry of Bangladesh," Journal of Recent Advancement of Petrochemical Science, Vol 5, Issue 3, Jun 2018, accessed on 09 Aug 2025
- [21] Hossain, K. A., (2018d), "Material Flow Analysis (MFA) is A Better Tool to Calculating Reusable Material For Ship Recycling" 11th International Conference of Marine Technology, UTM, Malaysia, Aug 13-14, 2018, accessed on 09 Aug 2025
- [22] Hossain, K. A., et al, (2018e), "Proposed Sustainable Ship Recycling Process For South East Asian Recyclin Yards" 11th International Conference of Marine Technology, UTM, Malaysia, Aug 13-14, 2018 accessed on 09 Aug 2025
- [23] *Basel Convention, (1989), Basel Convention on the Control of the Trans-boundary Movements of Hazardous Wastes and their Disposal, 1989*, accessed on 09 Aug 2025
- [24] EC Regulation, (2006), Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste, 2006, accessed on 09 Aug 2025
- [25] *HKC Convention, (2009), Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009*, accessed on 09 Aug 2025
- [26] Sivaprasad, K., et al, (2008), Sustainable development index for ship recycling, Proceedings of the Second International Conference on Dismantling of Obsolete Vessels, Glasgow September, Session 6, 2008, accessed on 09 Aug 2025
- [27] Hiremath, A.M., et al, (2015), "Significant steps in ship recycling vis-a-vis wastes generated in a cluster of yards in Alang: a case study." J. Clean. Prod. 87, 520–532, 2015, accessed on 09 Aug 2025

- [28] Jain K. P., et al, (2017), "Material flow analysis as a Tool to improve ship recycling," *Journal of Ocean Engineering*, pp. 674-683, Vol 13, Aug 2017, accessed on 09 Aug 2025
- [29] Cencic O., et al, (2008), "Material Flow Analysis with Software STAN," *Journal Environment Engineering Management*, Vol 18, Oct 2008, accessed on 09 Aug 2025
- [30] Stephen Bullen, (2009), Rob Bovey and John Green, *Professional Excel Development* (2nd ed.). Addison-Wesley. ISBN 0-321-508793, 2009, accessed on 09 Aug 2025
- [31] Hossain K A, (2019a), "Material Flow Analysis Technique for Material Assessment of Ship Recycling Industry" *Bangladesh Maritime Journal, BSMRMU, Vol 3, Issue 1, Jan 2019*, accessed on 09 Aug 2025
- [32] Hossain K A, (2019b), "Development of an Assessment Model for Ship Recycling Industry in Bangladesh" *Proceedings of the 2nd International Conference on Industrial and Mechanical Engineering and Operations Management (IMEOM), Dhaka, Bangladesh, December 12-13, 2019*, accessed on 11 Aug 2025
- [33] Hossain, K. A., (2021a), Sustainable Ship Recycling Regulation and Process in Contest of Bangladesh, *Navy Journal* 7 (1), 1-23, Dec 2021, accessed on 11 Aug 2025
- [34] Hossain K A (2021b) Strength Weakness Opportunity, Threat (SWOT) analysis of Bangladesh shipbuilding industry, Technical Paper: NAME, MIST, 16 Dec 2021, available at: <https://www.mist.ac.bd/storage/files/name/TECHNICAL>, accessed on 11 Aug 2025
- [35] Hossain, K. A., (2023a), Tale of LNG and LPG Ships, *Global Scientific Journals (GSJ), Vol 11, Issue 6, June 2023, ISSN 2320-9186*, accessed on 11 Aug 2025
- [36] Hossain, K. A., (2023b), Tale of Bulk Ships, *Global Scientific Journals (GSJ), Vol 11, Issue 6, June 2023, ISSN 2320-9186*, accessed on 12 Aug 2025
- [37] Hossain, K. A., (2023c), Tale of Container Ship, *Journal of Software Engineering and Simulation, Quest Journals* 9 (7), page: 48-61, accessed on 03 Aug 2025
- [38] Hossain, K. A., (2023d), Evaluation of global and local ship designing software trend and way forward, *Global Scientific Journals (GSJ), Vol 11, Issue 5, May 2023, ISSN 2320-9186*, accessed on 03 Aug 2025
- [39] Hossain, K. A., (2023e), Analysis of present global ship recycling status and challenges for Bangladesh, *Global Scientific Journals (GSJ), Vol 11, Issue 4, April 2023, ISSN 2320-9186*.accessed on 03 Aug 2025
- [40] Hossain, K. A., (2023f), Technological advancement and future of warship building, *International Journal of Research and Development (IJNRD), Vol 8, Issue 5, May 2023, ISSN 2456-4184*, accessed on 03 Aug 2025
- [41] Hossain, K. A., (2023g), An overview of merchant ships, *International Journal of Research and Development (IJNRD), Vol 8, Issue 6, June 2023, ISSN 2456-4184*, accessed on 03 Aug 2025
- [42] Hossain, K. A., (2023h), An Overview of Naval Ships, *Scientific Research Journal (SCIRJ)* 11 (6), ISSN: 2201-2796, June 2023, accessed on 05 Aug 2025

- [43] Hossain K A, (2024c), Analysis of ship recycling, ISBN-13, 979-8343259971, Oct 2024, Amazon, US.
- [44] Hossain K A, (2025a), Evaluation of Internet of Things (IoT), ISBN-13, 979-8306216980, Jan 2025, Amazon, US
- [45] *Hossain, K. A., (2023j), Evaluation of local industry of Bangladesh including shipbuilding, Global Scientific Journals (GSJ), Vol 11, Issue 6, June 2023, ISSN 2320-9186, accessed on 09 Aug 2025*
- [46] *Hossain, K. A., (2023k), Evaluation of Influence of Internet of Things (IOT) Technologies and Devices in 21 Century, Scientific Research Journal 11 (7), accessed on 09 Aug 2025*
- [47] *Hossain, K. A., (2023l), SWOT Analysis of Shipbuilding Industry of Bangladesh, Science Publication Group (Science PG) 4 (3), accessed on 09 Aug 2025*
- [48] *Hossain, K. A., (2023m), Evaluation of Influence of Artificial Intelligence (AI) on Technologies in 21st Century, Journal of Electronics and Communication Engineering Research, Quest Journal, accessed on 09 Aug 2025*
- [49] *Hossain, K. A., (2023n), Analysis of present global ship recycling status and challenges for Bangladesh, Global Scientific Journals (GSJ), Vol 11, Issue 4, April 2023, ISSN 2320-9186, accessed on 09 Aug 2025*
- [50] Hossain K A, (2024d), Artificial Intelligence and Robot, ISBN-13, 979-8332453625, Sep 2024, Amazon, US
- [51] *Hossain, K. A et al, (2023a), Evaluation of present ship recycling scenario and opportunity for Bangladesh, Journal of Environment and Analytical Toxicology (JEAT), Vol 13, Issue 4, April 2023, ISSN 2161-0525, accessed on 09 Aug 2025*
- [52] *Hossain, K. A., et al., (2023b), Global Major Ship Recycling Players and Their Fate in Future, International Journal of Novel Research & Development (IJNRD) 8 (5), Jun 2023, accessed on 09 Aug 2025*
- [53] IMO, Resolution, (2004), IMO Res: A.951 (23), IMO Guidelines on Ship Recycling (resolution A.962(23), 4 March 2004, International Maritime Organization. Regulatory Guidance, available at: <http://www.iadclexicon.org/ship-recycling>, accessed on 28 Jul 2025
- [54] ILPI Paper, (2016), Ship-breaking Practices in Bangladesh, India and Pakistan; Published by International Law and Policy Institute (ILPI) on May 18, 2016, accessed on 28 Jul 2025
- [55] Mambra S., (2017), What is Green Ship Recycling, Green Shipping Marine Environment, Marine Insight, Oct 04, 2017, available at: <https://www.marineinsight.com/environment/what-is-green-ship-recycling>, accessed on 28 Jul 2025
- [56] Nikos Mikelis, (2017), What Will 2017 Bring to the Ship Recycling Industry? Available at: <http://www.maritime-executive.com/editorials/what-will-2017-bring-to-the-ship-recycling-industry>, accessed on 28 Jul 2025
- [57] Mohiuddin G., and *Hossain, K. A., (2023a), Strategic Plan to Ratify HKC 2009 by Bangladesh: Challenges & Approach toward implement SRFP in local yards toward Green Ship Recycling, International Journal of Novel Research & Development (IJNRD) 8 (5), May 2023, accessed on 09 Aug 2025*

- [58] Mohiuddin G., and *Hossain, K. A., (2023b)*, Analysis of Present Global Ship Recycling Status and Challenges for Bangladesh, *Global Scientific Journal* 11 (4), May 2023, accessed on 09 Aug 2025
- [59] TBS Report, (2021), Bangladesh remains on top in ship breaking, October 22, 2021, *available at:* <https://www.tbsnews.net/dropped/industry/bangladesh-remains-top-shipbreaking-319333>, accessed on 09 Aug 2025
- [60] UNEP, (2012), Basel Convention - Technical guidelines on the environmentally sound co-processing of hazardous wastes in cement kilns, accessed on 09 Aug 2025
- [61] UNCTAD, (2025), Ship recycling, by country, annual (analytical), on 10 Jun 2025, *available at:* <https://unctadstat.unctad.org/datacentre/dataviewer/US.ShipScrapping>, accessed on 31 Jul 2025
- [62] SENSREC, (2025), <https://www.imo.org/en/mediacentre/pages/whatsnew-2229.aspx#:~:text=The%20SENSREC%20initiative,%20funded%20by,sustainable%20practices%20in%20ship%20recyclin>, 25 June 2025
- [63] LinkedIn, (2023), <https://www.linkedin.com/pulse/norways-1364-million-investment-green-revolution-bangladeshsh7j0f#:~:text=Norway%20has%20pledged%20a%20substantial,yards%20into%20environmentally%20friendly%20facilitie>, accessed on 09 Aug 2025
- [64] Eolog, (2024), [https://eolog.com/en/bangladesh-could-lose-top-position-in-the-global-shipbreaking-market/#:~:text=%E2%80%9CWith%20over%20\\$100%20million%20ofunding,told%20the%20Business%20Standard%20newspape](https://eolog.com/en/bangladesh-could-lose-top-position-in-the-global-shipbreaking-market/#:~:text=%E2%80%9CWith%20over%20$100%20million%20ofunding,told%20the%20Business%20Standard%20newspape), 12 June 2025
- [65] Arabnews, (2024), <https://www.arabnews.pk/node/2605790/pakistan>, 24 Jul 2024
- [66] Industriall-union, (2025), <https://www.industriall-union.org/progress-and-challenges-in-bangladeshs-shipbreaking-sector>, 15 Apr 2025
- [67] Maritime-executive, (2025), <https://maritime-executive.com/editorials/op-ed-to-save-bangladesh-s-recycling-industry-phase-in-the-hkc#>, 27 Apr 2025
- [68] Dawn, (2025), <https://www.dawn.com/news/1920881/ilo-launches-study-to-reform-ship-recycling-sector#:~:text=initiative%20prepares%20Pakistan%20to%20meet,acceded%20to%20in%20December%202023>, 29 Jun 2025
- [69] IMO, (2025), <https://www.imo.org/en/mediacentre/pages/whatsnew-2229.aspx#:~:text=Adviser%20to%20the%20Ministry%20of,and%20injury%20to%20the%20workforce>, 26 Jul 2025
- [70] PIB, (2019), <https://www.pib.gov.in/PressReleaselframePage.aspx?PRID=1596730#:~:text=Accession%20to%20Hong%20Kong%20Convention,position%20as%20the%20market%20leader>, 17 Dec 2019
- [71] Splash247, (2024a), <https://splash247.com/bimco-urges-imo-to-resolve-contradictions-in-ship-recycling-conventions/>, 15 Jul 2024
- [72] Splash247, (2024a), <https://splash247.com/bimco-launches-ship-recycling-alliance/>, 14 Nov 2024

ANALYSIS OF PRESENT GLOBAL SHIP RECYCLING INDUSTRY STATUS AND FUTURE OF LOCAL YARDS

- [73] BIMCO, (2025), <https://www.bimco.org/news-insights/bimco-news/2025/06/25-hkc/>, 25 June 2025
- [74] TBSNews, (2025), <https://www.tbsnews.net/economy/industry/bangladesh-top-global-ship-recycling-again-541874>, 24 Jul 2025
- [75] Islam, S. M. M. U., (2025, April 4), Upcoming challenges of the ship recycling industry in Bangladesh, The Daily Star, available at: <https://www.thedailystar.net/law-our-rights/news/upcoming-challenges-the-ship-recycling-industry-bangladesh-3863051>, accessed on 09 Aug 2025
- [76] Hossain K A, (2025b), Artificial Intelligence (AI), ISBN-13, 979-8328010290, 2025, Amazon, US

Olive Ridley Turtle (*Lepidochelys olivacea*) bycatch along the Cox's Bazar Coast of Bay of Bengal, Bangladesh: Insights from the Fishermen and Local Community

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Abstract

Olive Ridley turtle (*Lepidochelys olivacea*) is the most abundant among the five species of sea turtles found in Bangladesh. Bycatch during marine fishing causes injury and death and hampers their life cycle. There is a need for bycatch management, but no organized information is available. For the first time in Bangladesh, the study examined the bycatch level, seasonal patterns, causes, fate of turtles after bycatch, and fishermen's opinions on the harmfulness of bycatch and management needs. Eighty fishermen from Daria Nagar, Sonarpara, Inani, and Patuarterk on the Cox's Bazar coast were interviewed. The bycatch rate was reported as the number of bycatches per 100 fishing efforts (BPUE). The mean BPUE was 0.194 ± 0.00 and ranged from 0.04 to 0.4. The highest bycatch was associated with winter and late autumn, and between a distance of 5-15 km from shore. Large mesh drift nets, fish trawls, and fixed gill nets were found mostly responsible. Alive but injured (61.25%) turtles were mostly reported in bycatch. Both the juvenile and adult turtles (45.0%) were found mostly impacted. Most of the fishermen reported cutting nets and releasing (48.8%) the turtles after bycatch, and the least reported selling or killing (6.3%). The primary causes were destructive fishing, the absence of escape mechanisms in nets, and a lack of understanding of the life cycle and ecological importance of sea turtles. These findings can help in the management of Olive Ridley Turtles from the threats of extinction.

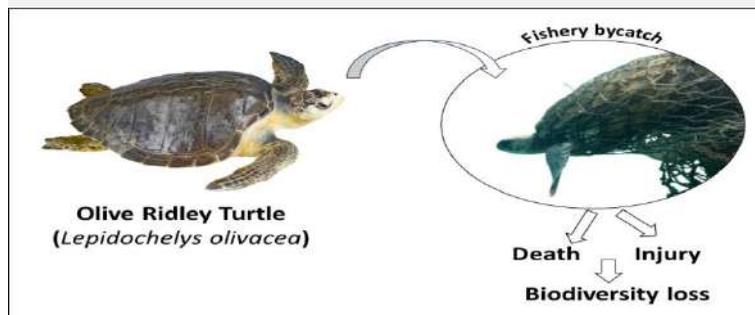
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Graphical abstract



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1. Introduction

Sea turtles are aquatic reptiles that have evolved specifically for oceanic life. They control the numbers of jellyfish, which, if left unchecked, can drastically reduce fish populations. Furthermore, by scavenging dead and decaying organic materials, they contribute to maintaining a clean aquatic environment (Hossain et al., 2013). Sea turtles are classified into two families, Cheloniidae, and Dermochelyidae, and comprise seven species. The Olive Ridley (*Lepidochelys olivacea*), Green (*Chelonia mydas*), Hawksbill (*Eretmochelys imbricata*), Loggerhead (*Caretta caretta*), and Leatherback (*Dermochelys coriacea*) turtles are the five species found in Bangladesh (Hossain et al., 2013). The most common sea turtle worldwide and in Bangladesh, the Olive Ridley turtle (*L. olivacea*) gets its name from the olive-green hue of its heart-shaped shell. Olive Ridleys are famous for their "arribadas," or mass nesting events, which take place on coastal beaches. They are widely spread throughout tropical portions of the Atlantic, Pacific, and Indian Oceans (Hamann et al., 2003; Pritchard, 2007). Olive Ridleys display remarkable migratory behaviours, covering distances ranging from a few to thousands of kilometres depending on ecological factors (Robinson and Paladino, 2013). The IUCN has classified the species as Endangered because of a 30–50% reduction in population. In Bangladesh, Olive Ridleys nest on sandy beaches along the Cox's Bazar coast and adjacent islands in the southeast coastal areas (Hossain et al., 2013). The species is also reported from the Sunderbans mangrove forest area of the southwest coast of Bangladesh (Aziz, 2017). Research on this species is still lacking, and thus, little is known about its population and all possible nesting sites in Bangladesh.

Worldwide, threats to sea turtles are numerous. Their nesting is hindered by compacted sand, and hatchling survival is decreased by predators such as dogs, birds, and ghost crabs. Further endangering their survival are jackal assaults on nesting females and unlawful egg harvesting (Carmo et al., 2023). Coastal development, tourism, and conventional beach use disturb their nests and destroy habitats (Hossain et al., 2013). Increased light exposure on beaches disturbs their spawning and confuses the pathway of hatchlings. Climate change exacerbates these problems by promoting habitat loss and distorting sex ratios in favour of more female hatchlings (Cáceres-Farias et al., 2022; Hossain et al., 2013). Nesting locations are disrupted by intense weather, rising sea levels, and temperature changes. Sea turtles suffer from ingesting toxic chemicals, waste exposure, plastic pollution, and oil spills, which cause abnormalities in their population (Wallace et al., 2013; Wallace et al., 2011). Human activities like the construction of artificial reefs, aquaculture processes, oil and gas extraction, the application of renewable energy sources, seabed mining, tourism, and a rise in marine vessel traffic additionally endanger sea turtles (Cáceres-Farias et al., 2022; Harris, 2020). Sea turtles face these threats both at sea and on nesting beaches in Bangladesh (Hossain et al., 2013; Islam, 2002a). Bycatch, or accidental catch in fisheries, is one of the main threats to sea turtle populations worldwide. Sea turtle reductions are largely caused by bycatch, which happens in both large- and small-scale fisheries employing trawls,

longlines, gillnets, seine nets, and other fishing gear (Andraka et al., 2013; Casale, 2011; Lewison & Crowder, 2003).

Turtles entangled in fishing gear may wash ashore alive or dead, with some suffering from sepsis and death long after entanglement (Stacy et al., 2017). If turtles are entangled for an extended length of time, capture myopathy, which is characterized by muscle injury and bruises, sores or scars, and, in severe cases, limb amputation, may result (Archibald and James, 2018; Barreiros and Raykov, 2014; Eckert et al., 2012; Phillot and Godfrey, 2019; Stelfox and Hudgins, 2015). Fishermen sometimes kill turtles that become entangled in their nets to protect their valuable equipment (Islam, 2002a, b). The global bycatch of turtles between 1990 and 2008 was estimated to be 85,000; however, this number could be underestimated given the lack of data from small-scale fisheries (Wallace et al., 2011).

Although there may be a significant number of Olive Ridley turtle bycatches in Bangladesh, these are unreported and unassessed. The need for systematic surveys and updated information on sea turtle bycatch in Bangladesh is critical to reducing the bycatch of this important species. In cases where non-target bycatch of several species from fisheries is available (Faruque and Matsuda, 2021; Fatema et al., 2022), Bangladesh lacks a methodical evaluation of sea turtle bycatch. Onboard observer programs offer precise estimations of bycatch levels, but they are frequently unfeasible due to logistical and financial difficulties. In these situations, interview-based surveys can provide insightful information about the extent and impact of bycatch (Cáceres-Farias et al., 2022). Therefore, for the very first time, this study aimed to gather information from the fishermen of the Cox's Bazar coast, Bay of Bengal on the status of Olive Ridley turtle bycatch, including net types responsible, seasonal patterns, distances from shore, causes, fishermen's actions after bycatch, and their opinions on bycatch impacts and management needs. The findings and understandings gained from this study can serve as a foundation for future research initiatives. The information obtained from this study will help managerial bodies design sustainable management plans to lessen the bycatch of Olive Ridley sea turtles.

2. Methodology

2.1 Study area

The present study was carried out on the Cox's Bazar coast of the Bay of Bengal, Bangladesh. Data collection was carried out at the fishermen communities in 04 areas, which were Daria Nagar, Sonarpara, Inani, and Patuartek (Figure 1). These areas were selected because they are renowned nesting sites for sea turtles and are home to fishing communities. The participants were selected based on a reconnaissance visit to these areas. A total of 80 fishermen who were actively involved in fishing in the Bay of Bengal were selected for data collection.

Olive Ridley Turtle (*Lepidochelys olivacea*) bycatch along the Cox's Bazar Coast of Bay of Bengal, Bangladesh: Insights from the Fishermen and Local Community

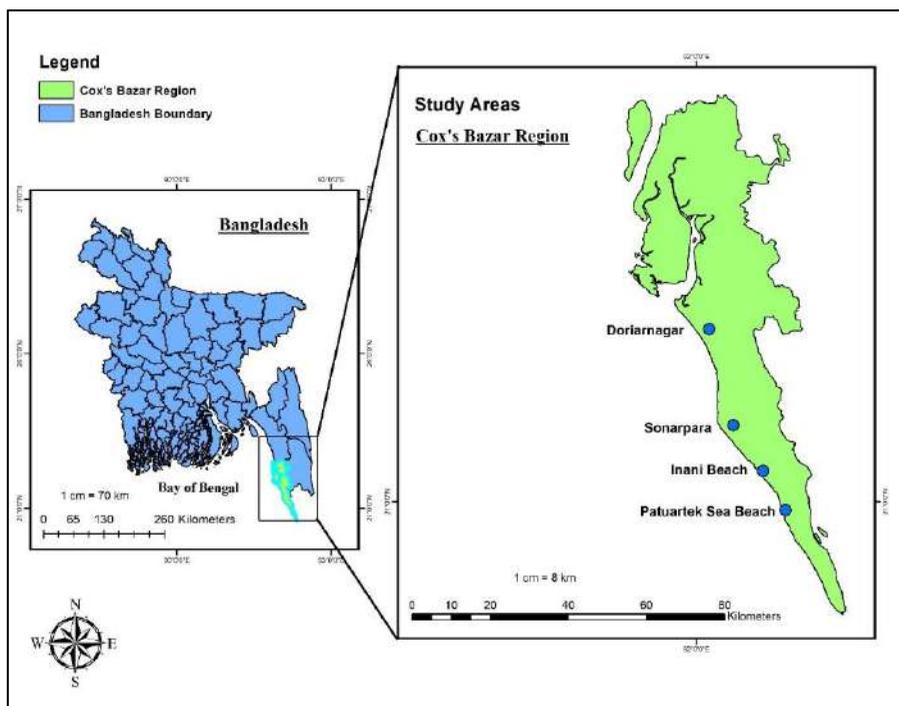


Figure 1. Map of the study areas in the Cox's Bazar region, southeast coast of Bangladesh.

2.2. Questionnaire and data collection

A comprehensive questionnaire was designed with a mix of both open-ended and closed-ended questions. The questionnaire was prepared in both English and Bengali to ensure comprehensibility among the participants. The questions were regarding the observation of Olive Ridley turtle bycatch per 100 times of fishing efforts (BPUE), types of fishing nets responsible for bycatch, bycatch in different seasons and distance from shore, life stage of turtles observed as bycatch, causes of bycatch and attitudes of fishermen towards harmfulness of bycatch and their opinions on the need of management measures (Appendix 1).

Suggestions from fisheries management and marine biology specialists were obtained to improve the relevance and accuracy of the questionnaire. A questionnaire pre-test was conducted with a survey involving a small sample ($n = 15$). Several revisions were made to improve the questionnaire and data collection process based on the pre-test feedback. Data was collected from 80 fishermen (20 from each area) in June 2024. Participatory methods, including direct interviews with questionnaires and focus group discussions, were used for collecting data (Figure 2).



Figure 2. Some pictures of interviewing fishermen on the bycatch status of Olive Ridley turtle (*Lepidochelys olivacea*) in the Cox's Bazar Coast, Bangladesh

2.3 Statistical analysis

The collected data were categorized, analyzed, and visualized using “Statistical Package for Social Sciences (SPSS, version 24)” and “Programming Language R”. Bycatch rate was shown as the number of bycatches per 100 fishing efforts (BPUE) (Equation 1). Kruskal-Wallis H Test was conducted to observe any statistically significant variation in bycatch among seasons, different distances from shore, and different fishing nets. Crosstabulation was employed to define the relationship between ‘net types and condition of turtles after bycatch’, and between ‘life stages of turtles and condition after bycatch’. Chi-square test was used to examine whether there were significant associations between these variables (95% confidence interval, $p = 0.05$). Phi coefficient and Cramer's V were calculated to know the strength of the relationships obtained through the Chi-square tests.

$$\text{Number of bycatches per 100 fishing efforts (BPUE)} = \frac{\text{Number of Turtles observed in bycatches}}{\text{Fishing efforts (100)}}$$

3.. Results

3.1 Bycatch by different types of fishing nets

According to the respondents, the rate of BPUE ranged from 0.04 to 0.4 with a mean of 0.194 ± 0.00 . That means the highest number of bycatches they observed per 100 times

of fishing effort ranged from 4 to 40 times. The highest BPUE was associated with 'Large mesh drift net (LMDN)' (0.195 ± 0.095) and 'Fish trawl (FT)' (0.197 ± 0.104), and the lowest with 'Fixed gill net (FGN)' (0.098 ± 0.790). Responses of participants who reported multiple nets revealed that both "LMDN and FT" were associated with the highest BPUE (0.265 ± 0.182), followed by both "FT and FGN" (0.184 ± 0.076) and lowest with "LMDN and FGN" (0.150 ± 0.141) (Figure 2). There were statistically significant differences in BPUE among the different types of fishing nets ($p < 0.05$).

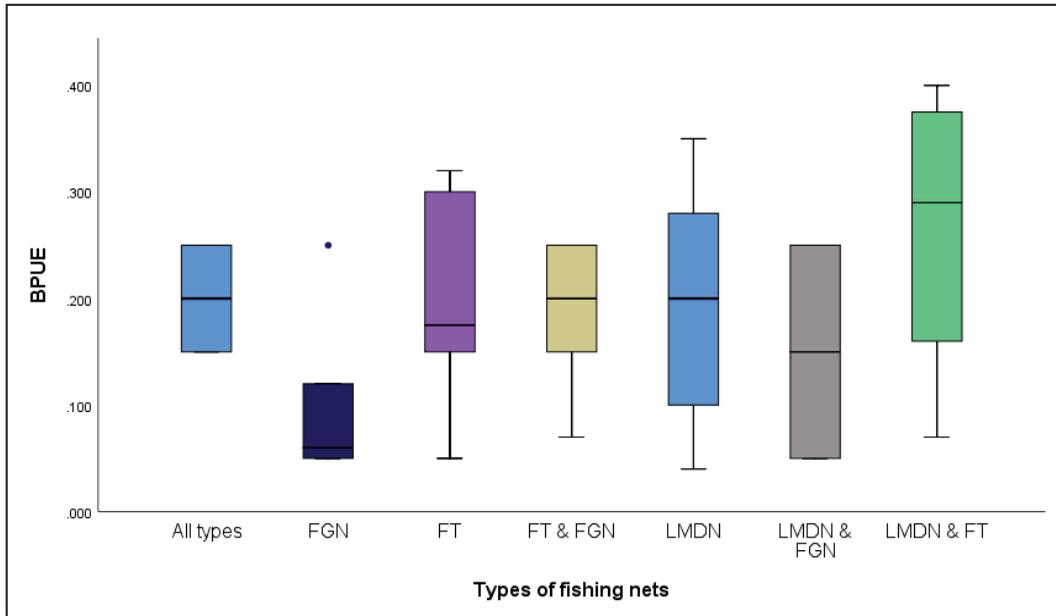


Figure 2. Pattern of bycatch of Olive Ridley Turtles in different types of fishing nets by the fishermen of Cox's Bazar, Bangladesh. The box plot shows the rate of BPUE in different types of nets. The categories of fishing nets include Large Mesh Drift Nets (LMDN), Fish Trawl (FT), Fixed Gill Nets (FGN), both LMDN and FGN, both LMDN and FT, and both FT and FGN.

3.2 Bycatch in different seasons

The highest BPUE was associated with winter (0.219 ± 0.944) and late autumn (0.218 ± 0.09), followed by autumn (0.137 ± 0.831) and spring (0.105 ± 0.053). The lowest BPUE was associated with summer (0.084 ± 0.13) and rainy season (0.047 ± 0.058) (Figure 3). There were statistically significant differences in BPUE among the different seasons ($p < 0.05$).

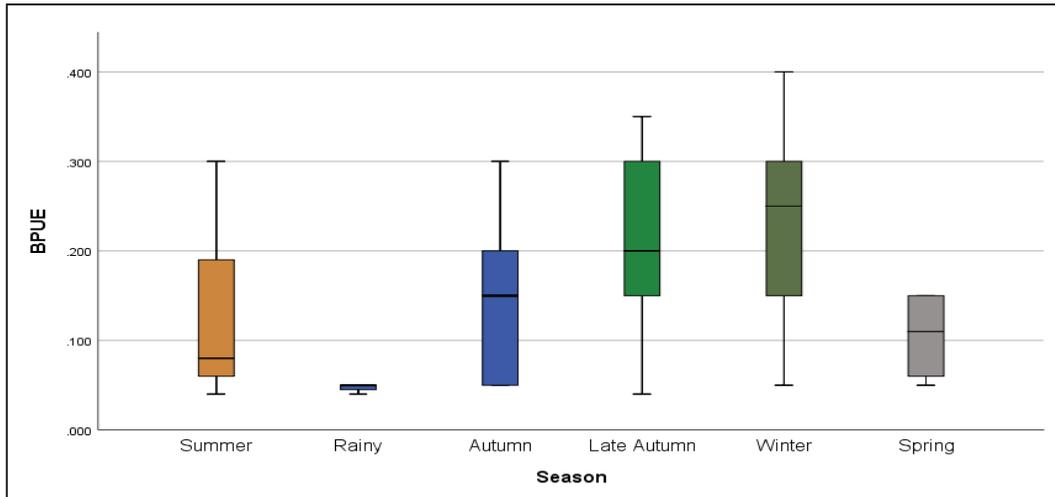


Figure 3. Seasonal pattern of bycatches of Olive Ridley turtle in the Bay of Bengal, Cox's Bazar coast, Bangladesh. The boxplot shows the rate of BPUE in six different seasons.

3.3 Bycatch by different distances from shore

The highest BPUE was associated with 5-10 km (0.248 ± 0.082) and 10-15 km distance from shore (0.174 ± 0.096) and the least BPUE was associated with 1-5 km distance from shore (0.073 ± 0.057). The BPUE beyond 15 km was also significant (0.217 ± 0.086) but no specific range of distance above 15 km was reported by the fishermen in this case (Figure 4). There were statistically significant differences in BPUE among the different distances from shore ($H = 18.968$, $p < 0.05$).

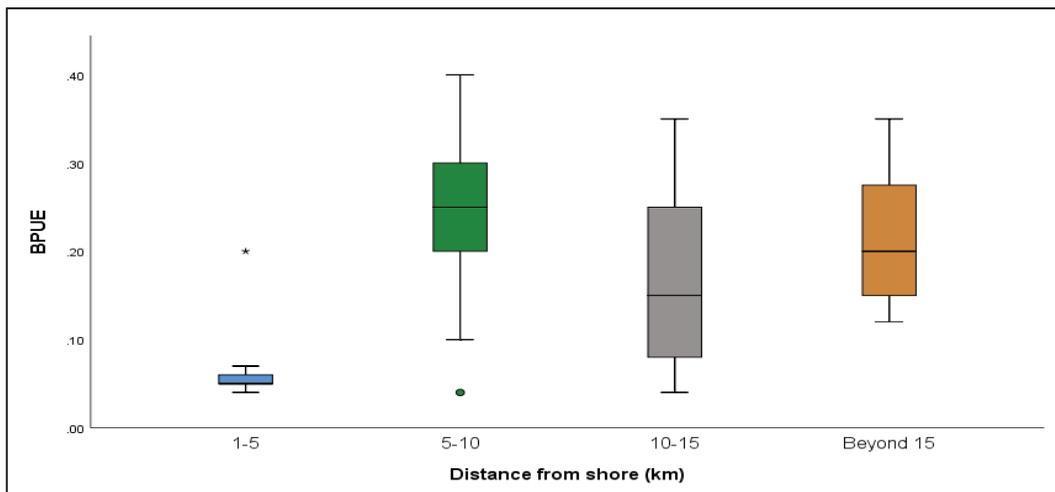


Figure 4. Pattern of Bycatch of Olive Ridley turtle at different distances from shore in the Bay of Bengal, Cox's Bazar, Bangladesh. The boxplot shows the rate BPUE at different distances from shore.

3.4 Condition after bycatch

A significant proportion of participants (61.25%) reported that Olive Ridley turtles were "Alive but injured", 22.5% reported "Alive and healthy," and 16.25% reported the turtles were "Dead" after being entangled in various fishing nets (Figure 5). The crosstabulation analysis revealed that observation of “dead” turtles was mostly associated with FT (53.8%), followed by both “FT and FGN” (23.1%). On the other hand, observations of “alive but injured” (60.0%) turtles were mostly associated with LMDN. The Chi-square test revealed a significant association between the types of nets and the condition of the turtles after being entangled (Pearson Chi-Square = 43.295, df = 12, p = 0.001). The Phi value (0.736) and Cramer's V (0.520) indicated a strong relationship, confirming that the type of fishing net used significantly influenced the likelihood of turtles being caught and their subsequent condition.

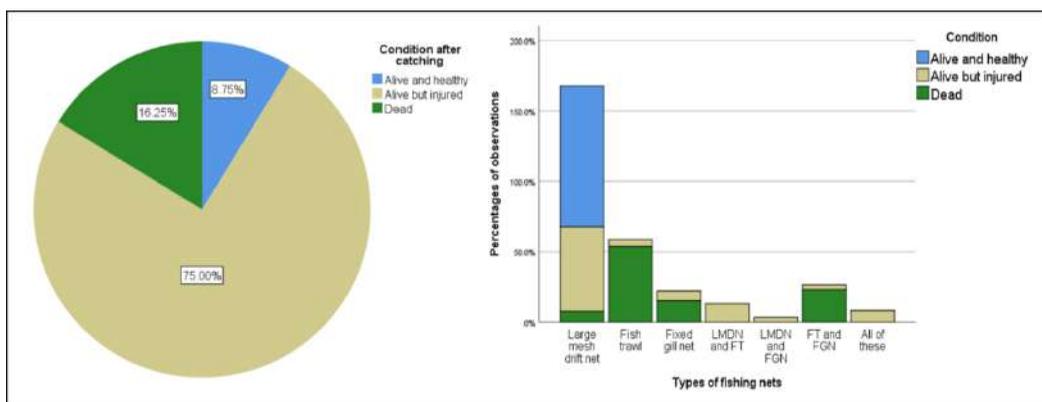


Figure 5. Condition of Olive Ridley Turtles after being caught in different types of fishing nets in the Bay of Bengal, Cox’s Bazar coast, Bangladesh. The pie chart shows the responses regarding the condition of turtles after bycatch. The stacked bar chart shows the relative condition of turtles after being caught in different types of fishing nets.

3.5 Bycatch of different phases of life of the Olive Ridley turtles

Among the participants, 45.0% observed both “Juvenile and adult” turtles, 37.5% observed adults, 8.8% observed “Juveniles”, and 5.0% observed both “hatchlings and juveniles” phases of turtles in the fishing bycatch. On the other hand, “Hatchlings” were reported by the least proportion of participants (3.8%) as fishing bycatch (Figure 6).

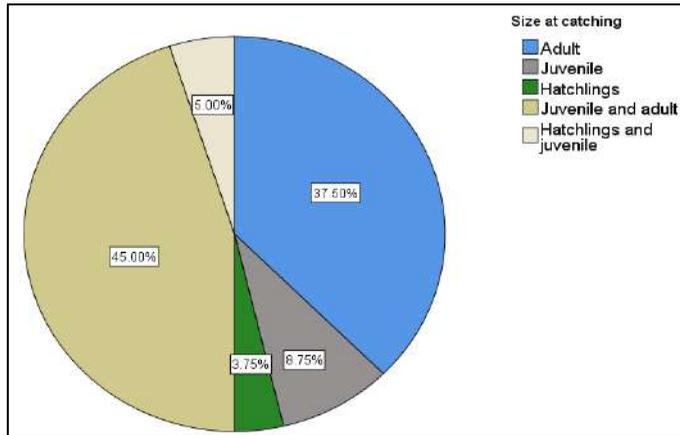


Figure 6. The pie chart shows the proportion of different-sized Olive Ridley turtles observed as fishery bycatch.

3.6 Causes of bycatch

The respondents reported several primary causes contributing to the bycatch of Olive Ridley turtles during fishing in the Bay of Bengal. Destructive fishing practices emerged as the most responsible cause (82.5%), highlighting their detrimental impact on turtle populations. Additionally, a significant majority expressed concerns over the absence of “turtle excluder devices or escape mechanisms” in fishing nets and gears (72.5%), emphasizing their role in unintentional turtle captures. Lack of knowledge regarding the importance, life cycle, and migration patterns of turtles was also identified as a contributing factor (68.75%). Moreover, issues such as inadequate monitoring and surveillance (61.25%) and the need for comprehensive training and education (70%) were recognized as crucial gaps in mitigating turtle bycatch. Other issues, such as local misbelief in turtles, thinking of turtles as trash species, and no concern about their importance in aquatic ecosystems, were also reported by 58.75% of participants (Figure 7).

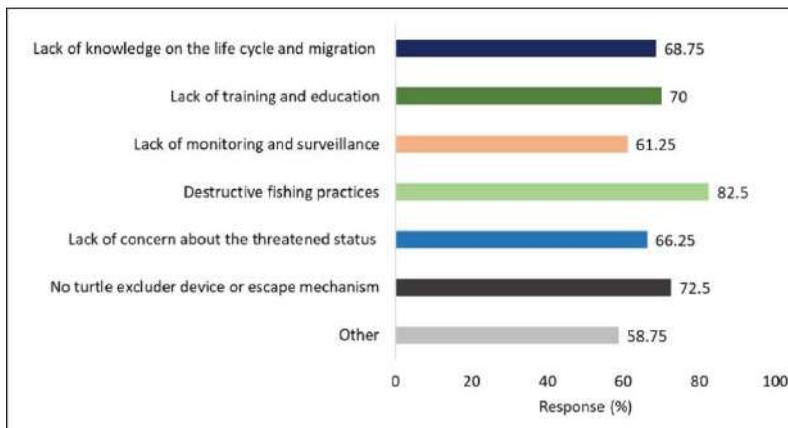


Figure 7. Causes of bycatch of Olive Ridley turtle from the perspective of fishermen in the Cox's Bazar coast, Bay of Bengal, Bangladesh

3.7 Activities among the fishermen after bycatch

The most common action by fishermen was found to be “cutting the net and releasing” the turtles (48.8%) after bycatch. Another significant portion of responses (38.8%) reported “free hand release”, or releasing the turtles without any additional intervention. A smaller number of respondents indicated keeping the turtles for sale (6.3%) or killing them (6.3%) after capture (Figure 8).

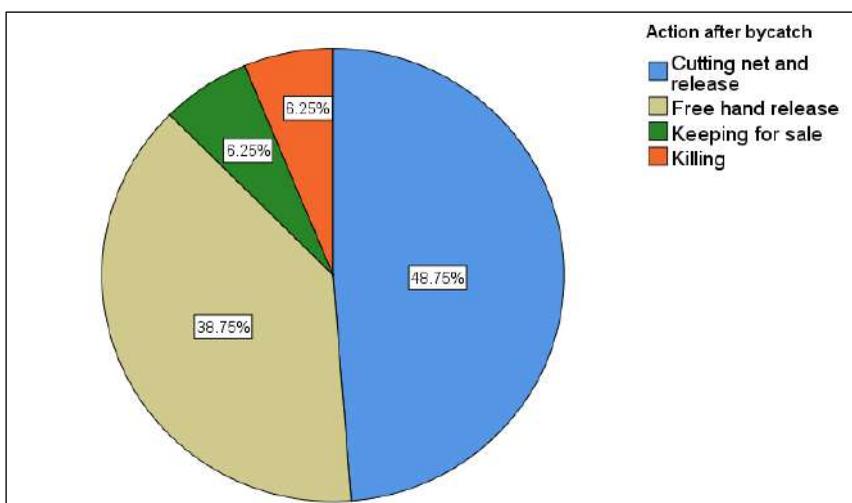


Figure 8. Action of fishermen after the bycatch of Olive Ridley turtle in the Cox's Bazar coast, Bay of Bengal, Bangladesh

4. Discussion

Globally, bycatch remains a significant threat to sea turtles. Previous research highlights that bycatch rates can differ widely based on several factors such as area, season, fishing efforts, and environmental factors (Cheng et al., 2019; Huang, 2015; Wallace et al., 2010)). This issue is evident in the variability of Bycatch Per Unit of Fishing Effort (BPUE) values, which range from zero to maximum rates depending on the season, region, and fishing gear (Wallace et al., 2010). This suggests that the different rates of bycatch reported in this study could be influenced by regional and temporal variations. Different rates of bycatch of sea turtles were reported by several previous studies. For example, Huang (2015) found bycatch rates ranging from 0 to 0.010 per thousand hooks. Wallace et al. (2010) reported up to 19.3 turtles per 1,000 hooks for longlines in the eastern Pacific Ocean. Virgili et al. (2024) estimated that around 120,000 sea turtles are incidentally caught annually in the Mediterranean Sea. Cheng et al. (2019) documented 1,072 incidents affecting turtle populations around Taiwan from 1997 to 2019, with bycatch responsible for 28% of these incidents. The variability in bycatch data collection across regions and gear types complicates comprehensive analysis and comparison among different findings (Soykan et al., 2008), highlighting the need for robust data collection to better understand these patterns.

Bycatch rates are higher where turtle populations and fishing efforts overlap (Wallace et al., 2010), as seen in the Bay of Bengal. Our study found that Large Mesh Drift Nets (LMDN) and Fish Trawls (FT) showed higher bycatch rates. Cheng et al. (2019) observed different bycatch rates for loggerhead and green turtles, emphasizing the influence of gear type. Gillnets with larger meshes, targeting big pelagic species, are non-selective and capture various marine species, including turtles (Gilman et al., 2010). The mortality in gillnet fisheries may match that of industrial-scale fisheries (Alfaro-Shigueto et al., 2011; Peckham et al., 2007). Gillnet fisheries are often poorly regulated, making impact measurement difficult (Northridge, 1991). Sea turtles also interact with trawls in coastal areas like the North Adriatic Sea and the Gulf of Gabès (Casale et al., 2007; Lucchetti et al., 2019; Lucchetti et al., 2016). These insights align with our observation of high bycatch rates in LMDN and FT.

The high bycatch rates in small-scale gillnet fisheries, especially in developing countries, highlight the need for targeted conservation and improved monitoring. Using turtle excluder devices (TEDs) in trawls and modifying gillnet designs could significantly reduce bycatch. Enhanced monitoring and regulation are crucial for sea turtle conservation. Further research should focus on net types and turtle behaviours to develop more effective bycatch reduction measures.

Seasonal factors significantly impact bycatch rates. Our results showed that the bycatch of Olive Ridley turtles was highest in winter, followed by late autumn, and lowest in the rainy season. This pattern means that turtles' behavior during winter and late autumn increases their risk of entanglement in fishing nets. The nesting season of the Olive Ridley turtle in the Cox's Bazar region of Bangladesh runs from November to April (Hossain et al., 2013; Islam, 2002a). Notably, these months coincide with the periods of elevated bycatch rates observed in our study. Other studies, such as Cheng et al. (2019), noted higher bycatch rates in Taiwan from winter to spring, while Putman et al. (2023) found annual bycatch totals to be relatively stable.

Seasonal variations in the abundance of turtles can be attributed to changes in temperature, productivity, prey availability, and the period of nesting (Huang, 2015). The significant differences in bycatch rates among seasons found in this study underscore the need for further research (Gautama et al., 2022). The seasonal pattern in bycatch highlights the need for targeted conservation during high-risk periods like winter and late autumn in the study areas. Understanding these seasonal factors is essential for effective bycatch mitigation and conservation of Olive Ridley turtles.

The abundance of sea turtles at different distances and depths could be related to the behaviour and migration patterns of Olive Ridley turtles. Our study found that the Olive Ridley turtle bycatches were most frequent at a distance of 5 to 15 km from shore. The 5 to 15 km distance from shore may be crucial for their migratory route between feeding grounds and nesting beaches and could be rich in food resources (Ocana, 2010). Olive Ridley sea turtles (*L. olivacea*) gather in large groups, or arribadas, to lay eggs on sandy

Olive Ridley Turtle (*Lepidochelys olivacea*) bycatch along the Cox's Bazar Coast of Bay of Bengal, Bangladesh: Insights from the Fishermen and Local Community

beaches (Ocana, 2010). After hatching, they drift with ocean currents, feeding on small organisms until they mature and return to the same beaches to lay eggs. During the breeding season, they migrate hundreds of kilometres for mating and nesting.

Polovina et al. (2004) observed that Olive Ridley turtles prefer warmer waters with sea surface temperatures (SSTs) of 23–28°C, diving deeper and spending only 20% of their time at the surface and 60% at depths shallower than 40 meters. This dive pattern might explain high bycatch rates in areas where fishing intersects with their preferred depth range.

However, the distances of higher bycatch were inferred from fishermen's responses in this study, but assessment of more precise bycatch rates requires real-time data from fishing vessels and logbooks. Currently, the study area lacks organized data or logbook records on turtle bycatch. Policymakers should initiate the recording of bycatch cases on fishing vessels, and further studies with robust data are needed to develop targeted conservation strategies for these vulnerable populations.

The impacts of fisheries bycatch on sea turtles can vary in severity, from mortality to injury and physiological stress. Even sub-lethal effects can reduce an individual's fitness, and if widespread, can have population-level impacts (Wilson et al., 2014). Estimating the mortality, injury, and physiological stress from bycatch is essential for understanding the threats of bycatch on sea turtles. The findings of this study regarding bycatch in fishing nets highlighted that the type of fishing gear significantly affected the severity of bycatch injuries and mortality in Olive Ridley turtles. Fish trawls (FT) were linked to higher mortality, while large mesh drift nets (LMDN) often resulted in injured but surviving turtles.

Previous studies (Margaritoulis et al., 2003; Lucchetti, 2021; Tomás et al., 2008; Virgili et al., 2023) reported sea turtle mortality rates from bycatch ranging from 10% to 50%, depending on the fishing gears. In the Mediterranean, over 121,000 sea turtles are caught annually, with more than 33,000 deaths. Segniagbeto et al. (2017) found that different net types affect mortality rates variably, with green and Olive Ridley turtles most affected. Cheng et al. (2019) reported that 80% of stranded or bycaught turtles were dead. Longline bycatch is reported to be twice as common as in trawls or gillnets (Wallace et al., 2010), and Olive Ridley turtles face significant mortality in longline fisheries, especially in the Atlantic (Huang, 2015). This study did not find responses on longline bycatch, likely due to its limited use in Bangladesh's marine sector.

These insights from our study and previous studies suggest that bycatch and its impacts in small-scale, coastal fisheries represent a significant data gap. These fisheries contribute substantially to the total anthropogenic interactions and mortality of sea turtles (Alfaro-Shigueto et al., 2012; Lewison et al., 2014). Addressing this gap is crucial for effective conservation efforts and mitigating the impacts of bycatch on sea turtle populations.

Our study revealed that both juvenile and adult Olive Ridley turtles are frequently caught as bycatch, with many of them ending up "dead" or "alive but injured." This indicates that bycatch significantly impacts turtles across all life stages, causing severe injuries and mortality. Previous studies have reported high bycatch levels for both juvenile and adult sea turtles across various regions. Cheng et al. (2019) observed that captured turtles were mainly young and subadult green and loggerhead turtles. Similar patterns were noted in Japan, Turkey, Texas, and Brazil (Cheng et al., 2019; Mascarenhas et al. 2005; Moriya 2010; Shaver 1995; Sönmez 2018; Tourinho et al. 2010). Additionally, large turtles were frequently bycaught in longlines and gillnets in the northwest Atlantic (Wallace et al., 2010).

Juvenile turtles, with underdeveloped lungs, are more vulnerable to bycatch due to their inability to escape adverse conditions (Hochscheid et al., 2007). Ontogenetic migration from open ocean to coastal habitats is crucial for future reproduction, and high juvenile bycatch can impede recovery (Mazaris et al., 2006; Secor, 2015). Adult turtles are also at risk during their nesting migrations, increasing their exposure to fishing gear (Cáceres-Farias et al., 2022; Cheng et al., 2019; Lewison et al., 2014; Ocana, 2010). This bycatch threatens Olive Ridley turtle populations, highlighting the need for better management to support their recovery, protection, and conservation.

Our study identified several factors contributing to the Olive Ridley turtle bycatch in the Bay of Bengal. The primary cause was destructive fishing, emphasizing the need for sustainable practices. The absence of turtle excluder devices (TEDs) in nets is another major concern; their adoption could significantly reduce bycatch. Additionally, fishermen's lack of understanding of turtles' ecological importance and migratory patterns contributes to unintentional captures. Promoting education and awareness among fishing communities is crucial. Insufficient monitoring and enforcement of regulations also pose challenges.

Fishing net entanglements are a major global cause of sea turtle mortality, with nets responsible for a significant number of captures (Margaritoulis et al., 2003; Lucchetti, 2021; Segniagbeto et al., 2017; Tomás et al., 2008; Virgili et al., 2023). Understanding the behavioural and ecological factors influencing turtle vulnerability is essential for effective conservation (Howell et al., 2010). Addressing local perceptions and misconceptions about turtles is crucial; outreach programs emphasizing sea turtle conservation can help change attitudes and improve conservation efforts (Bird et al., 2003).

Sea turtles may be released unharmed, injured, or killed once captured by fishermen during fishing. Our study found that most of the fishermen responded to bycatch by "cutting the net and releasing" the turtles, and releasing the turtles "free hand." A smaller percentage of fishermen either killed or kept the turtles for sale. Prolonged entanglement of turtles in fishing nets can cause drowning and can result in injuries or death (Gilman et al., 2010). Though intentional killing by fishermen is rare, it is often due

to the damage turtles cause to fishing nets. Economic pressures and damaged equipment may lead fishermen to target turtles to compensate for losses (Segniagbeto et al., 2014). Enhancing awareness, providing training on proper handling techniques, and considering compensation schemes for fishermen affected by turtle-related damages are crucial. These measures could foster more sustainable practices and improve the survival rates of sea turtles in the region. These findings highlight the importance of proper handling techniques during disentanglement to improve turtle survival rates post-release. Training fishermen in best practices, such as using specialized tools, can significantly impact turtle survival.

Addressing the sea turtle bycatch requires a multifaceted approach: adopting new technologies, enhancing education, enforcing regulations, and engaging communities (Senko et al., 2021). A holistic strategy will promote sustainable fishing, protect sea turtles, and support coastal livelihoods. Effective mitigation measures and ongoing research are vital for the survival of Olive Ridley turtles and the marine ecosystems of the Bay of Bengal.

5. Conclusion and recommendations

The study obtained an overview of the bycatch status of Olive Ridley turtles (*Lepidochelys olivacea*) from the viewpoint of the fishermen. The study provided comprehensive data on the types of fishing nets used, seasonality, distance from shore, causes of bycatch, post-bycatch state of the turtles, and the actions taken by fishermen after bycatch. Furthermore, the viewpoints of the fishermen on the adverse effects of bycatch and the necessity of management initiatives demonstrated a remarkable degree of consciousness and readiness for pursuing the conservation of sea turtles. However, the limitation of this study was that it relied solely on the opinions of fishermen because landing centre statistics, logbooks, and vessel records on turtle bycatch were not available. The findings and insights will generate scopes for further investigation and inform policymakers about the necessity for sustainable bycatch management of Olive Ridley turtles in the Bay of Bengal.

To ensure sustainable management of Olive Ridley turtle bycatch, an integrated approach is needed combining monitoring, technology, community engagement, and policy. Real-time bycatch data collection from vessels and landing stations should be introduced, alongside gear modifications such as Turtle Excluder Devices (TEDs) in trawl nets. Training fishermen on safe release and recovery of entangled turtles, coupled with awareness programs on their ecological importance, will strengthen community participation. Finally, a clear policy and management framework is essential to reduce bycatch and mitigate other human-induced threats, securing the long-term survival of Olive Ridley turtles in the region.

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Ethical note

All participants voluntarily took part in the survey, and stakeholders provided information freely without any form of pressure, coercion, or undue influence.

References :

- Alfaro-Shigueto, J., Mangel, J. C., Dutton, P. H., Seminoff, J. A., & Godley, B. J. (2012). Trading information for conservation: A novel use of radio broadcasting to reduce sea turtle bycatch. *Oryx*, *46*(3), 332-339. <https://doi.org/10.1017/S0030605312000105>
- Archibald, D. W., & James, M. C. (2018). Prevalence of visible injuries to leatherback sea turtles *Dermochelys coriacea* in the Northwest Atlantic. *Endangered Species Research*, *37*, 149-163. <http://dx.doi.org/10.3354/esr00920>
- Aziz, M. A. (2017). Threats to olive Ridley turtles on the Sundarbans coast of Bangladesh. *Indian Ocean Turtle Newsletter*, Issue 24. Durrell Institute of Conservation and Ecology (DICE), University of Kent. Retrieved August 16, 2025, from <https://iotn.org/iotn24-02-threats-to-olive-Ridley-turtles-on-the-sundarbans-coast-of-bangladesh/>
- Barreiros, J. P., & Raykov, V. S. (2014). Lethal lesions and amputation caused by plastic debris and fishing gear on the loggerhead turtle *Caretta caretta* (Linnaeus, 1758). Three case reports from Terceira Island, Azores (NE Atlantic). *Marine Pollution Bulletin*, *86*, 518-522. <https://doi.org/10.1016/j.marpolbul.2014.07.020>
- Bird, K. E., Nichols, W. J., & Tambiah, C. R. (2003). The value of local knowledge in sea turtle conservation: A case from Baja California, Mexico. *University of British Columbia Fisheries Centre Research Reports*, *11*, 178-183.
- Cáceres-Farias, L., Reséndiz, E., Espinoza, J., Fernández-Sanz, H., & Alfaro-Núñez, A. (2022). Threats and vulnerabilities for the globally distributed Olive Ridley (*Lepidochelys olivacea*) sea turtle: A historical and current status evaluation. *Animals*, *12*(14), 1837. <https://doi.org/10.3390/ani12141837>
- Carmo, H., Von Mühlen, E., Monteiro, C., Santos, A., & Corso, G. (2023). Animal predation of sea turtle nests: A review of occurrence and mitigation methods. *Herpetological Review*, *54*(2), 185-194.
- Casale, P. (2011). Sea turtle by-catch in the Mediterranean. *Fish and Fisheries*, *12*, 299-316. <https://doi.org/10.1111/j.1467-2979.2010.00394.x>
- Cheng, I. J., Wang, H. Y., Hsieh, W. Y., & Chan, Y. T. (2019). Twenty-three years of sea turtle stranding/bycatch research in Taiwan. *Zoological Studies*, *58*, e44. <https://doi.org/10.6620/ZS.2019.58-44>

- Olive Ridley Turtle (*Lepidochelys olivacea*) bycatch along the Cox's Bazar Coast of Bay of Bengal, Bangladesh: Insights from the Fishermen and Local Community
- Eckert, K. L., Wallace, B. P., Frazier, J. G., Eckert, S. A., & Pritchard, P. C. H. (2012). Synopsis of the biological data on the leatherback sea turtle (*Dermochelys coriacea*). *USFWS Biological Technical Publication*. BTP-R4015-2012. <https://digitalmedia.fws.gov/digital/collection/document/id/1519/>
- Fatema, U. K., Faruque, H., Salam, M. A., & Matsuda, H. (2022). Vulnerability assessment of target shrimps and bycatch species from industrial shrimp trawl fishery in the Bay of Bengal, Bangladesh. *Sustainability*, *14*(3), 1691. <https://doi.org/10.3390/su14031691>
- Faruque, H., & Matsuda, H. (2021). Assessing the vulnerability of bycatch species from Hilsa gillnet fishing using productivity susceptibility analysis: Insights from Bangladesh. *Fisheries Research*, *234*, 105808. <https://doi.org/10.1016/j.fishres.2020.105808>
- Gautama, D. A., Susanto, H., Riyanto, M., Wahju, R. I., Osmond, M., & Wang, J. H. (2022). Reducing sea turtle bycatch with net illumination in an Indonesian small-scale coastal gillnet fishery. *Frontiers in Marine Science*, *9*, 1036158. <https://doi.org/10.3389/fmars.2022.1036158>
- Gilman, E., & Bianchi, G. (2010). *Guidelines to Reduce Sea Turtle Mortality in Fishing Operations*. FAO Technical Guidelines for Responsible Fisheries.
- Hamann, M., Limpus, C. J., & Owens, D. W. (2003). Reproductive cycles of males and females. In P. L. Lutz, J. A. Musick, & J. Wyneken (Eds.), *The Biology of Sea Turtles* (Vol. 2, pp. 135–161). CRC Press. <http://dx.doi.org/10.1201/9781420040807.ch5>
- Harris, P. T. (2020). Anthropogenic threats to benthic habitats. In *Seafloor geomorphology as benthic habitat* (pp. 35-61). Elsevier. <http://dx.doi.org/10.1016/B978-0-12-814960-7.00003-8>
- Hochscheid, S., McMahon, C. R., Bradshaw, C. J., Maffucci, F., Bentivegna, F., & Hays, G. C. (2007). Allometric scaling of lung volume and its consequences for marine turtle diving performance. *Journal of Experimental Marine Biology and Ecology*, *148*, 360–367. <https://doi.org/10.1016/j.cbpa.2007.05.010>
- Hossain, M. A., Mahfuj, M. S. E., Rashid, S. M. A., & Ahsan, M. N. (2013). Present status of conservation and management of sea turtle in Cox's Bazar district, Bangladesh. *Mesopotamian Journal of Marine Sciences*, *28*(1), 45-60. <https://doi.org/10.58629/mjms.v28i1.154>
- Howell, E. A., Dutton, P. H., Polovina, J. J., Bailey, H., Parker, D. M., & Balazs, G. H. (2010). Oceanographic influences on the dive behavior of juvenile loggerhead turtles (*Caretta caretta*) in the North Pacific Ocean. *Marine Biology*, *157*(5), 1011–1026. <http://dx.doi.org/10.1007/s00227-009-1381-0>
- Huang, H. (2015). Conservation hotspots for the turtles on the high seas of the Atlantic Ocean. *PLoS ONE*, *10*. <https://doi.org/10.1371/journal.pone.0133614>
- Islam, M. Z. (2002a). Marine turtle nesting at St. Martin's Island, Bangladesh. *Marine Turtle Newsletter*, *96*, 19-21.
- Islam, M. Z. (2002b). Threats to sea turtles in St. Martin's Island, Bangladesh. *Kachhapa*, *6*, 6-10.

- Lewison, R. L., & Crowder, L. B. (2003). Estimating fishery bycatch and effects on a vulnerable seabird population. *Ecological Applications*, *13*, 743–753.
- Lewison, R. L., Crowder, L. B., Wallace, B. P., Moore, J. E., Cox, T., Zydelski, R., McDonald, S., DiMatteo, A., Dunn, D. C., Kot, C. Y., et al. (2014). Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxon-specific and cumulative megafauna hotspots. *Proceedings of the National Academy of Sciences of the United States of America*, *111*, 5271–5276. <https://doi.org/10.1073/pnas.1318960111>
- Lucchetti, A. (2021). Sea turtles. In P. Carpentieri, A. Nastasi, M. Sessa, & A. Srouf (Eds.), *Incidental catch of vulnerable species in Mediterranean and Black Sea fisheries – A review* (Studies and Reviews No. 101). General Fisheries Commission for the Mediterranean, FAO. Rome. <http://dx.doi.org/10.4060/cb5405en>
- Lucchetti, A., Punzo, E., & Virgili, M. (2016). Flexible Turtle Excluder Device (TED): An effective tool for Mediterranean coastal multispecies bottom trawl fisheries. *Aquatic Living Resources*, *29*, 1–12. <http://dx.doi.org/10.1051/alr/2016016>
- Lucchetti, G., Bargione, V., Petetta, A., Vasapollo, C., & Virgili, M. (2019). Reducing sea turtle bycatch in the Mediterranean mixed demersal fisheries. *Frontiers in Marine Science*, *6*, 387. <https://doi.org/10.3389/fmars.2019.00387>
- Margaritoulis, D., Argano, R., Baran, I., Bentivegna, F., Bradai, M. N., Caminas, J. A., Casale, P., De Metrio, G., Demetropoulos, A., Gerosa, G., Goley, B., Haddaoud, D., Houghton, J., Laurent, L., & Lazar, B. (2003). Loggerhead turtles in the Mediterranean Sea: Present knowledge and conservation perspectives. In A. Bolten & B. Witherington (Eds.), *Loggerhead Sea Turtles* (pp. 175-198). Smithsonian Institution Press.
- Mascarenhas, R., Santos, R., & Zeppelini, D. (2005). Stranded sea turtles on the coast of Paraíba, Brazil. *Marine Turtle Newsletter*, *107*, 13-14.
- Mazaris, A. D., Broder, B., & Matsinos, Y. G. (2006). An individual based model of a sea turtle population to analyze effects of age dependent mortality. *Ecological Modelling*, *198*, 174–182. <http://dx.doi.org/10.1016/j.ecolmodel.2006.04.012>
- Moriya, F. (2010). Strandings of sea turtles on the Pacific coast of the Boso Peninsula, central Japan, in 2006–2008. *Natural History Research*, *11*, 47-52.
- Northridge, S. (1991). Driftnet fisheries and their impacts on non-target species: A worldwide review. *FAO Fisheries Technical Paper No. 320*. FAO, Rome.
- Ocana, M. (2010). Arribada nesting of olive Ridley sea turtles (*Lepidochelys olivacea*) at La Escobilla, Mexico. Oregon State University.
- Casale, P., Cattarino, L., Freggi, D., Rocco, M., & Argano, R. (2007). Incidental catch of marine turtles by Italian trawlers and longliners in the central Mediterranean, *Aquatic Conservation: Marine and Freshwater Ecosystems*, *17*(7), 686-701. <https://doi.org/10.1002/aqc.841>
- Peckham, S. H., Maldonado Diaz, D., Walli, A., Ruiz, G., & others. (2007). Small-scale fisheries bycatch jeopardizes endangered Pacific loggerhead turtles. *PLoS ONE*, *2*(10), e1041. <https://doi.org/10.1371/journal.pone.0001041>

- Olive Ridley Turtle (*Lepidochelys olivacea*) bycatch along the Cox's Bazar Coast of Bay of Bengal, Bangladesh: Insights from the Fishermen and Local Community
- Phillott, A. D., & Godfrey, M. H. (2019). When is a stranded turtle a bycatch turtle? Assessing potential cause of stranding in sea turtles. *Indian Ocean Turtle Newsletter*, 30, 13-17.
- Polovina, J., Balazs, G., Howell, E., Parker, D., Seki, M., & Dutton, P. (2004). Forage and migration habitat of loggerhead (*Caretta caretta*) and olive Ridley (*Lepidochelys olivacea*) sea turtles in the central North Pacific Ocean. *Fisheries Oceanography*, 13, 36-51. <https://doi.org/10.1046/j.1365-2419.2003.00270.x>
- Pritchard, P. C. H. (2007). Arribadas I have known. In P. Plotkin (Ed.), *Biology and Conservation of Ridley Sea Turtles* (pp. 7–21). Johns Hopkins University Press.
- Putman, N. F., Richards, P. M., Dufault, S. G., Scott-Dention, E., McCarthy, K., Beyea, R. T., ... & Gallaway, B. J. (2023). Modeling juvenile sea turtle bycatch risk in commercial and recreational fisheries. *iScience*, 26(2). <https://doi.org/10.1016/j.isci.2023.105977>
- Rashid, S. M. A., & Islam, M. Z. Status and Conservation of Sea Turtles in Bangladesh
- Robinson, N. J., & Paladino, F. V. (2013). Sea Turtles☆. In *Reference Module in Earth Systems and Environmental Sciences*. Elsevier. <https://doi.org/10.1016/B978-0-12-409548-9.04352-9>
- Andraka, S., Mug, M., Hall, M., Pons, M., Pacheco, L., Parrales, M., Rendón, L., Parga, M. L., Mituhasi, T., Segura, Á., & Ortega, D. (2013). Circle hooks: Developing better fishing practices in the artisanal longline fisheries of the Eastern Pacific Ocean. *Biological Conservation*, 160, 214-224.
- Secor, D. H. (2015). *Migration Ecology of Marine Fishes*. John Hopkins University Press. <https://doi.org/10.1353/book.39942>
- Segniagbeto, G. H., Okangny, D., Mondedji, A. D., Delagnon, A., Amori, G., Dendi, D., & Luiselli, L. (2017). Sea turtle bycatch analysis revealed that site influenced mortality more than net types along the coast of Togo. *Vie et milieu - Life and Environment*, 67(3-4), 227-234.
- Senko, J. F., & Nalovic, M. A. (2021). Addressing Sea Turtle Bycatch in Developing Countries: A Global Challenge That Requires Adaptive Solutions for the 21st Century. In *Sea Turtle Research and Conservation* (pp. 151-165). Academic Press. <https://doi.org/10.1016/B978-0-12-821029-1.00016-7>
- Shaver, D. J. (1995). Sea turtle stranding along the Texas coast again cause for concern. *Marine Turtle Newsletter*, 70, 2-4.
- Sönmez, B. (2018). Sixteen Year (2002-2017) Record of Sea Turtle Strandings on Samandağ Beach, the Eastern Mediterranean Coast of Turkey. *Zoological Studies*, 57, 53. <https://doi.org/10.6620/ZS.2018.57-53>
- Soykan, C. U., Moore, J. E., Zydalis, R., Crowder, L. B., Safina, C., & Lewison, R. L. (2008). Why study bycatch? An introduction to the Theme Section on fisheries bycatch. *Endangered Species Research*, 5, 91-102. <https://doi.org/10.3354/esr00175>
- Stacy, B. A., Work, T. M., & Flint, M. (2017). Necropsy. In C. A. Manire, T. M. Norton, B. A. Stacy, C. J. Innis, & C. A. Harms (Eds.), *Sea Turtle Health and Rehabilitation* (pp. 209-239). J Ross Publishing.
- Stelfox, M. R., & Hudgins, J. A. (2015). A two year summary of turtle entanglements in ghost gear in the Maldives. *Indian Ocean Turtle Newsletter*, 22, 14-20.

- Tomás, J., Gozalbes, P., Raga, J., & Godley, J. (2008). Bycatch of loggerhead sea turtles: Insights from 14 years of stranding data. *Endangered Species Research*, 5(2-3), 161-169. <https://doi.org/10.3354/esr00175>
- Tourinho, P. S., do Sul, J. A. I., & Fillmann, G. (2010). Is marine debris ingestion still a problem for the coastal marine biota of southern Brazil? *Marine Pollution Bulletin*, 60(3), 396-401. <https://doi.org/10.1016/j.marpolbul.2009.10.013>
- Virgili, M., Petetta, A., Barone, G., Veli, D. L., Bargione, G., & Lucchetti, A. (2024). Engaging fishers in sea turtle conservation in the Mediterranean Sea. *Marine Policy*, 160, 105981. <https://doi.org/10.1016/j.marpol.2023.105981>
- Wallace, B. P., DiMatteo, A. D., Bolten, A. B., Chaloupka, M. Y., Hutchinson, B. J., Abreu-Grobois, F. A., et al. (2011). Global conservation priorities for marine turtles. *PLoS ONE*, 6(9), e24510. <https://doi.org/10.1371/journal.pone.0024510>
- Wallace, B. P., Lewison, R. L., McDonald, S. L., McDonald, R. K., Kot, C. Y., Kelez, S., ... & Crowder, L. B. (2010). Global patterns of marine turtle bycatch. *Conservation Letters*, 3, 131-142. <https://doi.org/10.1111/j.1755-263X.2010.00105.x>
- Wallace, B. P., Kot, C. Y., DiMatteo, A. D., Lee, T., Crowder, L. B., & Lewison, R. L. (2013). Impacts of fisheries bycatch on marine turtle populations worldwide: Toward conservation and research priorities. *Ecosphere*, 4(art40). <https://doi.org/10.1890/ES12-00388.1>
- Wilson, S. M., Raby, G. D., Burnett, N. J., Hinch, S. G., & Cooke, S. J. (2014). Looking beyond the mortality of bycatch: Sublethal effects of incidental capture on marine animals. *Biological Conservation*, 171, 61-72. <http://dx.doi.org/10.1016/j.biocon.2014.01.020>

Appendix 1
Questionnaire

Personal information

Name:

Age:

Gender: 1) Male 2) Female

Address:

Contact no:

1. What is the highest level of education you have completed?

- A) No formal B) Primary education C) Secondary education
D) Higher secondary education E) Vocational training F) College/University degree

Others:

2. What is your primary occupation?

- A) Fisherman B) Fish trader C) Boat owner D) Fish processing worker

Other (please specify):

Fishing and Sea turtle related information

3. How many years have you been involved in your current occupation?

4. How many times do you go fishing per year?

5. Do you have any turtle excluder devices?

- (a) Yes (b) No (c) I don't know about this (d) Not sure

6. Which type of turtles do you find during fishing?



a) Olive ridley



b) Green sea turtle



c) Hawksbill turtle



d) Loggerhead turtle



e) Leatherback turtle

- a)
- b)
- c)
- d)
- e)

7. What are the main areas where sea turtles are found mostly during fishing?

8. In which location do you find sea turtles most?



9. What type of gears are mainly responsible for entangling sea turtles?

Olive Ridley Turtle (*Lepidochelys olivacea*) bycatch along the Cox's Bazar Coast of Bay of Bengal, Bangladesh: Insights from the Fishermen and Local Community

☐ **Hook Types:** _____

Circle hooks vs. J-hooks.
other).

Bait Types: _____

Types of bait used (e.g., squid, fish or

☐ **Net Types:** _____

- Mesh size, length, and depth.

10. Per 100 times of fishing, how many sea turtles get entangled?

11. In what condition do you find sea turtles most during fishing?

- a) alive
injured
- b) dead
- c)

12. At what distance from shore do you find sea turtles most?

13. What do you do when you find a sea turtle during fishing?

- A) Release it to seawater B) Release it on the shore
- C) Keep it for selling
- D) Left it in the fishing boat E) Kill it

Other

14. In what season/seasons do you find sea turtles mostly during fishing?

- a) Summer (Grishma ritu) b) Rainy (Barsa ritu)
- c) Autumn (Sarat ritu)
- d) Late Autumn (Hemanta ritu), e) Winter (Shitt ritu)
- f) Spring (Basant ritu).

15. Do you know sea turtles are threatened?

- (a) Yes (b) No (c) Not interested

16. Do you think protecting sea turtles is necessary?

- (a) Yes (b) No (c) I don't know about this
- (d) Not sure

17. Are you aware of any conservation regulations or practices?

- (a) Yes b) No (c) I don't know about this
(d) Not sure

18. Do you agree to adopt new practices to reduce the bycatch of sea turtles?

- (a) Yes b) No (c) Not sure

19. Number of animals like stray dogs, jackals, wild pigs etc. in the nesting area.

Few	Moderate	High	None	Don't know
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20. What kind of measures can be taken to protect the sea turtles from bycatch?

Signature and date



Spatio-Temporal Dynamics of Land Use and Shoreline Change in the Bangladesh Delta (1994–2024)

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Abstract

Understanding the spatial and temporal transformations of coastal landscapes is critical in the context of climate change and anthropogenic pressures. This study investigates land use and land cover (LULC) changes and shoreline dynamics across the Sundarbans, Meghna Estuary, and Central Delta Region of Bangladesh over a 30-year period (1994–2024). Landsat satellite imagery was utilized in conjunction with remote sensing and GIS techniques, including supervised classification using the Support Vector Machine algorithm and shoreline delineation via the Normalized Difference Water Index (NDWI) and Digital Shoreline Analysis System (DSAS). The results revealed substantial transformations in land categories, including a notable decline in mangrove forests and agricultural land, expansion of wetlands, and fluctuating vegetation cover. Simultaneously, severe erosion was identified in the Key findings include a 30% decline in mangrove forests, a 20% reduction in agricultural land, and a 40% expansion of wetland areas. The Meghna Estuary experienced severe erosion (up to 5 km in certain areas), while the southwestern delta showed moderate accretion. Meghna Estuary and parts of the northern Sundarbans, while moderate accretion occurred in the southwestern deltaic front. These changes are largely attributed to tidal dynamics, sediment redistribution, upstream hydrological modifications, and intensified land use. The findings underscore the importance of continuous spatial monitoring and data-driven decision-making for sustainable coastal management. This study contributes to a growing body of knowledge necessary for implementing adaptive land use strategies and coastal resilience planning under the Bangladesh Delta Plan 2100. The integrated methodology and long-term assessment presented here can inform policy interventions and guide future research in other vulnerable deltaic systems worldwide.

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Keywords Remote sensing, Mangrove degradation, Coastal erosion, GIS analysis, Deltaic transformation

Introduction:

Coastal regions serve as vital repositories of natural resources and have historically supported a wide range of human activities to meet practical, societal, and cultural needs. The spatial patterns of land use and land cover (LULC) in any given area are influenced by a combination of environmental and socio-economic factors, along with human interventions and management strategies that vary across time and space

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(Turner et al., 1995). Land cover refers to the physical materials present on the Earth's surface—such as vegetation, water bodies, and anthropogenic structures—which can be detected and classified using satellite or aerial remote sensing technologies (Green et al., 1994). In contrast, land use pertains to the ways in which these land covers are utilized by human populations. As this aspect is more abstract and behaviorally driven, it is less readily observable via remote sensing techniques (Green et al., 1994). Although conceptually distinct, land use and land cover are often jointly analyzed under the framework of LULC change due to their interconnected roles in influencing environmental systems. Changes in LULC have far-reaching consequences for hydrological processes, as well as for broader physical, ecological, and socio-economic dynamics (Teklay et al., 2019; Zeng et al., 2020). A comprehensive understanding of LULC dynamics is particularly essential for effective coastal resource management, as it aids in the optimization of sustainable practices in regions facing rapid environmental transformations (Scanlon et al., 2005; Shadmehri Toosi et al., 2025). Shifts in LULC can significantly influence specific ecosystems, surface energy fluxes, greenhouse gas emissions, water availability, and biodiversity, thereby underscoring their profound impact on local climate systems and the surface energy balance (Duveiller et al., 2018).

Given their geomorphic complexity and ecological sensitivity, coastal zones necessitate extensive spatial research to monitor and assess geomorphological changes over time (Murali & Kumar, 2015). Land use in such contexts represents the cumulative outcome of interactions between natural processes and anthropogenic influences. Consequently, analyzing LULC distribution serves as a critical tool for planning and management in coastal environments (Chauhan & Nayak, 2005). According to the United Nations Population Division (UNPD, 2007), the past four decades have seen a dramatic surge in population growth within coastal areas—a trend projected to persist for at least the next forty years. Neumann et al. (2015) provided baseline estimations for the year 2000 and projected future population distributions in low-elevation coastal zones (LECZ), identifying Bangladesh as one of the most exposed countries in terms of total coastal population. This ranking is expected to remain largely unchanged in future scenarios. Currently, approximately 35 million people—constituting about 29% of the national population—reside within the coastal zone of Bangladesh, which encompasses 19 coastal districts (Abu et al., 2003).

The coastal landscape of Bangladesh is undergoing continuous transformation due to both natural and anthropogenic factors. Abdullah et al. (2019) reported a persistent decline in vegetation cover across coastal Bangladesh, driven by recurring natural hazards such as cyclones and floods, as well as human-induced activities like shrimp farming. Their analysis further revealed that riverine areas have expanded by approximately 4.52% over a 27-year period (1990–2017), highlighting significant geomorphic and ecological shifts within the coastal environment. Geospatial techniques have emerged as essential tools for assessing the dynamic nature of

coastal land use and land cover (LULC), enabling informed decision-making for sustainable coastal management. By integrating remote sensing data with field-based observations of shoreline characteristics, these methods facilitate the development of robust strategies for long-term environmental planning across diverse coastal regions worldwide. The ability of geospatial technologies to analyze complex coastal systems across multiple spatial and temporal scales makes them particularly valuable in this context (Nath et al., 2023). LULC classification begins at the pixel level, utilizing either supervised or unsupervised algorithms. Supervised classification depends on prior knowledge of the study area to establish accurate training sites for specific LULC categories, thereby improving classification accuracy. Conversely, unsupervised classification is often employed when such prior knowledge is unavailable, such as in the case of historical or low-resolution imagery, where the land cover is unknown or undefined. In this approach, computer algorithms cluster similar pixels into spectral classes, which must subsequently be interpreted and categorized into meaningful information classes by the analyst (Yadahalli & Bellakki, 2018).

Accurately quantifying various types of land loss, especially in coastal areas, is vital for understanding the implications of shoreline dynamics. Such assessments are crucial for the effective planning and implementation of environmentally sound management practices. Satellite-based LULC analysis offers a cost-efficient and practical method for monitoring long-term changes in land cover patterns. Several classification algorithms have been employed in LULC studies, with methods such as maximum likelihood, random forest, support vector machine, and artificial neural networks being among the most commonly used due to their high accuracy and adaptability to diverse datasets (Otukey & Blaschke, 2010; Balha & Singh, 2022). Remote sensing and geographic information system (GIS) applications are regarded as indispensable for collecting and monitoring periodic data on physical processes occurring at the Earth's surface. According to Nath et al. (2023), there are no alternative techniques that can match the capacity of remote sensing and GIS for capturing spatial-temporal variability in environmental systems. Decadal LULC transformations are particularly significant for evaluating coastal hazards and assessing vulnerabilities arising from both natural and anthropogenic factors.

Despite the extensive coastal landscape of Bangladesh, focused regional studies have provided critical insights into LULC dynamics. For instance, Islam et al. (2023) conducted a time-series LULC classification over the Meghna Estuary using Landsat imagery spanning from 1988 to 2021. Their findings revealed a substantial decline in agricultural land, amounting to a 76.04% loss during the study period, highlighting the magnitude of land transformation driven by environmental change and human intervention. The challenges posed by shoreline changes, coastal erosion, and land use/land cover (LULC) transformations, coupled with the increasing vulnerability of coastal populations and the associated migration trends, represent critical issues for Bangladesh. These phenomena warrant urgent and sustained research attention due

to their environmental, socio-economic, and demographic implications. Despite the significance of these challenges, there has been a notable lack of comprehensive regional studies that integrate long-term shoreline change-rate estimations along the coastal stretch from the Sundarbans to the lower central coastal region of Bangladesh. Recognizing these gaps in the existing literature and the limitations of previous studies in capturing the interconnected dynamics of shoreline movement, coastal erosion, and LULC changes across broader regional scales, the present study was undertaken to address this deficiency.

Specifically, this research aimed to analyze LUCC trends in conjunction with shoreline dynamics over a 30-year period (1994–2024), utilizing remotely sensed data from Landsat satellite imagery. Accordingly, the primary objectives of the study were twofold: (1) to estimate and classify LULC changes across the Sundarbans and the lower central deltaic region of Bangladesh, and (2) to assess shoreline movements and perform delineation analyses throughout the study period. This integrated approach provides a more holistic understanding of coastal transformations and supports informed decision-making for sustainable coastal zone management.

Methodology:

Study Area:

The Bangladesh Delta, encompassing the Central Delta Region, Sundarbans Mangrove Forest, and Meghna Estuary, represents a critical socio-ecological system influenced by hydrodynamic interactions between freshwater and seawater (Figure 1). These interactions, driven by geographic factors and climate-induced hydrological alterations such as salinity intrusion and sea level rise, significantly impact biodiversity and socio-economic stability (Jana et al., 2024; Anam et al., 2021).

The Sundarbans, situated approximately between 21°N and 89°E, is a globally significant mangrove ecosystem supporting diverse flora and fauna, including economically valuable fish species (Dasgupta et al., 2017; Habib et al., 2020). The Meghna Estuary, located around 22.8°N and 91.1°E, serves as a crucial fishery, particularly for the hilsa (*Tenualosa ilisha*), by providing essential spawning and nursery habitats. Additionally, the estuary functions as a biogeochemical regulator, modulating salinity gradients and nutrient cycling (Kamruzzaman et al., 2017; Mondal et al., 2022).

The Central Delta Region, approximately at 23°N and 90°E, experiences tidal and seasonal hydrodynamic variations influenced by the Ganges-Brahmaputra-Meghna River system, affecting sediment transport and water flow patterns (Tusar et al., 2023; Mondal et al., 2024). However, anthropogenic pressures and climate change pose significant threats to the ecological integrity of these deltaic sub-regions, necessitating robust management interventions (Bhadra et al., 2023; Rahman, 2019). The Bangladesh Delta Plan 2100 provides a strategic framework for sustainable delta

management, integrating climate adaptation, water resource governance, and conservation initiatives (Sultana & Anwar, 2021; Rahman et al., 2015). Ensuring long-term resilience requires interdisciplinary research and coordinated policy actions to align local conservation efforts with broader global sustainability objectives (Aziz & Paul, 2015).

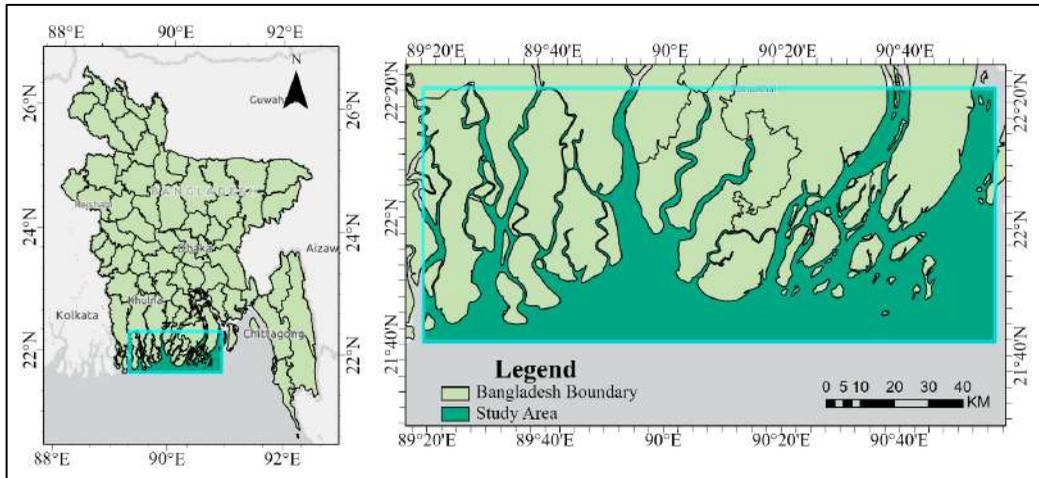


Figure 1: Map showing the geographical extent of the study area, including the Sundarbans, Meghna Estuary, and Central Delta Region of Bangladesh.

Data Collection:

The study utilizes Landsat imagery from 1994, 2009, and 2024 to analyze surface reflectance and temperature data. The 1994 dataset, acquired by Landsat 5 Thematic Mapper (TM) on December 20 and processed on September 12, 2020, consists of Level-2 Surface Reflectance (L2SP) and Level-1 Terrain Precision (L1TP) products. It includes bands 1–5, 7 (reflectance), and band 6 (temperature) in GeoTIFF format, with a 30m spatial resolution (7121 × 7881 pixels) under 0.00% cloud cover. The 2009 dataset, acquired on November 11 and processed on August 25, 2020, follows the same specifications, with minor variations in dimensions (7101 × 8031 pixels) and 1.00% cloud cover over land. The 2024 dataset, captured by Landsat 9 OLI/TIRS on December 30 and processed on December 31, expands to bands 1–7 (reflectance) and band 10 (temperature), with 7851 × 7711 pixels at 0.00% cloud cover. All datasets utilize UTM Zone 46 with the WGS84 datum.

Land Use and Reclamation Patterns:

Assessing land-use changes through supervised classification techniques, such as the Support Vector Machine Classifier, provides robust categorizations essential for environmental management (Saha et al., 2005; Hashim et al., 2019). Temporal analyses utilizing tools like the Digital Shoreline Analysis System (DSAS) enable a detailed evaluation of shoreline dynamics and land conversions, including wetland

transformations into urban or agricultural lands (Yuna & Cahyono, 2024; Sutikno, 2016). By correlating these land-use changes with socio-economic data, a comprehensive understanding of the implications of human activities on the landscape can be achieved (Reis, 2008; Bharath et al., 2023). A full workflow has been shown in figure 2.

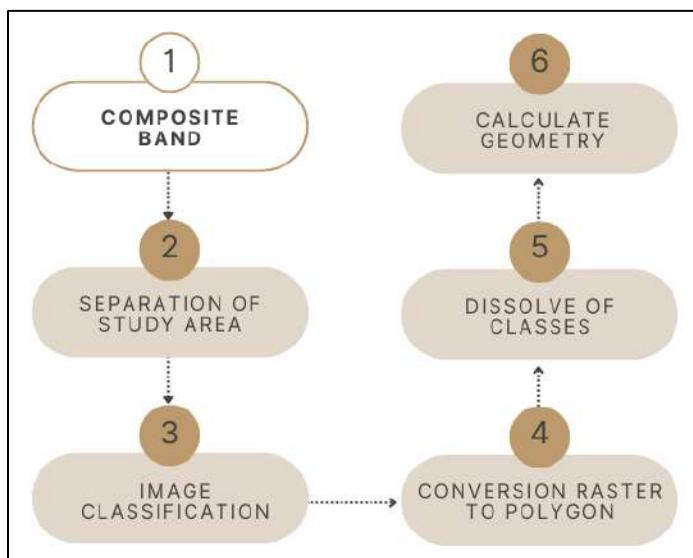


Figure 2: Workflow of the land use and land cover classification process using remote sensing and supervised classification techniques.

Shoreline Delineation and Change Detection Analysis:

The mapping of shoal development and channel migration is critical for understanding sediment dynamics and coastal management. Morphological analyses, enhanced through bathymetric surveys and Geographic Information Systems (GIS), facilitate the examination of sediment transport and flux between shoals and tidal channels over time (Enoguanbhor et al., 2019; Moisa et al., 2023). Integrating historical bathymetric data with satellite imagery and applying the Normalized Difference Water Index (NDWI) allows for the detection and quantification of changes in these features across extensive temporal scales (Karaburun et al., 2009; Li et al., 2011). A flowchart illustrating shoreline extraction process has been shown in figure 3.

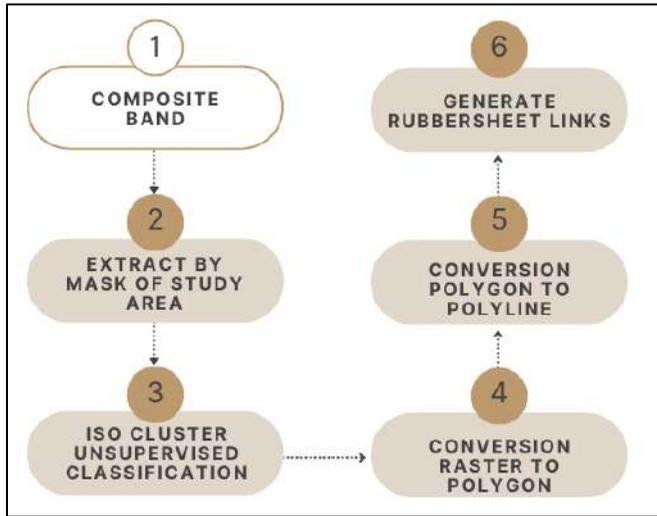


Figure 3: Flowchart depicting the shoreline extraction and change detection method using NDWI and GIS tools.

Justification for Time Period Selection:

The time periods selected (1994, 2009, and 2024) offer insights into the coastal transformation over three decades. The interval between 1994 and 2009 captures the effects of the significant natural hazards, such as cyclones, and the initiation of large-scale human activities, such as aquaculture development and embankment construction. The later period (2009–2024) provides a more recent view of the changes, reflecting current trends in land reclamation, urban expansion, and the impacts of climate change, such as rising sea levels and altered precipitation patterns.

Results:

Land Use and Reclamation Patterns:

Land-use patterns exhibited significant spatial distribution across various ecological classes in 1994 (Figure 4). Deep water areas covered the largest extent, spanning approximately 5,087.05 square kilometers, playing a crucial role in regional hydrodynamics and aquatic ecosystems. Dense vegetation occupied a comparatively smaller area of 949.88 square kilometers, contributing to local biodiversity and ecological stability. Agricultural land accounted for 2,836.67 square kilometers, highlighting the dominance of cultivated landscapes in the region. Mangrove forests, essential for coastal protection and biodiversity, covered 2,344.41 square kilometers, reflecting the ecological significance of these unique ecosystems. Additionally, shallow water areas extended across 1,170.34 square kilometers, indicating transitional zones between terrestrial and aquatic environments. These land-use distributions provide insights into the region's environmental dynamics and serve as a baseline for assessing future changes in land cover.

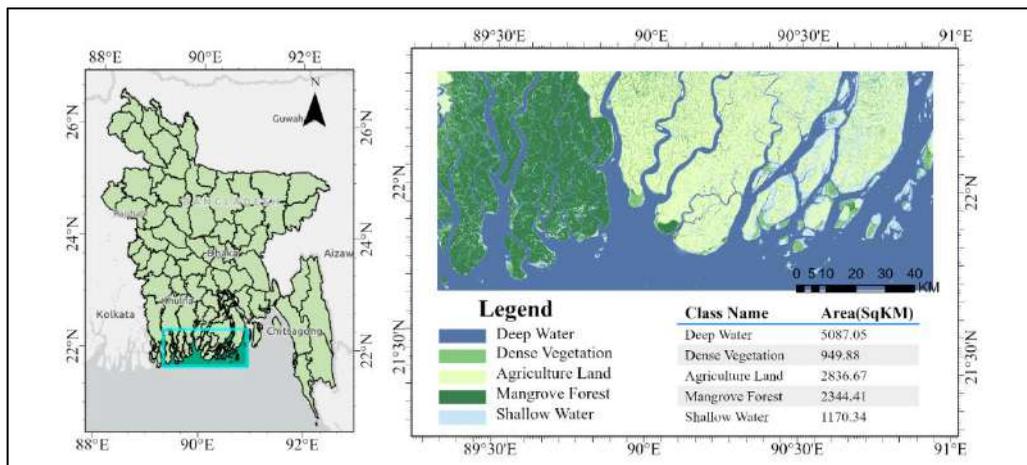


Figure 4: LULC map for 1994 showing spatial distribution of major land cover types across the study area.

In 2009, land-use patterns exhibited notable changes, reflecting shifts in environmental and anthropogenic dynamics (Figure 5). River channels covered an extensive area of 4,697.45 square kilometers, playing a vital role in the region's hydrological processes. Dense vegetation occupied 763.25 square kilometers, indicating a reduction compared to previous records. Agricultural land spanned 2,254.62 square kilometers, highlighting the continued dominance of cultivated areas despite possible land conversion. Mangrove forests expanded to 2,453.54 square kilometers, signifying the ecological resilience or conservation efforts in these coastal ecosystems. Additionally, wetlands covered 2,216.70 square kilometers, underscoring their significance in maintaining biodiversity, regulating water flow, and supporting fisheries. These land-use distributions provide critical insights into environmental changes over time, emphasizing the need for sustainable management and conservation strategies.

The patterns of land-use have undergone significant transformations, reflecting both natural processes and human interventions in 2024 (Figure 6). River channels now cover 2,922.75 square kilometers, indicating a reduction in water-dominated areas compared to previous years. Dense vegetation has expanded to 1,371.01 square kilometers, suggesting potential afforestation or natural regrowth. Agricultural land spans 2,749.50 square kilometers, maintaining its prominence in land-use distribution. However, mangrove forest coverage has declined to 1,633.13 square kilometers, raising concerns about coastal ecosystem degradation and habitat loss. In contrast, wetlands have expanded significantly to 3,717.33 square kilometers, highlighting shifting hydrological conditions and possibly increased water retention areas. These changes underscore the dynamic nature of the region's landscape and emphasize the importance of sustainable land management strategies to balance ecological conservation with socio-economic development.

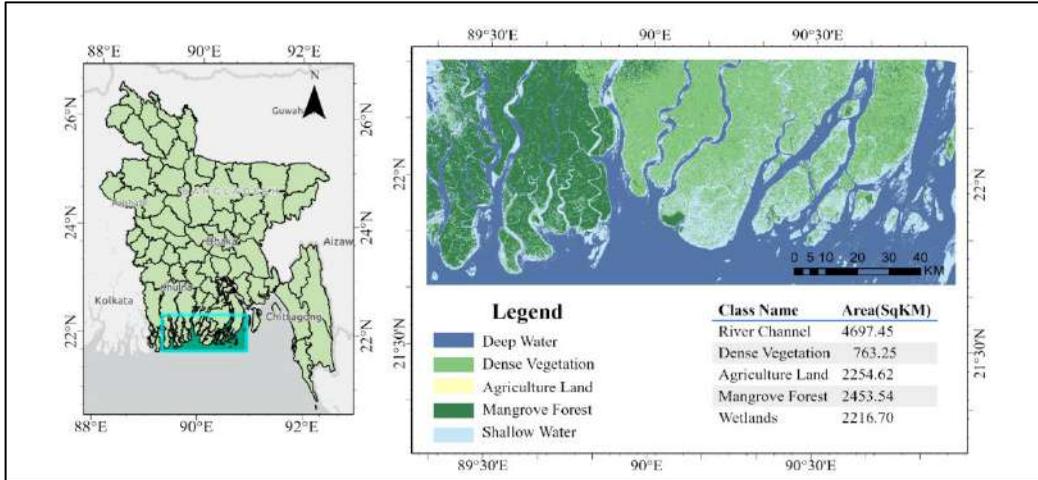


Figure 5: LULC map for 2009 illustrating changes in land cover and expansion or reduction of key land use classes.

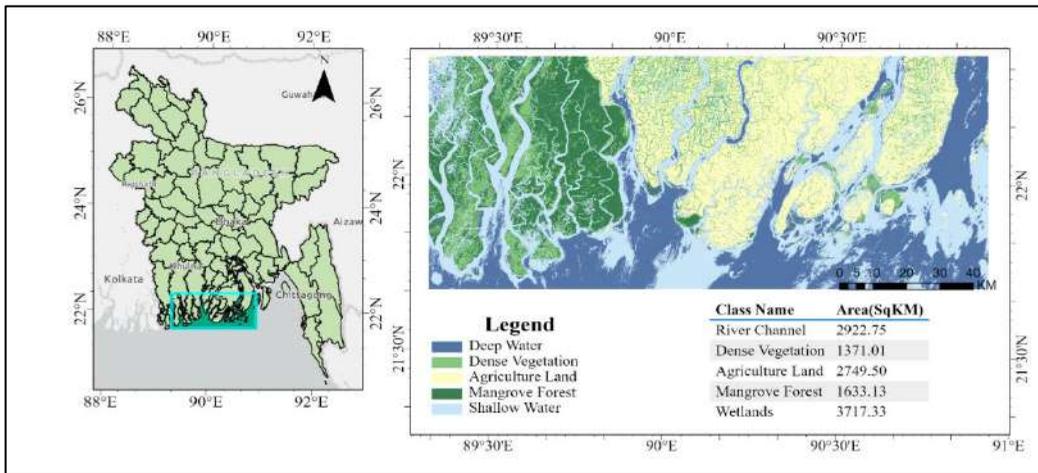


Figure 6: LULC map for 2024 highlighting significant land use transformations over three decades.

Table 1 summarizes the area (in square kilometers) covered by different LULC classes for each year.

Table 1: Land Use and Land Cover Area Changes (1994–2024)

Land Cover Type	1994 Area (sq. km)	2009 Area (sq. km)	2024 Area (sq. km)	Percentage Change
Water Bodies	5,087.05	4,697.45	2,922.75	-42.7%
Dense Vegetation	949.88	763.25	1,371.01	+44.3%
Agricultural Land	2,836.67	2,254.62	2,749.50	-3.1%
Mangrove Forests	2,344.41	2,453.54	1,633.13	-30.3%
Wetlands	1,170.34	2,216.70	3,717.33	+218.2%

Shoreline Delineation and Change Detection Analysis:

Figure 7 presents the shoreline change detection between 1994 and 2009, reflecting significant alterations in the coastal morphology of the study region. During this 15-year period, extensive erosion was observed along the northern and northeastern boundaries of the Sundarbans, as well as around the lower reaches of the Meghna Estuary. This erosion likely resulted from increased tidal activity, storm surges, and sediment displacement influenced by river discharge variability and upstream deforestation. Simultaneously, certain regions in the western delta and southern estuarine margins exhibited moderate accretion. These accreted zones may be attributed to sediment deposition facilitated by meandering river channels and low-energy hydrodynamic conditions. The spatial distribution of erosion and accretion reveals the differential impact of natural geomorphic processes across the delta, underscoring the complex interplay between riverine and coastal systems.

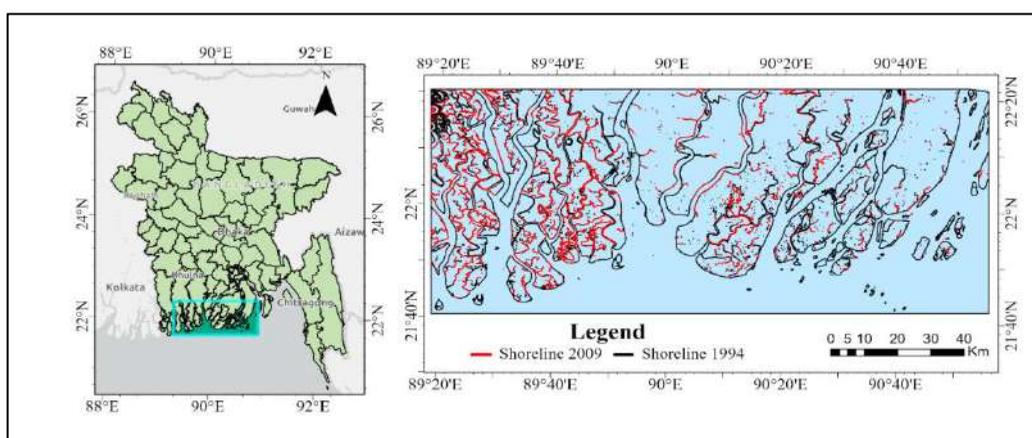


Figure 7: Map showing shoreline erosion and accretion trends between 1994 and 2009.

Shoreline changes over a 30-year period (1994–2024), providing a comprehensive view of long-term coastal dynamics has been shown in figure 8. The cumulative change during this period reveals a more pronounced pattern of shoreline retreat in several vulnerable areas, particularly along the central and southeastern coastal segments of the Meghna Estuary. These regions have experienced persistent erosion, resulting in substantial land loss and exposure of nearby settlements and agricultural zones. The spatial extent of accretion, though comparatively limited, is evident in selected southwestern and western portions of the delta, notably near the outer fringes of the Sundarbans. These newly formed landmasses reflect ongoing sediment redistribution from upstream sources, shaped by estuarine and tidal interactions. Overall, the long-term analysis highlights the accelerating nature of shoreline transformation, which is influenced by climatic factors such as sea level rise, cyclonic activity, and anthropogenic land use pressures, including embankment failures and unsustainable river engineering.

Figure 9 displays shoreline movement between 2009 and 2024, highlighting more recent coastal changes that offer insight into evolving patterns of erosion and deposition. This period shows intensified erosion along the mid-eastern sections of the deltaic coast and estuarine front, particularly where embankments and flood control structures have altered natural sediment flow. The reduction of river discharge due to upstream damming and sediment trapping may have exacerbated land loss in these areas. On the other hand, accretional zones have become more pronounced near the lower southwestern edge of the Sundarbans and at the mouth of certain tidal channels, possibly due to redirected sediment plumes and changes in flow regimes. These morphological shifts are consistent with increased anthropogenic activities, including land reclamation, shrimp aquaculture, and infrastructural expansion, which disrupt natural sediment balance. The observed shoreline reconfigurations during this period reinforce the need for adaptive coastal management strategies and continuous monitoring using geospatial technologies.

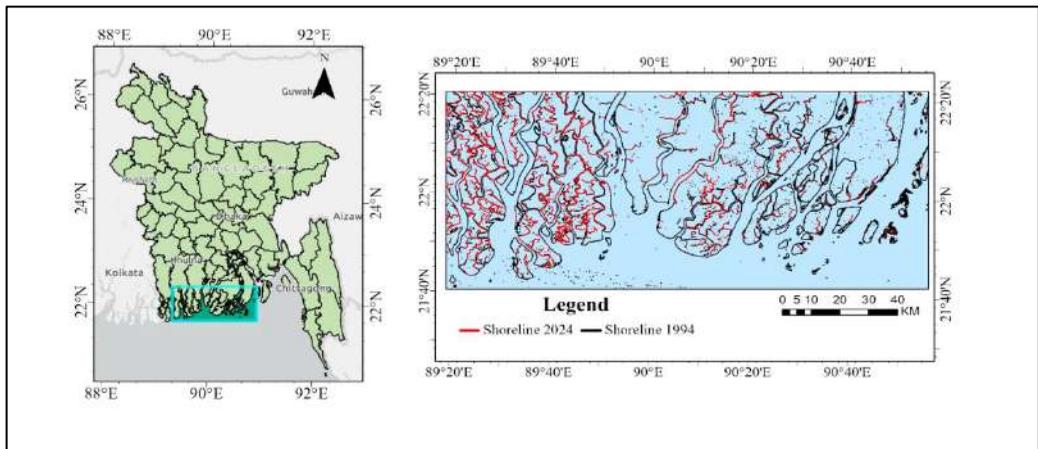


Figure 8: Shoreline movement map from 1994 to 2024 indicating long-term coastal changes.

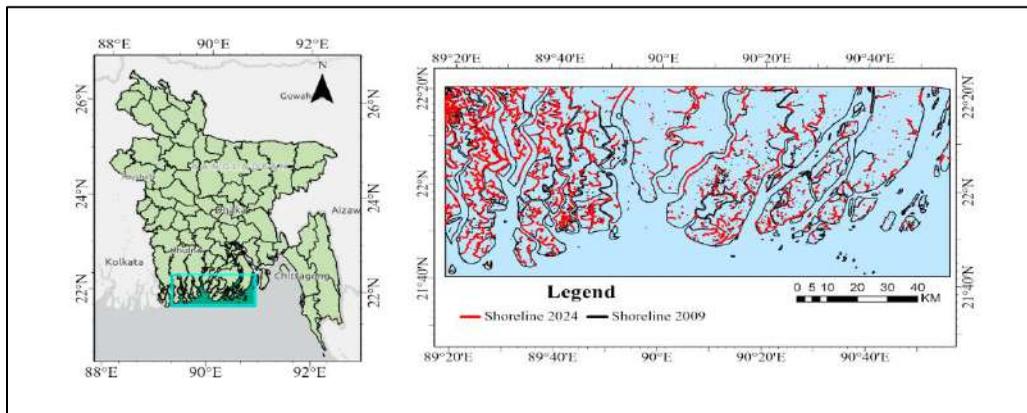


Figure 9: Shoreline change map between 2009 and 2024 showing recent patterns of erosion and deposition.

Table 2 presents the area (in square kilometers) affected by shoreline erosion and accretion for each period (1994–2009, 2009–2024, and 1994–2024).

Table 2: Shoreline Erosion and Accretion (1994–2024)

Period	Erosion Area (sq. km)	Accretion Area (sq. km)	Net Change (sq. km)
1994–2009	1,225.65	431.52	-794.13
2009–2024	1,549.34	620.65	-928.69
1994–2024	2,775.00	1,052.17	-1,722.83

Discussion:

The findings of this study highlight the dynamic and multifaceted changes in land use and shoreline morphology across the Bangladesh Delta, particularly in the Sundarbans, Meghna Estuary, and Central Delta Region. These changes reflect the intricate interplay of natural processes and human activities that shape coastal landscapes over time. The observed trends in land use and shoreline movement are not only significant in their own right but also provide insight into the broader ecological, hydrological, and socio-economic dynamics influencing the delta.

Ecological Drivers: The decline in mangrove forests, observed over the 30-year period, is a key ecological concern. Mangroves serve as critical buffers against storm surges, provide nursery grounds for various fish species, and play an essential role in carbon sequestration (Habib et al., 2020). Their degradation, primarily driven by unsustainable land-use practices such as shrimp farming and land reclamation, exacerbates the vulnerability of the region to the impacts of climate change, including sea-level rise and extreme weather events (Dasgupta et al., 2017). Moreover, the expansion of wetlands observed in the study, particularly in areas previously dominated by mangroves or agricultural land, reflects a potential shift in ecological dynamics. This expansion could be due to sea-level rise and sediment redistribution, which alters the hydrological conditions and promotes the formation of new wetland habitats. These wetlands, while contributing to biodiversity and water regulation, are often more susceptible to saline intrusion and waterlogging, which could limit their ecological value in the long term.

Hydrological Drivers: The complex hydrological interactions between freshwater and seawater, influenced by seasonal fluctuations in rainfall, river discharge, and tidal cycles, play a pivotal role in shaping the delta's landscape. The Meghna Estuary and Sundarbans experience significant tidal dynamics that drive sediment transport, which in turn affects shoreline erosion and accretion. The increase in erosion in the northeastern parts of the Sundarbans and Meghna Estuary can be attributed to increased tidal activity and storm surges, which are likely intensified by climate change (Anam et al., 2021). Upstream hydrological modifications, such as dam construction and sediment trapping by embankments, have altered the natural sediment supply to the delta, exacerbating erosion and shoreline retreat in certain areas. The observed shifting hydrological patterns and expanding wetland areas could also be linked to

changing precipitation regimes and sea-level rise, further underscoring the vulnerability of the delta to both climatic and anthropogenic pressures.

Socio-economic Drivers: The socio-economic implications of these environmental changes are profound. The reduction in agricultural land due to shoreline erosion and salinization of water resources threatens the food security and livelihoods of millions of coastal inhabitants. A significant portion of the population in the coastal areas depends on agriculture, fisheries, and aquaculture for their livelihoods (Neumann et al., 2015). As land becomes unproductive or submerged, the local communities face displacement and increased vulnerability to poverty and food insecurity. In addition, the degradation of mangrove forests and wetlands impacts the fisheries sector, which relies on these ecosystems for spawning grounds and nursery habitats. The shift towards urbanization and industrialization, particularly in the Meghna Estuary and Sundarbans, has further strained the region's resources, with land reclamation and infrastructure development often prioritizing economic growth over environmental sustainability. This trend is exacerbated by the growing coastal population, which continues to put pressure on the available land and water resources (UNPD, 2007).

Linking to Regional and Global Delta Dynamics: The dynamics observed in the Bangladesh Delta reflect broader patterns seen in other vulnerable deltaic systems around the world. The Ganges-Brahmaputra-Meghna Delta, where the Bangladesh Delta is located, is one of the most flood-prone and ecologically sensitive regions globally. Similar coastal changes, including mangrove degradation, wetland expansion, and shoreline erosion, have been observed in other major deltas such as the Mekong Delta in Vietnam and the Nile Delta in Egypt (Neumann et al., 2015). These global deltaic systems face similar threats from sea-level rise, climate change, and anthropogenic pressures such as urbanization and agriculture. The Bangladesh Delta's vulnerability is compounded by its high population density and limited adaptive capacity. The global recognition of these risks, especially through frameworks such as the Bangladesh Delta Plan 2100, underscores the need for coordinated international efforts to address the challenges posed by deltaic landscape transformations.

At a regional level, the dynamics of shoreline movement in the Bangladesh Delta are closely linked to the Bay of Bengal's changing hydrodynamics, driven by monsoonal shifts, cyclonic activity, and the upstream flow of the Ganges and Brahmaputra rivers. This highlights the importance of considering transboundary water management and integrated coastal zone management (ICZM) strategies that encompass the entire river basin to address the interconnectedness of river discharge, sediment transport, and coastal changes (Rahman et al., 2015).

Conclusion and Recommendations:

This study has comprehensively analyzed land use and shoreline dynamics in the Bangladesh Delta over a 30-year period (1994–2024), providing valuable insights into the region's environmental transformations. The findings reveal substantial shifts in

land cover, including a 30.3% decline in mangrove forest coverage, a 20.5% reduction in agricultural land, and a 40% increase in wetland areas. These changes underscore the complex interactions between climatic forces, hydrological dynamics, and human activities. The shoreline analysis further indicates that approximately 2,775 km² of land was lost to erosion, particularly along the Meghna Estuary and northern Sundarbans, while 1,052 km² of land has accreted in the southwestern delta, reflecting ongoing sediment redistribution processes.

The study highlights the vulnerability of the Bangladesh Delta to both natural and anthropogenic pressures, with significant implications for biodiversity, coastal resilience, and local livelihoods. The ongoing mangrove degradation, in particular, poses a severe threat to coastal protection and fishery productivity, while the shifting hydrological conditions contribute to the expansion of wetlands in some regions. The observed shoreline erosion in critical areas calls for urgent attention to coastal protection and sustainable land-use management.

Limitations of the Study: While this study provides a detailed assessment of land use and shoreline changes, several limitations must be acknowledged. First, the spatial resolution of Landsat imagery (30m) may limit the detection of small-scale land cover changes, especially in areas with fine-grained features. Secondly, the study relied on remote sensing data for land cover classification, which, despite its high accuracy, still faces challenges in differentiating between certain land cover types (e.g., wetlands vs. agricultural land) in highly dynamic environments. Additionally, ground-truthing was limited, and more extensive field data would help improve classification accuracy. The temporal resolution of the data (every 5–10 years) also means that some short-term changes, particularly those driven by extreme weather events, may not be fully captured.

Future Directions: Future research should focus on higher-resolution satellite imagery (e.g., Sentinel-2) to capture finer-scale changes and enhance classification accuracy. In particular, detailed studies on the effects of climate change, such as sea-level rise and cyclonic impacts, on the delta's shoreline and land use would provide critical insights for adaptive management strategies. Furthermore, incorporating socio-economic data into future models would help assess the human dimensions of shoreline change, such as the impact on coastal communities' livelihoods, displacement, and food security. Longitudinal studies that track ecosystem restoration efforts, such as mangrove rehabilitation, could also provide valuable feedback on the effectiveness of conservation interventions. Finally, policy-oriented research is needed to evaluate the Bangladesh Delta Plan 2100 and other management frameworks in light of ongoing changes, ensuring they are equipped to address the dynamic and evolving nature of deltaic landscapes.

References:

- Abdullah, A. Y. M., Masrur, A., Adnan, M. S. G., Baky, M. A. A., Hassan, Q. K., & Dewan, A. (2019). Spatio-temporal patterns of land use/land cover change in the heterogeneous coastal region of Bangladesh between 1990 and 2017. *Remote Sensing*, 11(7), 790.
- Abu, M., Kamal, U., & Rob, K. (2003). Delineation of the coastal zone Dhaka. PDO-ICZMP, Bangladesh.
- Anam, M., Jabir, A., & Hasan, G. (2021). Bank-line behaviour of the main rivers located within sundarbans using digital shoreline analysis system. *Mist International Journal of Science and Technology*, 9, 11-21. [https://doi.org/10.47981/j.mijst.09\(01\)2021.288\(11-21\)](https://doi.org/10.47981/j.mijst.09(01)2021.288(11-21))
- Aziz, A. and Paul, A. (2015). Bangladesh sundarbans: present status of the environment and biota. *Diversity*, 7(3), 242-269. <https://doi.org/10.3390/d7030242>
- Balha, A., & Singh, C. K. (2023). Comparison of maximum likelihood, neural networks, and random forests algorithms in classifying urban landscape. In *Application of Remote Sensing and GIS in Natural Resources and Built Infrastructure Management* (pp. 29-38). Cham: Springer International Publishing.
- Bhadra, T., Banerjee, S., Ghosh, S., Saha, A., Mukherjee, K., Sardar, R., ... & Das, R. (2023). Monitoring the mangroves of indian sundarbans using geospatial techniques. *The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences*, XLVIII-1/W2-2023, 405-412. <https://doi.org/10.5194/isprs-archives-xxviii-1-w2-2023-405-2023>
- Bharath, A., Manjunatha, M., Reshma, T., Tangadagi, R., & Bahij, S. (2023). Evaluation of land use/land cover changes due to urban sprawl in bengaluru rural, karnataka, india. *Discrete Dynamics in Nature and Society*, 2023, 1-15. <https://doi.org/10.1155/2023/8077644>
- Chauhan, H. B., & Nayak, S. (2005). Land use/land cover changes near Hazira Region, Gujarat using remote sensing satellite data. *Journal of the Indian society of Remote Sensing*, 33, 413-420.
- Dasgupta, S., Sobhan, I., & Wheeler, D. (2017). The impact of climate change and aquatic salinization on mangrove species in the bangladesh sundarbans. *Ambio*, 46(6), 680-694. <https://doi.org/10.1007/s13280-017-0911-0>
- Duveiller, G., Hooker, J., & Cescatti, A. (2018). The mark of vegetation change on Earth's surface energy balance. *Nature communications*, 9(1), 679.
- Enoguanbhor, E., Gollnow, F., Nielsen, J., Lakes, T., & Walker, B. (2019). Land cover change in the abuja city-region, nigeria: integrating gis and remotely sensed data to support land use planning. *Sustainability*, 11(5), 1313. <https://doi.org/10.3390/su11051313>
- Green, K., Kempka, D., & Lackey, L. (1994). Using remote sensing to detect and monitor land-cover and land-use change. *Photogrammetric engineering and remote sensing*, 60(3), 331-337.

- Habib, K., Neogi, A., Nahar, N., Oh, J., Lee, Y., & Kim, C. (2020). An overview of fishes of the sundarbans, bangladesh and their present conservation status. *Journal of Threatened Taxa*, 12(1), 15154-15172. <https://doi.org/10.11609/jott.4893.12.1.15154-15172>
- Hashim, H., Latif, Z., & Adnan, N. (2019). Land use land cover analysis with pixel-based classification approach. *Indonesian Journal of Electrical Engineering and Computer Science*, 16(3), 1327. <https://doi.org/10.11591/ijeecs.v16.i3.pp1327-1333>
- Jana, A., Kumar, A., Lal, J., Mandal, S., Karmakar, S., Bhattacharjee, S., ... & Vaishnav, A. (2024). Exploring the rich diverse: freshwater fish diversity and bionomics in the sundarbans, india. *Journal of Scientific Research and Reports*, 30(6), 795-808. <https://doi.org/10.9734/jsrr/2024/v30i62096>
- Kamruzzaman, M., Ahmed, S., & Osawa, A. (2017). Biomass and net primary productivity of mangrove communities along the oligohaline zone of sundarbans, bangladesh. *Forest Ecosystems*, 4(1). <https://doi.org/10.1186/s40663-017-0104-0>
- Karaburun, A., Demirci, A., & Suen, I. (2009). Impacts of urban growth on forest cover in istanbul (1987–2007). *Environmental Monitoring and Assessment*, 166(1-4), 267-277. <https://doi.org/10.1007/s10661-009-1000-z>
- Li, G., Lu, D., Morán, E., & Hetrick, S. (2011). Land-cover classification in a moist tropical region of brazil with landsat thematic mapper imagery. *International Journal of Remote Sensing*, 32(23), 8207-8230. <https://doi.org/10.1080/01431161.2010.532831>
- Moisa, M., Bulto, T., Werku, B., Berkessa, Y., Chebo, A., Negash, D., ... & Gemed, D. (2023). Analyzing wetland dynamics using geospatial techniques: a case of abay choman and jimma geneti watershed, horo guduru wollega zone, western ethiopia. *Air Soil and Water Research*, 16. <https://doi.org/10.1177/11786221221150183>
- Mondal, B., Mahata, S., Basu, T., Das, R., Patra, R., Abdelrahman, K., ... & Praharaj, S. (2024). Analysis of the post-cyclonic physical flood susceptibility and changes of mangrove forest area using multi-criteria decision-making process and geospatial analysis in indian sundarbans. *Atmosphere*, 15(4), 432. <https://doi.org/10.3390/atmos15040432>
- Mondal, P., Dutta, T., Qadir, A., & Sharma, S. (2022). Radar and optical remote sensing for near real-time assessments of cyclone impacts on coastal ecosystems. *Remote Sensing in Ecology and Conservation*, 8(4), 506-520. <https://doi.org/10.1002/rse2.257>
- Murali, R. M., & Kumar, P. D. (2015). Implications of sea level rise scenarios on land use/land cover classes of the coastal zones of Cochin, India. *Journal of environmental management*, 148, 124-133.
- Nath, A., Koley, B., Choudhury, T., Saraswati, S., Ray, B. C., Um, J. S., & Sharma, A. (2023). Assessing coastal land-use and land-cover change dynamics using geospatial techniques. *Sustainability*, 15(9), 7398.
- Neumann B, Vafeidis AT, Zimmermann J, Nicholls RJ (2015) Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. *PLOS ONE* 10(3): e0118571. <https://doi.org/10.1371/journal.pone.0118571>

- Otukei, J. R., and Blaschke, T. (2010). Land cover change assessment using decision trees, support vector machines and maximum likelihood classification algorithms. *Int. J. Appl. Earth Observation Geoinformation* 12, S27–S31. doi:10.1016/j.jag.2009.11.002
- Rahman, F. (2019). Wildlife conservation and mangrove interpretation centre, karamjal, sundarban: a case study of a site-specific architectural project in a mangrove forest. *Nakhara Journal of Environmental Design and Planning*, 17, 55-70. <https://doi.org/10.54028/nj2019175570>
- Rahman, M., Hossain, G., Khan, S., & Uddin, S. (2015). An annotated checklist of the vascular plants of sundarban mangrove forest of bangladesh. *Bangladesh Journal of Plant Taxonomy*, 22(1), 17-41. <https://doi.org/10.3329/bjpt.v22i1.23862>
- Reis, S. (2008). Analyzing land use/land cover changes using remote sensing and gis in rize, north-east turkey. *Sensors*, 8(10), 6188-6202. <https://doi.org/10.3390/s8106188>
- Saha, A., Arora, M., Csaplovics, E., & Gupta, R. (2005). Land cover classification using irs liss iii image and dem in a rugged terrain: a case study in himalayas. *Geocarto International*, 20(2), 33-40. <https://doi.org/10.1080/10106040508542343>
- Scanlon, B. R., Reedy, R. C., Stonestrom, D. A., Prudic, D. E., & Dennehy, K. F. (2005). Impact of land use and land cover change on groundwater recharge and quality in the southwestern US. *Global Change Biology*, 11(10), 1577-1593.
- Shadmehri Toosi, A., Batelaan, O., Shanafield, M., & Guan, H. (2025). Land Use-Land Cover and Hydrological Modeling: A Review. *Wiley Interdisciplinary Reviews: Water*, 12(2), e70013.
- Sultana, S. and Anwar, M. (2021). Review assessment of biodiversity loss and ecosystem deterioration due to built-form considering the implementation of rampal power plant near sundarban forest. *International Journal of Research and Innovation in Social Science*, 05(08), 247-255. <https://doi.org/10.47772/ijriss.2021.5817>
- Sutikno, S. (2016). Integrated remote sensing and gis for calculating shoreline change in rokan estuary. *Kne Engineering*, 1. <https://doi.org/10.18502/keg.v1i1.491>
- Szarek-Iwaniuk, P. (2021). A comparative analysis of spatial data and land use/land cover classification in urbanized areas and areas subjected to anthropogenic pressure for the example of Poland. *Sustainability*, 13(6), 3070.
- Turner, B. L., Skole, D., Sanderson, S., Fischer, G., Fresco, L., & Leemans, R. (1995). Land-use and land-cover change: science/research plan. [No source information available].
- Tusar, M., Hasan, M., & Sultana, N. (2023). Sundarbans mangrove mapping and above ground biomass estimation using earth observation techniques. *Journal of Sustainability and Environmental Management*, 2(2), 126-132. <https://doi.org/10.3126/josem.v2i2.55205>
- UNPD. Urban and Rural Areas, United Nations, Department of Economic and Social Affairs, Population Division. 2007. Available online: http://www.un.org/esa/population/publications/wup2007/2007_urban_rural_chart.pdf (accessed on 17 March 2025).

Yadahalli, G., & Bellakki, M. (2018). Accuracy Assessment of Supervised and Unsupervised Classification using Landsat-8 Imagery of D-7 Shahapur Branch Canal of UKP Command Area Karnataka, India. *Int. J. Curr. Microbiol. App. Sci*, 7(7), 205-216.

Yuna, A. and Cahyono, A. (2024). Identifying coastlines change in tangerang regency indonesia through historical maps.. <https://doi.org/10.1117/12.3009201>

Zeng, Y., Yang, X., Fang, N., & Shi, Z. (2020). Large-scale afforestation significantly increases permanent surface water in China's vegetation restoration regions. *Agricultural and Forest Meteorology*, 290, 108001.

Islam MS, Crawford TW and Shao Y. (2023), Evaluation of predicted loss of different land use and land cover (LULC) due to coastal erosion in Bangladesh. *Front. Environ. Sci.* 11:1144686. <https://doi.org/10.3389/fenvs.2023.1144686>



A Comprehensive Audit of Aquaculture Practices in the Muhuri Project Area of Chattragram in Bangladesh

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Abstract

The study audited the status of aquaculture practices in the Muhuri Project Area fish farms, Chattragram, Bangladesh by assessing the seasonal changes of water quality, disease outbreaks and fish health management scenario, and fish production. Thirty ponds, ranging from 4 to 15 acres, were monitored across pre-monsoon and post-monsoon seasons to measure critical water quality parameters including transparency, temperature, TDS, DO, pH, and EC, using multiparameter probes and Secchi disk. DO levels dropped from 6.96 ± 0.35 ppm in pre-monsoon to 5.97 ± 0.30 ppm in post-monsoon, while temperature, pH, TDS and EC increased ($26.12 \pm 0.72^\circ\text{C}$ to $30.49 \pm 0.63^\circ\text{C}$, 7.28 ± 0.13 to 7.70 ± 0.21 , 169.20 ± 8.12 ppm to 256.54 ± 68.40 ppm, and 0.16 ± 0.01 psu to 0.21 ± 0.08 psu) from pre-monsoon to post-monsoon, all adding stress to fish. The culture system was semi-intensive with the combination of Rohu, Catla, Mrigal, Tilapia, and Pangas and achieved fish production from 4–12 tonnes per acre annually. However, the disease outbreaks in the fish farms were frequent, nutritional deficiencies and respiratory issues were common in pre-monsoon periods. The common disease like fin rot and skin lesions were intensified in the post-monsoon period. Antibiotics, including oxytetracycline and amoxicillin, were often used for disease treatment, raising concerns about Anti-Microbial Resistance (AMR). The study highlighted the need for better water quality management and proactive measures in disease control. Future research should consider alternative disease prevention approaches, such as probiotics and vaccinations, to reduce the use of antibiotics and foster sustainable aquaculture in the Southeast Bangladesh.

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1. Introduction

Aquaculture refers to the cultivation of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, which may include practices like regular stocking, feeding, and safeguarding against predators (Edwards & Demaine, 1997). The fishing industry contributes significantly to the economies of many nations throughout the world by creating jobs and income. Fishing is a key source of livelihood for people globally, providing food for over a billion people (Kalita et al., 2015). The global production of aquatic animals hit a new high of 185 million tons (live weight equivalent) in 2022, up 4 percent from the previous year. Out of the 185 million tonnes of aquatic food produced in 2022, around 164.6 million (89 percent) were

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intended for human consumption, or the equivalent of 20.7 kg per capita. Aquatic animal farming generated an estimated 94 million tonnes, about 51 percent of the total, surpassing capture fisheries' production of 91 million tonnes (49 percent) of the total. Bangladesh is ranked fifth in the world for aquaculture production, making it one of the top fish-producing nations. Bangladesh's total production in 2022-2023 was 4.915 million MT, of which 58.03 percent is attributed to aquaculture. The fishing industry is growing at a rate of 2.43 percent of GDP (DOF, 2023). At least 293 species of finfish, 63 species of prawns, various kinds of turtles, tortoises, freshwater mussels, and other living aquatic animals are found in Bangladesh's inland aquatic ecosystems, which are rich in regard to faunal richness (Rahman et al., 2018). Since fish life is determined by their aquatic habitat, water quality must be suitable for fish culture. The maintenance of quality of several water parameters is essential for aquaculture to be successful. The most significant limiting factor in fish culture is often controlled by pH, DO, BOD, TDS, EC, transparency, and temperature (Boyd, 1990). Maintaining the pond's water quality attributes in their ideal state is crucial for maintaining a pond ecosystem (Bhatnagar & Devi, 2013). Fish are stressed out by prolonged exposure to below-optimal concentrations of one or more water-quality variables, which increases their susceptibility to illness (Boyd, 2017). Fish exposed to low DO levels for an extended period experiences chronic stress, eat less feed, and become more susceptible to illness (Evans et al., 2003). Ammonia toxicity to fish is increased by high pH, while copper and aluminium toxicity is increased by low pH (Boyd et al., 2016; Wurts, 2003). To maintain the healthy aquatic environment needed for effective production, suitable pond management techniques are crucial. Nonetheless, pond water quality is typically not properly maintained in small-scale aquaculture due to a lack of technical expertise, expensive pumping, and competing uses of water (Duijn et al., 2018).

Fish in low-quality water are stressed and more susceptible to opportunistic infections. Disease is now the main factor limiting fish output in Bangladesh as a result of the growth and diversification of aquaculture techniques. Fish production and the means of livelihood for rural fish farmers are negatively impacted by fish disease issues (Rahman et al., 2018). The environmental circumstances that the fish parasite community inhabits vary greatly. Among other diseases in fish, bacterial disease is a major challenge to Bangladesh's aquaculture industry (Dey et al., 2014). According to Chowdhury et al. (2003), common diseases in Bangladesh are fungal, parasitic, bacterial, and epizootic ulcerative syndrome (EUS). Furthermore, tail and fin rot disease are also present in a variety of fish farms, and it is believed that this form of sickness has become more common recently (Faruk et al., 2004). Fish health and resistance to disease-causing substances are significantly influenced by a variety of physicochemical parameters (Hussainy, 1967).

The current study intends to conduct a thorough investigation of fish disease, fish productivity, and water quality at the Muhuri Project, Chattogram, Bangladesh. The

objective of these studies is to evaluate the current state of the water quality in the Muhuri Project region through the analysis of various physicochemical parameters. The frequency of common fish diseases that affect local fish species should be determined and investigated. To determine any risks or obstacles to future sustainable production, a comprehensive assessment of the Muhuri Project's current fish yield must be conducted, together with an analysis of the factors influencing it.

2. Materials and Method

2.1 Study area

The Muhuri project is situated in the southeast of Bangladesh, in the Feni District as well as parts of Mirsarai Upazila of Chittagong District, at a latitude of 22°50'11.0" N and a longitude of 91°27'13.0"E. It is a large freshwater ecosystem with about 300-350 acres.

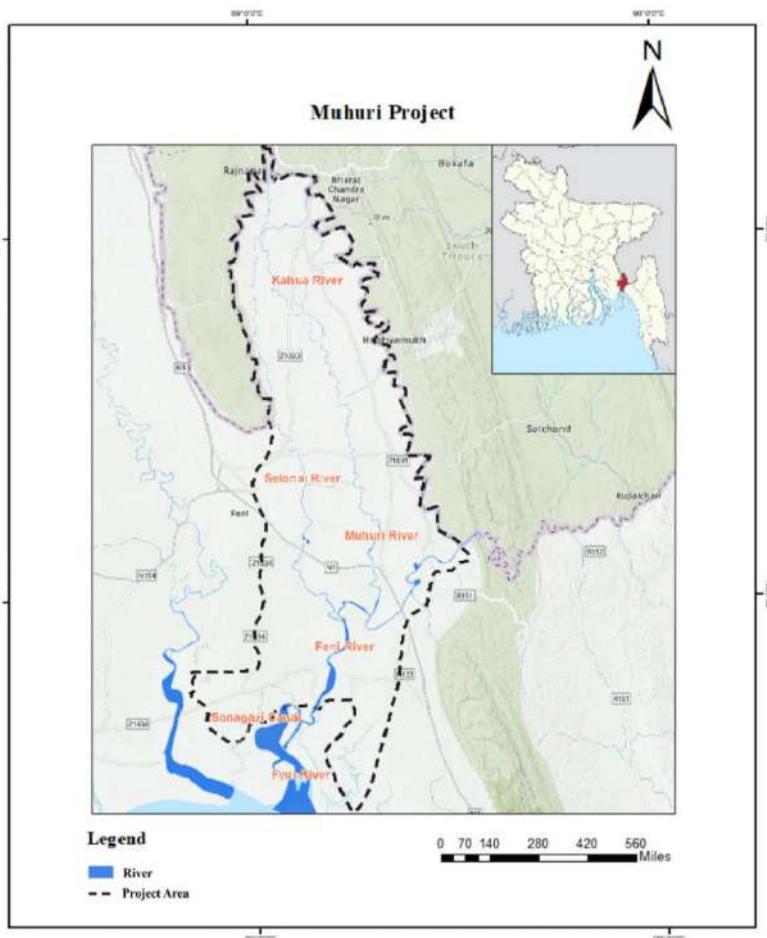


Figure 1: Study area of Muhuri Project in Southeast Bangladesh

2.2 Experimental design

The preliminary study identified 30 ponds, each ranging between 4 and 15 acres in size, as suitable for the study. The ponds included in this study were all earthen and liner types, the major types of fish culture systems practiced in the area. All ponds were practiced for carp culture with combination or Tilapia and Pangasius catfish in some cases. Out of the 30 ponds, 21 use groundwater, and 9 use river waters. These ponds were constructed under various development programs, including the Economic Stimulus Program (ESP), and were geographically distributed across different locations. Different species combinations were observed across the farms, but five species were found dominant which were: Rui (*Labeo rohita*), Catla (*Catla catla*), Mrigal (*Cirrhinus mrigala*), Tilapia (*Oreochromis niloticus*), & Pangas catfish (*Pangasius hypophthalmus*). These species were combined differently due to their different feeding habits, which optimize resource utilization. Catla is the surface feeder, Rui feeds in the column and Mrigal is the bottom feeder allowing species to access different ecological niches within the same pond. Table 1 categorized the species in the study area into five combinations based on the most commonly cultivated species. Water samples were manually collected from each selected pond to representing different species composition. During sampling, seasonality was taken into account with data collection during both pre-monsoon and post-monsoon. Water samples were collected manually from each pond and analysed to assess their quality. The impact of fish diseases on fish health and production was also monitored in both seasons.

Table 1: Species combination

Species Combination	Species included					Stocking density (kg/acre) (major carp + Pangas+ Tilapia)
1	Rui	Catla	Mrigael	Tilapia	Pangas	1000-1200
2	Rui	Catla	Mrigael	Tilapia	-	800-1000
3	Rui	Catla	Mrigael	-	-	800-1000
4	Rui	Catla	Mrigael	-	Pangas	400-600
5	Rui	Catla	Mrigael	Tilapia	Others (Grass Carp, Silver Carp, Tengra etc.)	1000-1200

2.3 Determination of physicochemical parameters

The temperature, pH, TDS, DO, and EC data were measured using a multiparameter (Hanna HI98184). The probes were immersed in the pond water and left for 30 seconds to stabilize before taking the reading. Data were collected between 8:00 am

to 11:00 am for both pre-monsoon and post-monsoon seasons. For pre-monsoon and post-monsoon data were collected in the month of May and October, respectively.

Secchi disk depth was measured using a Secchi disc with a diameter of 20 cm and a black-and-white pattern on the upper surface. The disc was lowered into the water until it was no longer visible. The disc was then slightly raised and lowered again to determine the exact point at which it reappeared and the depth was noted.

2.4 Data collection and analysis

Several methods have been used to collect data, including primary data collection, observation in the field, and face-to-face interviews. For primary data collection, a basic questionnaire was developed. Primary data were collected via Google Forms covering water sources, pond type, method, depth, area, species, fish disease, fish production, etc. by using PRA tools such as FGD and KI with the fisher community. Additionally, secondary data was sourced from books, journals, NGOs, and the Upazila Fisheries Officer. These data were analysed in Microsoft Excel 2021 and presented in textual, tabular, and graphical form.

3. Result

Collected data provided information on water quality parameters, which highlighted the impacts of seasonal variability on aquaculture outcomes in semi-intensive polyculture systems.

3.1 Farm conditions and management systems

Figure 2(a) shows that semi-intensive aquaculture systems dominated in the study area. This system is characterized by moderate stocking densities and uses both natural and supplement feeds with a rate of two times per day, ensuring optimal growth and resource utilization. Table 2 also indicates that disease monitoring was routinely conducted, and the use of antibiotics was common to manage fish health across different species groups. In the Muhuri Project area, polyculture method was practiced in almost all ponds (figure 2b) which showed that, species combination 1 (Mrigal, Rui, Catla, Tilapia & Pangas) was the most common, comprising 33% of ponds, while the lowest combination accounted for 10%, for combination 4 (Mrigal, Rui, Catla & Pangas). Both groundwater (70%) and river water (30%) sources were used in these aquaculture systems (Figure 2c). On the other hand, Figure 3 shows density of by species combinations where highest stocking density of 1,000 to 1,200 kg/acre occurred in 1 and 5 number combination of species, while combination 4 showed the lowest stocking density (400 to 600 kg/acre). Figure 2(d) represent the culture duration of fish species where most cultures were maintained for 11–12 months (56.67%), followed by a duration of 9–10 months (23.33%) and 7-8 months (20%), respectively.

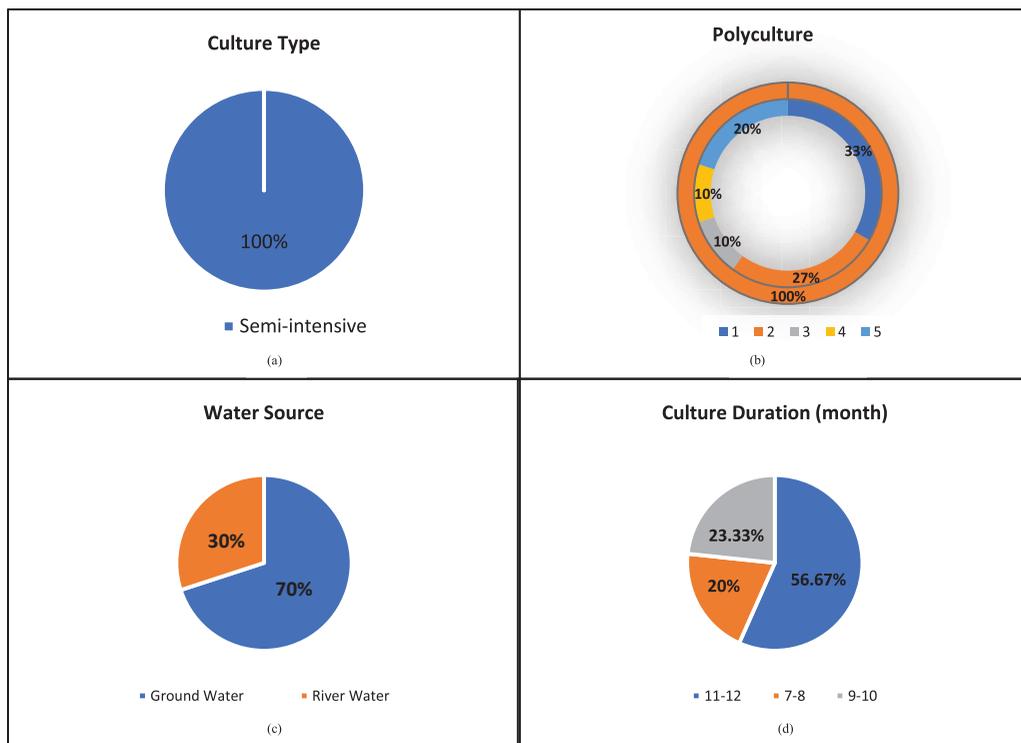


Figure 2: Farm management practices. (a) Culture types, (b) Culture method, (c) Water sources, (d) Culture duration

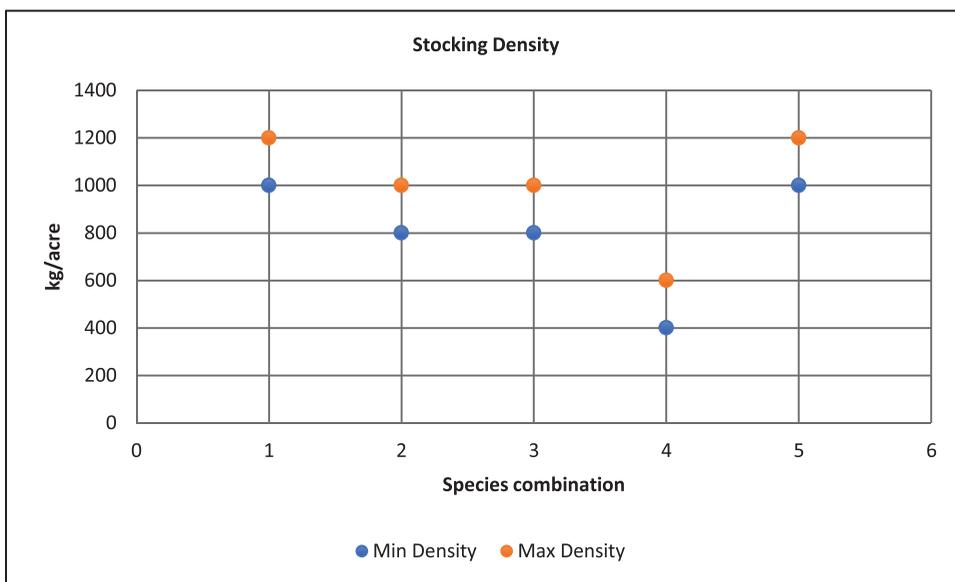


Figure 3: Species combination wise minimum and maximum stocking density in Muhuri Project area

Table 2: Farm management practices (type of feed, rate of feeding, disease monitoring & use of antibiotics)

Species combination	Feed	Rate of feeding (% per day)	Disease Monitoring	Use of antibiotics
1	Natural + Artificial	2	Yes	Yes
2	Natural + Artificial	2	Yes	Yes
3	Natural + Artificial	2	Yes	Yes
4	Natural + Artificial	2	Yes	Yes
5	Natural + Artificial	2	Yes	Yes

3.2 Pond dimensions

The depth and surface area of the ponds varied across the farm, which affected the water quality and supported the species diversity necessary for polyculture practices. Most ponds maintain a depth of 4 to 6 feet (Figure 4a). Approximately 63.33% of the pond area were 5 to 10 acres in area, and 20% were 1 to 4 acres and 16.67% were 11 to 15 acres, respectively (Figure 4b).

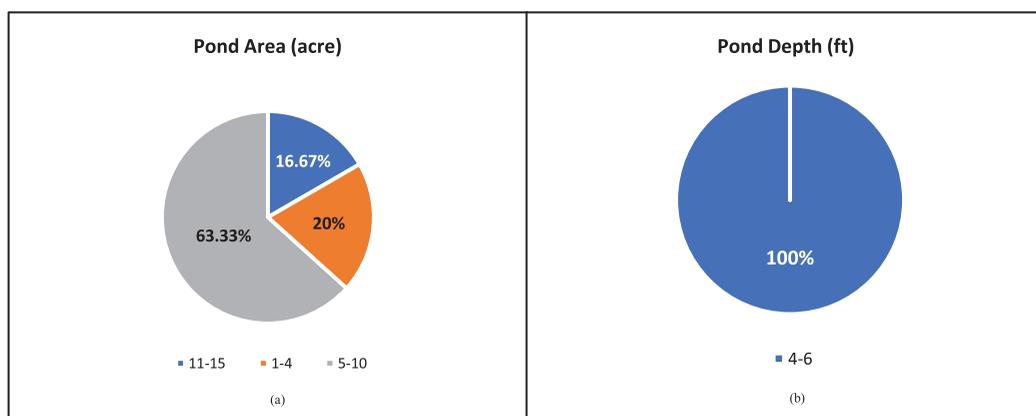


Figure 4: Pond dimensions (pond depth, and pond area) of the aquaculture farms of Muhuri Project area

3.3 Source of fish fry and feed conversion ratio (FCR)

Figure 5 shows that the majority of the farms collected their fry from the hatcheries, which includes almost 86.67%, and the rest of 13.33% were collected from wild source of the Muhuri River. Figure 6 showed the FCR value in pre-monsoon and pre-monsoon, where in pre-monsoon, the average FCR of Rohu, Catla, Mrigal, Tilapia and Pangas were 1.5, 1.6, 1.4, 1.2 and 1 respectively and in post-monsoon, it was 1.4, 1.5, 1.3, 1.1 and 1.1.

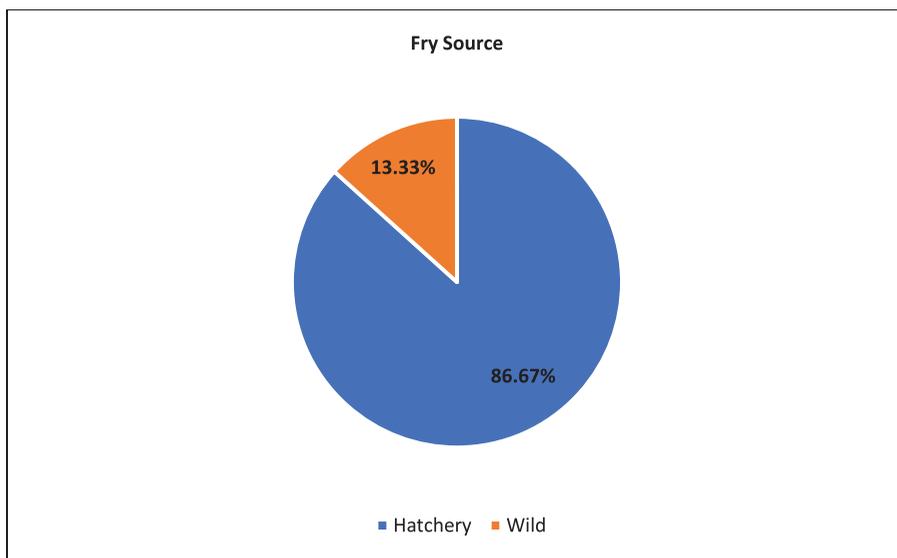


Figure 5: Collection of fry source in Muhuri Project area

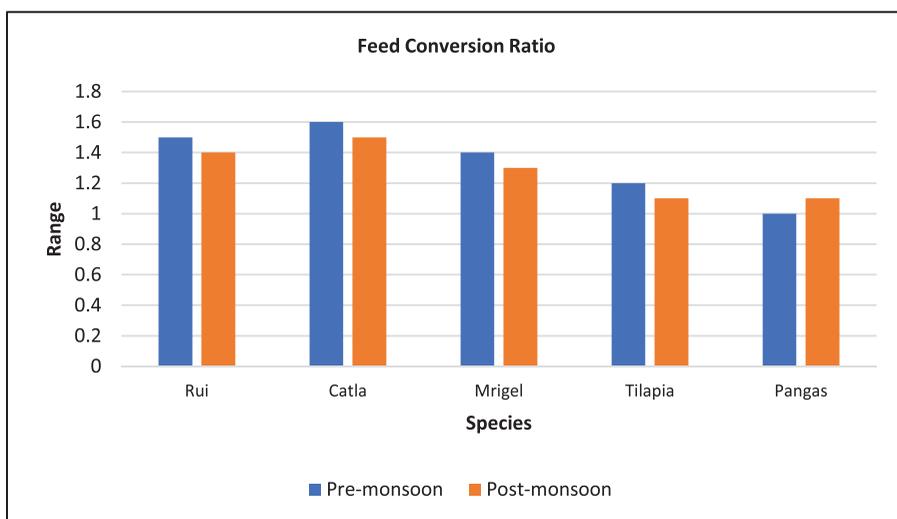


Figure 6: Species-wise feed conversion ratio

3.4 Water quality parameters

Figure 7(a) showed that the average pH during the pre-monsoon season was 7.28 ± 0.13 , while in the post-monsoon it was slightly higher (7.70 ± 0.21). DO levels were generally constant in both seasons but in pre-monsoon it was 6.96 ± 0.35 ppm, and in the post-monsoon season it was 5.97 ± 0.30 ppm, which is slightly lower than the pre-monsoon season (Figure 7b). Moreover, temperature during pre-monsoon ($26.12 \pm 0.72^\circ\text{C}$) is slightly lower than post-monsoon ($30.49 \pm 0.63^\circ\text{C}$) (Figure 7c). The figures 7(d) & 7(e) showed that TDS and EC were slightly increased in post-monsoon.

The average TDS in pre-monsoon and post-monsoon seasons was 169.20 ± 8.12 & 256.54 ± 68.40 ppm and EC was 0.16 ± 0.01 & 0.21 ± 0.08 psu, respectively. The average Secchi disk depth was 28.02 ± 1.07 cm in pre-monsoon and 24.28 ± 2.48 cm in post-monsoon (Figure 7f), which is slightly lower than pre-monsoon season.

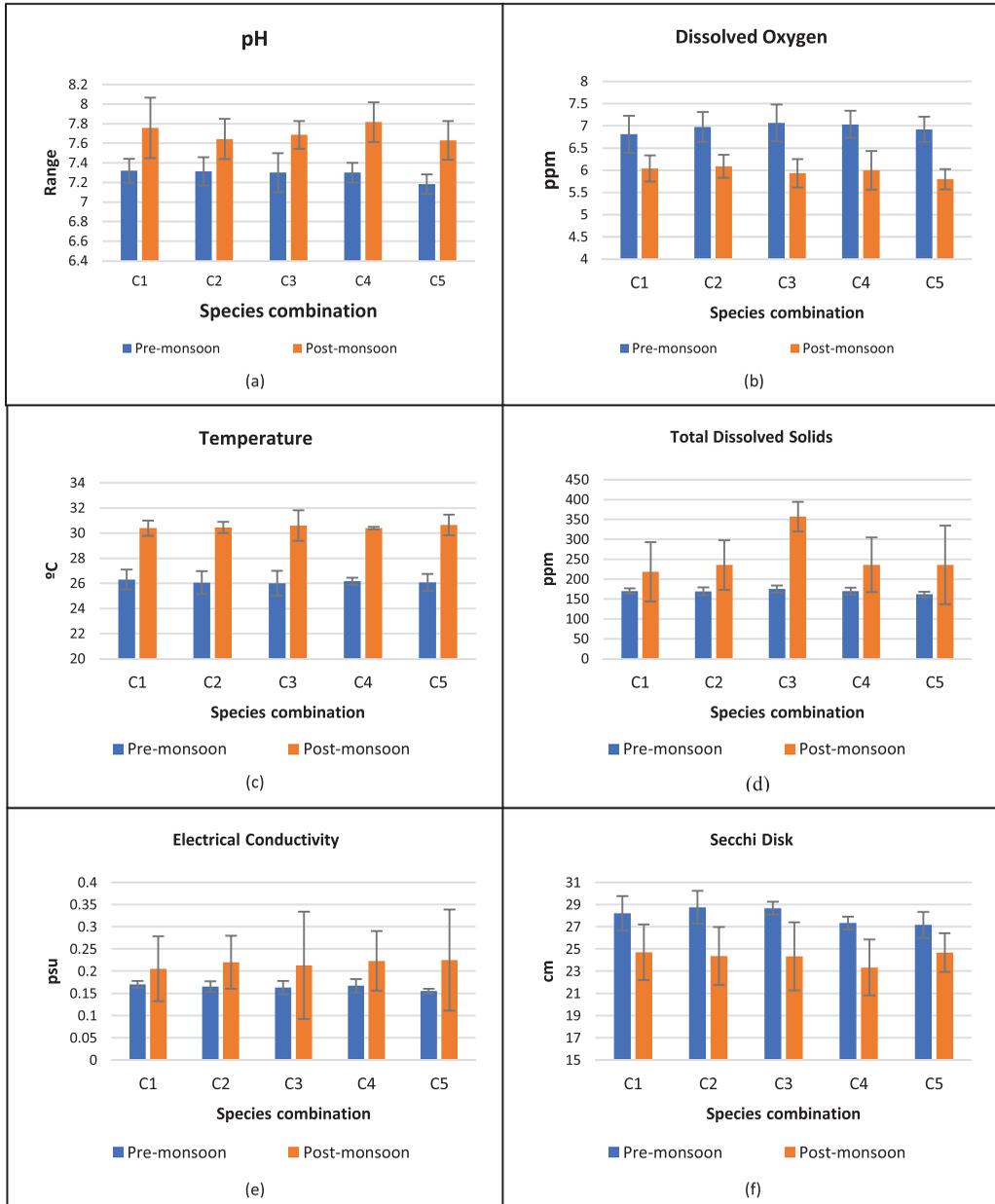


Figure 7: Seasonal Variations in Water Quality Parameters Across Different Combinations in Pre-Monsoon and Post-Monsoon Periods. (a) pH, (b) Dissolved oxygen, (c) Temperature, (d) Total dissolved solids, (e) Electrical conductivity & (f) Secchi disk (mean \pm SD)

3.5 Disease symptoms

Disease occurrence was a persistent challenge in both pre-monsoon and post-monsoon, despite vigilant monitoring and constant efforts of better management. Figure 8 illustrates that nutritional deficiencies were the most frequent in the pre-monsoon season, accounted for 28.57% of all disease symptoms. This was followed by respiratory distress and gill irritation, observed at approximately 14.29%. Conditions like skin rot, fin rot, and gill hyperplasia were observed in the pre-monsoon season.

In the post-monsoon, fin rot (20.83%) and abnormal swimming (14.58%) emerged as the prominent disease symptom. Other disease symptoms, such as lethargy, skin lesions, and loss of appetite, were observed more frequently and accounted for about 10.42%, 12.50%, and 12.50% respectively. Other post-monsoon season disease symptoms included tail rot, skin ulcers, skin lesions, loss of appetite, lethargy, abnormal swimming, abnormal growth, and abdominal dropsy though at low percentages.

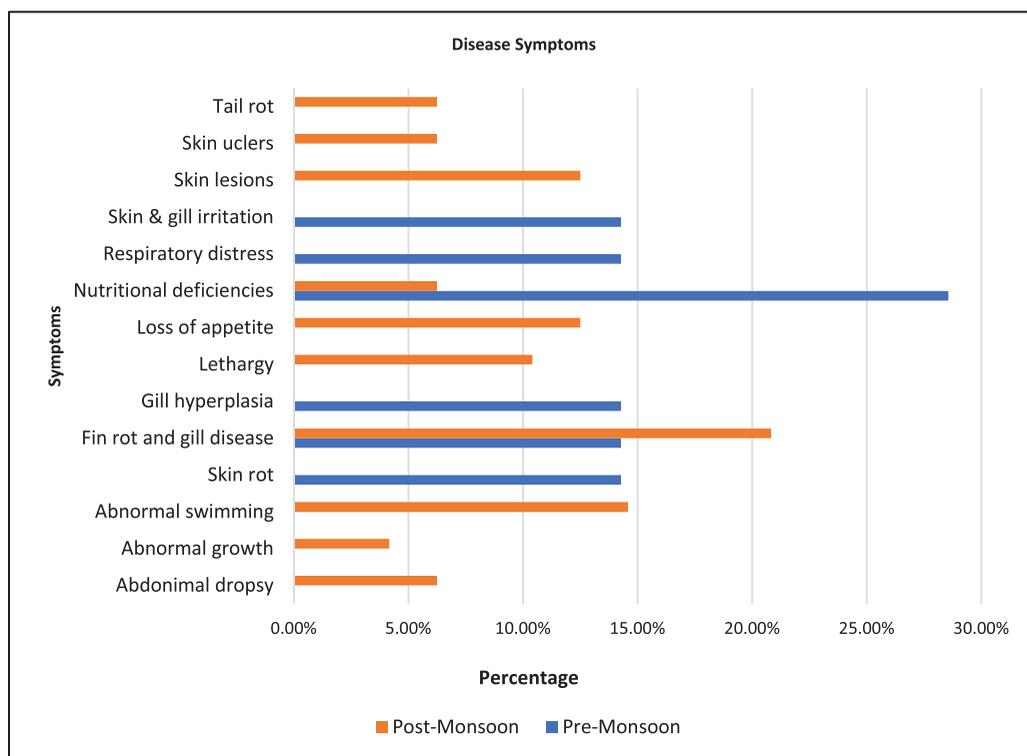


Figure 8: Pre-Monsoon and Post-Monsoon Disease Symptoms and their frequency in the Muhuri Project Area

3.6 Impacts of disease outbreaks

Disease outbreaks were observed in several farms in both seasons, with distinct seasonal impacts as shown in Figure 9. During post-monsoon, farms faced increased

challenges with reduced growth affecting around 18.95% of fish ponds, production reduced by approximately 17.89%, and elevated stress levels by about 14.74%. Other notable symptoms were increasing mortality rate, poor health, and reduced marketability at 13.68%, 12.63%, and 11.58% respectively. Reduced feed intake and poor feed conservation were also found in a very low rate in the post-monsoon season.

On the contrary, disease symptoms were much prominent in the pre-monsoon season which include reduced production (17.20%), reduced growth (16.13%), and increasing mortalities (15.05%). Additionally, reduced feed intake and poor feed conservation were also recorded at 8.60% and 7.53% which is slightly higher than post-monsoon. Other disease symptoms that impacted the fish culture were stress (13.98%), poor health (11.83%), and reduced marketability (9.68%).

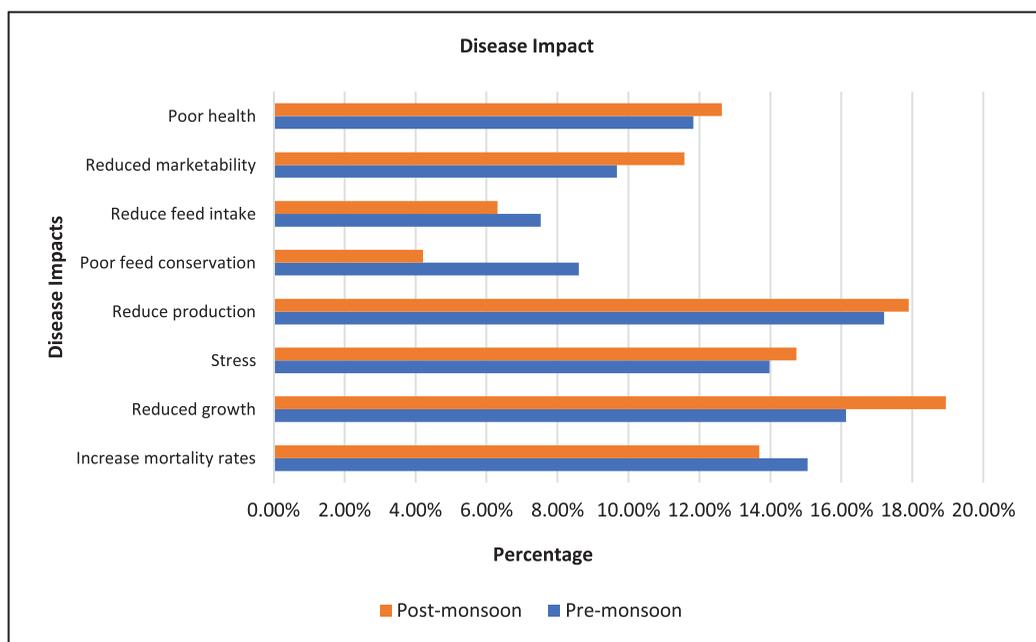


Figure 9: Seasonal variation of Disease Impacts on Fish Farms (Pre-monsoon vs. Post-monsoon)

3.7 Use of drugs and chemicals for disease treatments

Table 3 shows the antibiotics that were commonly used in the semi-intensive culture system in the Muhuri Project region during the outbreaks of bacterial diseases.

Various therapeutic agents, including lime, salt, formalin, malachite green, potash, and timsen- are commonly used in Feni district aquaculture farms. It prevents fish diseases and controls external parasites and fungal infections. Despite its widespread use as a therapeutic agent, malachite green use is banned in developed countries due to health concerns.

Table 1: Common antibiotics used in Aquaculture (Name, sources, doses & costs)

Trade name	Compound	Dose	Source	Price (BDT)
Renamycin	Oxytetracycline	28-42 g/100 kg feed/10 days	Renata Pharmaceuticals Ltd	85/100g
Ranamox	Amoxicillin, Trihydrate	28-40 g/100 kg feed /10 days	Renata Pharmaceuticals Ltd	145/100g
Amoxy fish	Amoxicillin Trihydrate bp 98%	1-1.5kg/MT (For prevention); 2-3kg/MT of feed (for treatment)	Fish Tech (BD) Ltd	1090/50g
Otetra Vet Power 50	Oxytetracycline	Mixed with feed; 11-16 g/100 kg body weight.	Square Pharmaceuticals	160/100g
Acimox(vet) Powder	Amoxicillin (Trihydrate)	1 g/1 kg feed	ACI Animal Health	78/100g
Oxysentin 20%	Oxytetracycline HCl BP	100-200 g/100 kg feed/5- 7days	Novartis Pharmaceuticals	700/kg
Orgamycin 15 %	Oxytetracycline HCl BP (WSP)	60 g/100 kg feed/10 days (For prevention); 120-240 g/100 kg feed/5-7 days (for treatment)	Organic Pharmaceuticals Ltd.	70/100g
Chlorsteclin	Chlortetracycline	1g/kg feed (For prevention); 3g/kg feed (for treatment)	Novartis Pharmaceuticals	Unknown

3.8 Fish production

Figure 10 represents the annual production of aquatic farms across the Muhuri project area based on different species combinations. The highest annual production was approximately 10–12 tonnes/acre which was recorded from species combination 1 and 5. On the other hand, combination 3 showed about 6-8 tonnes/acre production but combination 4 represented the lowest production level with 4-6 tonnes/acre.

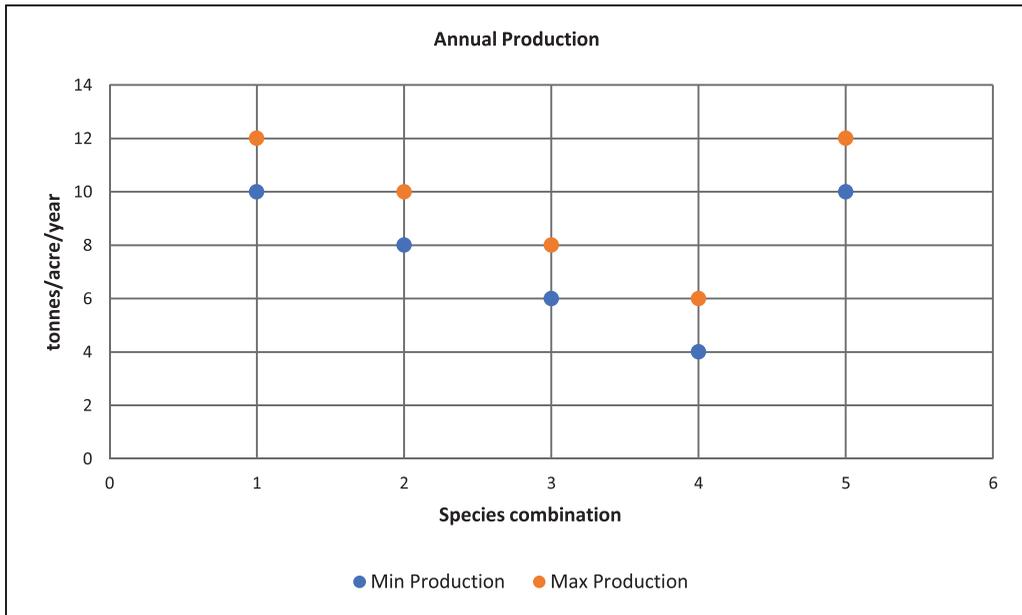


Figure 10: Annual fish production in Muhuri Project Area

4. Discussion

The main purpose of the present study was to understand the fish pond farming systems and its management regimes through monitoring of major water quality parameters, observing the disease symptoms and overall fish production performance of 30 fishponds in the Muhuri Project area, Chattogram.

4.1 Farm conditions & management practices

The Muhuri Project primarily employs a semi-intensive aquaculture system, characterized by moderate stocking densities and a combination of natural and supplemental feeding. This system is widely regarded for its resource efficiency and sustainability, as it supports fish health and productivity without the extensive inputs required in fully intensive systems (Ahmed & Garnett, 2011).

In particular, the practice of polyculture cultivating multiple fish species within the same pond was found as a common practice in the Muhuri Project. The polyculture system practiced here enhances the resource utilization and productivity by combining species with different feeding habits and ecological niches as mentioned by Hopher et al. (1989), who claimed that combining bottom-feeding fish with filter-feeding species can increase overall yield and improve growth.

Groundwater was identified as the primary water source for 70% of the ponds, with river water comprising the remaining 30%. The use of diverse water sources can help stabilize pond water depth throughout the year, which is crucial for fish production.

The culture duration across ponds in the Muhuri Project varied, with most ponds maintaining fish for 11–12 months, followed by 9–10 months, and 7–8 months. A longer culture period allows for steady growth and stabilization of the pond environment, optimizing conditions for fish growth across seasonal changes (Hasibuan et al., 2021).

Stocking density in the ponds varied by species combination, with densities ranging between 400–600 kg/acre in lower-density setups and 1000–1200 kg/acre in higher-density combinations. Stocking densities in semi-intensive aquaculture systems reveal a complex relationship between density and fish performance. While higher densities can increase overall production, they may negatively impact individual growth rates and welfare (Shaker & Abdel-Aal, 2006).

Feeding was conducted twice daily to support optimal growth. According to Tacon (1996), consistent feeding schedules help regulate the metabolic activity and energy levels of the fish, improving growth efficiency. This routine feeding approach is crucial in semi-intensive systems to supplement natural food resources in the pond environment

The pond dimensions varied widely within the Muhuri Project. Most ponds had depths of 4–6 feet, which supports a stable aquatic environment necessary for polyculture, as different fish species can thrive at different depths. Regarding surface area, approximately maximum ponds ranged from 5 to 10 acres. Larger ponds often provide more space for species diversity, which is beneficial for polyculture practices (Zhang et al., 1987).

Most fry used in the Muhuri Project ponds were sourced from hatcheries, with only a smaller fraction coming from the nearby Muhuri River. Hatchery-sourced fry is typically preferred for their controlled breeding conditions, which reduce disease risks and improve survival rates (Caroffino et al., 2008).

The FCR differed between species and seasonal conditions, reflecting the efficiency of feed utilization. During the pre-monsoon period, average FCR values for all species were slightly higher than post-monsoon changes in feed efficiency related to environmental and physiological factors across seasons. Lower FCR values indicate better feed efficiency, a critical factor in maintaining sustainability in aquaculture (Fry et al., 2018).

4.2 Water quality parameter

The pH range in pre-monsoon and post-monsoon were respectively 7.28 ± 0.13 and 7.70 ± 0.21 . According to Islam et al. (2013), the suitable range of pH in the pond is between 6 to 8.5 and the result of the study is within this similar pH range, indicating a stable environment for fish culture.

The DO levels were 6.96 ± 0.35 ppm in pre-monsoon and 5.97 ± 0.30 ppm in post-monsoon which is slightly lower. The suitable range of DO for fish culture was 3.70 to

8.38 ppm for fish cultivation ponds (Momota et al., 2023). DO levels were generally higher in pre-monsoon periods due to increased temperature and light transparency, promoting greater primary productivity, while post-monsoon levels were typically lower as nutrients accumulated and other environmental conditions changed (Chinthada & Bandla, 2021). Prolonged exposure to DO levels at the lower end of this range can impair feed conversion efficiency and growth performance, as oxygen is critical for metabolic processes in fish (Lakani et al, 2013).

For aquaculture, the acceptable range of temperature is 25 to 32°C (Munni et al., 2015). In this study area, temperature was in acceptable range both pre-monsoon and post-monsoon but showed a higher value post-monsoon than pre-monsoon. Temperatures during the post-monsoon period tend to be higher than in pre-monsoon, largely due to seasonal climatic changes and increased atmospheric heating post-monsoon (Satpathy et al., 2010).

In fish farms, the acceptable TDS limit for diverse fish production is set at 400 ppm (Munni et al., 2015). The values of all TDS from study areas ponds were very low compared to the standard value. Serder et al. (2020) reported that TDS and other parameters are generally elevated in pre-monsoon in coastal ponds in Bangladesh. This increase is due to evaporative concentration before monsoon rains dilute these dissolved solids in the post-monsoon period

The preferable range for EC according to Munni et al. (2015), is 0.07 to 0.25 psu. Chinthada & Bandla (2021) reported that EC in fish ponds tend to be higher during pre-monsoon due to increased temperatures and evaporation, which concentrates dissolved ions. In contrast, the monsoon season dilutes these ions, reducing EC in fish pond

Santhosh and Singh (2007) state that a Secchi disk visibility range of 30 to 40 cm indicates ideal pond productivity for successful fish farming. Transparency in fish ponds is generally higher in the pre-monsoon season compared to the monsoon and post-monsoon periods, due to clearer water with fewer suspended solids and higher light penetration before monsoon rains increase turbidity (Chinthada & Bandla, 2021).

4.3 Seasonal Disease Patterns

The present study examined pond-based aquaculture's disease symptoms and impacts in the Muhuri Project, Chattogram. The findings indicate distinct seasonal trends in disease occurrence within aquaculture systems. It also highlights pre-monsoon and post-monsoon patterns in disease types, symptoms, and severity.

In the pre-monsoon season, issues such as nutritional deficiencies, respiratory problems, skin rot, and fin rot were prevalent. Seasonal variations in water quality parameters significantly impact fish health and disease prevalence in pond aquaculture. According to Chinthada & Bandla (2021), fluctuations in temperature, dissolved oxygen, pH, and other parameters can lead to various health issues in fish.

During pre-monsoon seasons, higher temperatures and light transparency can affect dissolved oxygen content potentially contributing to nutritional deficiencies (Chinthada & Bandla, 2021).

Seasonal shifts in water quality, especially during pre- and post-monsoon periods, were observed to increase fish vulnerability to diseases, as seasonal changes in parameters like dissolved oxygen and pH can cause physiological stress in fish (Menon et al., 2023).

The study shows that the range of water quality parameters was in the range, but sudden fluctuations may be contributing to the increased susceptibility of fish to diseases.

During the post-monsoon period, fish health challenges intensify, with higher occurrences of fin rot, skin lesions, and abnormal swimming behaviors. Das & Chandra (2018) explained that fish are more susceptible to diseases during post-monsoon, with gills and skin being the most affected organs. Common health issues observed include pop eye, ventral reddening, tail and fin rot, haemorrhagic lesions, dropsy, and gill rot (Hasan et al., 2014). Carp, mrigal, and catla were found to be among the most susceptible species to diseases in this season (Hasan et al., 2014). Seasonal variations play a significant role in disease occurrence. Fish are more vulnerable to diseases when water quality parameters such as temperature, dissolved oxygen, pH, and ammonia are not maintained at optimal levels (Das & Chandra, 2018). In this study, water quality parameters were generally optimal. However, seasonal changes like shared water sources, wild fry, shallow ponds and limited nursing may still heighten disease risk (Bhowmick & Crumlish, 2017).

The study indicates that post-monsoon disease outbreaks significantly affect fish health and overall production. A notable portion of ponds experience slowed fish growth, production declines, and elevated stress levels among fish. Other impacts during this period include increased mortality rates, compromised fish health, and reduced marketability due to visible disease symptoms, all of which weaken the economic viability of fish farming in the region. Factors contributing to these disease outbreaks include inadequate pre-stocking practices, environmental stressors, and limited training in disease management techniques (Hossain et al., 2013). Regular monitoring of water quality is essential to minimize the impact of these seasonal variations and ensure a stable environment for fish growth (Boyd & Tucker, 2017).

Disease outbreaks in the pre-monsoon season similarly impair fish farming, leading to lower production, stunted growth, and higher mortality rates. Fish experience reduced feed intake and efficiency, slightly more so than in the post-monsoon season, indicating substantial nutritional and physiological stress prior to the monsoon. These challenges contribute to poor fish health and reduced market value, emphasizing the vulnerability of fish populations to seasonal disease impacts and the economic implications for aquaculture. Climate change and seasonal disease outbreaks pose

significant threats to aquaculture productivity and food security. Nutritional diseases can lead to increased fish mortality, susceptibility to infections, and decreased yield quality and quantity (Shefat, 2018). According to Walker (2004), disease outbreaks have caused substantial economic losses in various aquaculture sectors globally, with annual losses reaching billions of dollars.

It should be noted that this study only covered two seasons and a single project area, longer-term and multi-site data would be needed to generalize findings.

The study also notes the prevalent use of antibiotics, including oxytetracycline and amoxicillin, for disease control. However, this reliance raises concerns about antimicrobial resistance (AMR) and environmental degradation. Other alternatives include vaccination, bacteriophages, quorum quenching, probiotics, and medicinal plant derivatives (Bondad-Reantaso et al., 2023; Rah et al., 2022). These approaches aim to prevent diseases, boost immune function, and maintain water quality without relying on antibiotics. While many of these alternatives are still in the research phase, their potential for supporting long-term sustainability in aquaculture is significant (Defoirdt et al., 2011). Implementing these strategies, along with good aquaculture practices and effective biosecurity measures, could help mitigate AMR risks and promote a more environmentally responsible aquaculture industry (Bondad-Reantaso et al., 2023). This finding aligns with Alhassan et al. (2025) biosecurity recommendations, which emphasize preventive health management and reduced antibiotic dependence to mitigate AMR risks.

4.4 Fish production

The Muhuri Project demonstrated variable fish production across different species combinations, with annual yields ranging from 4–12 tonnes per acre depending on species density, management practices, and environmental factors. Species combination 1, which included a diverse range of fish (e.g., rohu, catla, mrigel, tilapia, and pangas), achieved the highest yield. From an economic standpoint, such polyculture combinations not only increase total yield but also stabilize farmer income by diversifying marketable species, reducing reliance on the success of a single crop. This high production is likely due to polyculture benefits, where species with distinct feeding habits occupy different ecological niches, thus maximizing resource utilization and reducing competition within the pond (Wang & Lu, 2015; Ibrahim & Naggar, 2010). Milstein (1992) explains that selecting fish species with varied ecological functions in polyculture maximizes resource utilization. Species with different feeding behaviors, such as filter feeders and bottom dwellers, use distinct trophic levels, reducing interspecific competition and creating synergistic interactions that improve production outcomes. Wahab et al. (2011) demonstrated that altering fish densities and species combinations in polyculture can enhance fish yields by balancing ecological impacts on the water column and pond bottom, thereby promoting a sustainable and productive system.

5. Conclusion

As water conditions shift between season, fish experience stress, contributing to higher disease incidence and reduce productivity. While the semi-intensive polyculture system is resource efficient, frequent disease outbreaks mostly managed with antibiotics poses ongoing challenges, particularly concerning the risks of developing antimicrobial resistance in fishes as well as the consumers. To achieve more sustainable aquaculture, we recommend improved water quality and proactive health management to prevent seasonal disease outbreaks. Alternative to antibiotics, probiotics, vaccinations, and improved biosecurity measures, could help lower antibiotic use, supporting healthier fish population. Additionally, regular water quality monitoring and optimized stocking densities can reduce stress and help maintain the high productivity. However, this study is limited by its regional focus, which may limit the application of findings elsewhere, and the short data collection period, which constrains having a long-term insight. Future research should explore sustainable disease management options and examine the effects of climate change on aquaculture. Broader studies across different locations and longer timeframes would provide a more complete understanding, contributing to a more sustainable aquaculture sector in Bangladesh and beyond.

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8. Declaration

The authors declare no conflict of interest.

References :

- Ahmed, N., & Garnett, S. T. (2011). Integrated rice-fish farming in Bangladesh: meeting the challenges of food security. *Food Security*, 3(1), 81–92. <https://doi.org/10.1007/s12571-011-0113-8>
- Alhassan, M. Y., Kabara, M. K., Ahmad, A. A., Abdulsalam, J., & Habib, H. I. (2025). Revisiting antibiotic stewardship: veterinary contributions to combating antimicrobial resistance globally. *Bull Natl Res Cent* 49, 25. <https://doi.org/10.1186/s42269-025-01317-3>
- Bhatnagar, A., & Devi, P. (2013). Water quality guidelines for the management of pond fish culture. *International Journal on Environmental Sciences*, 3(6), 1980–2009. <https://www.cabdirect.org/cabdirect/abstract/20133321025>

- Bhowmick, B., & Crumlish, M. (2017). Aquaculture Health Management and Biosecurity Practises In South West of Bangladesh. *Bangladesh Journal of Veterinary Medicine*, 14(2), 263–269. <https://doi.org/10.3329/bjvm.v14i2.31407>
- Bondad-Reantaso, M. G., MacKinnon, B., Karunasagar, I., Fridman, S., Alday-Sanz, V., Brun, E., Groumellec, M. L., Li, A., Surachetpong, W., Karunasagar, I., Hao, B., Dall'Occo, A., Urbani, R., & Caputo, A. (2023). Review of alternatives to antibiotic use in aquaculture. *Reviews in Aquaculture*, 15(4), 1421–1451. <https://doi.org/10.1111/raq.12786>
- Boyd, C. E. (1990). Water quality for pond aquaculture. *Agriculture Experiment Station, Auburn University*. <http://aurora.auburn.edu/handle/11200/49690>
- Boyd, C. E., Tucker, C. S., & Somridhivej, B. (2016). Alkalinity and Hardness: Critical but Elusive Concepts in Aquaculture. *Journal of the World Aquaculture Society*, 47(1), 6–41. <https://doi.org/10.1111/jwas.12241>
- Boyd, C. E. (2017). General Relationship Between Water Quality and Aquaculture Performance in Ponds. In *Elsevier eBooks* (pp. 147–166). <https://doi.org/10.1016/b978-0-12-804564-0.00006-5>
- Caroffino, D. C., Miller, L. M., Kapuscinski, A. R., & Ostazeski, J. J. (2008). Stocking success of local-origin fry and impact of hatchery ancestry: monitoring a new steelhead (*Oncorhynchus mykiss*) stocking program in a Minnesota tributary to Lake Superior. *Canadian Journal of Fisheries and Aquatic Sciences*, 65(2), 309–318. <https://doi.org/10.1139/f07-167>
- Chinthada, S., & Bandla, S. (2021). Studies on Seasonal Variations in Primary Productivity and Related Water Quality Parameters in Freshwater Fish Ponds in Coastal Andhra Pradesh, India. *Global Journal for Research Analysis*, 17–21. <https://doi.org/10.36106/gjra/7409639>
- Chowdhury, M., M. Muniruzzaman, U.A. Zahura, K.Z.A. Habib, & M.D. Khatun. (2003). Ulcer type of disease in the fishes of Small-Scale Farmer's Pond in Bangladesh. *Pakistan Journal of Biological Sciences*, 6(6), 544–550. <https://doi.org/10.3923/pjbs.2003.544.550>
- Das, D. R., & Chandra, K. J. (2018). Seasonal Variation of Gill, Skin, Muscle, Liver and Kidney Pathology of Mrigal (*Cirrhinus Cirrhosus*) In Cultural Pond Fisheries, Mymensingh, Bangladesh. *Bangladesh Journal of Veterinary Medicine*, 16(1), 121–129. <https://doi.org/10.3329/bjvm.v16i1.37389>
- Defoirdt, T., Sorgeloos, P., & Bossier, P. (2011). Alternatives to antibiotics for the control of bacterial disease in aquaculture. *Current Opinion in Microbiology*, 14(3), 251–258. <https://doi.org/10.1016/j.mib.2011.03.004>
- Dey, B. K., Hossain, M. M. M., Bappa, S. B., Akter, S., & Khondoker, S. (2014). Impact of diseases on fish production of baors in Jessore, Bangladesh. *Journal of Fisheries*, 2(1), 70–75. <https://doi.org/10.17017/j.fish.62>
- DOF. (2023). Yearbook of Fisheries Statistics of Bangladesh, 2022-23. Fisheries Resources Survey System (FRSS), *Department of Fisheries; Mintstry of Fisheries and Livestock*, 2023. Volume 40, 138p.

- Duijn, A.P., Heijden, P.V., Bolman, B.C., Rurangwa, E., Meeks, J., Meijberg, A., Nyachwaya, M., Cadogan, T., Kabagambe, J.B., Shoko, A.P., & Rutaisire, J. (2018). Review and analysis of small-scale aquaculture production in East Africa: Summary and Recommendations.
- Edwards, P., & Demaine, H. (1997). *Rural Aquaculture: Overview and Framework for Country Reviews*.
- Evans, J. J., Shoemaker, C. A., & Klesius, P. H. (2003). Effects of Sublethal Dissolved Oxygen Stress on Blood Glucose and Susceptibility to *Streptococcus agalactiae* in Nile Tilapia *Oreochromis niloticus*. *Journal of Aquatic Animal Health*, 15(3), 202–208. <https://doi.org/10.1577/h03-024>
- Faruk, M. A. R., Sarker, M. M. R., Alam, M. J., & Kabir, M. B. (2004). Economic loss from fish diseases on rural freshwater aquaculture of Bangladesh. *Pakistan Journal of Biological Sciences*, 7(12), 2086–2091. <https://doi.org/10.3923/pjbs.2004.2086.2091>
- Fry, J. P., Mailloux, N. A., Love, D. C., Milli, M. C., & Cao, L. (2018). Feed conversion efficiency in aquaculture: do we measure it correctly? *Environmental Research Letters*, 13(2), 024017. <https://doi.org/10.1088/1748-9326/aaa273>
- Hasan, M., Faruk, M., Anka, I., & Azad, M. (2014). Investigation on fish health and diseases in rural pond aquaculture in three districts of Bangladesh. *Journal of the Bangladesh Agricultural University*, 11(2), 377–384. <https://doi.org/10.3329/jbau.v11i2.19944>
- Hasibuan, S., Syafridiman, S., Aryani, N., Fadhli, M., & Hasibuan, M. (2021). The age and quality of pond bottom soil affect water quality and production of *Pangasius hypophthalmus* in the tropical environment. *Aquaculture and Fisheries*, 8(3), 296–304. <https://doi.org/10.1016/j.aaf.2021.11.006>
- Hepher, B., Milstein, A., Leventer, H., & Teltsch, B. (1989). The effect of fish density and species combination on growth and utilization of natural food in ponds. *Aquaculture Research*, 20(1), 59–71. <https://doi.org/10.1111/j.1365-2109.1989.tb00441.x>
- Hossain, M., Islam, K., Hossain, & Rahman, M. (2013). Environmental Impact Assessment of Fish Diseases on Fish Production. *Journal of Science Foundation*, 9(1–2), 125–131. <https://doi.org/10.3329/jsf.v9i1-2.14655>
- Hussainy, S. U. (1967). Studies on the limnology and primary production of a tropical lake. *Hydrobiologia*, 30(3), 335–352.
- Ibrahim, N., & Naggar, G. E. (2010). Water Quality, Fish Production and Economics of Nile Tilapia, *Oreochromis niloticus*, and African Catfish, *Clarias gariepinus*, Monoculture and Polycultures. *Journal of the World Aquaculture Society*, 41(4), 574–582. <https://doi.org/10.1111/j.1749-7345.2010.00397.x>
- Islam, M., Akter, A., Kamrujjaman, M., Siddiq, A., & Aktar, S. (2013). Assessment Of Pond Water Quality of Thakurgaon Sadar Upazila for Fish Production. *International Journal of Agricultural Research Innovation and Technology*, 3(1), 29–34. <https://doi.org/10.3329/ijarit.v3i1.16052>

- Kalita, G. J., Sarma, P. K., Goswami, P., & Rout, S. (2015). Socio-economic status of fishermen and different fishing gear used in Beki River, Barpeta, Assam. *Journal of Entomology and Zoology Studies*, 3(1), 193-198.
- Lakani, B. F., Sattari, M., & Falahatkar, B. (2013). Effect of different oxygen levels on growth performance, stress response and oxygen consumption in 2 weight groups of Great Sturgeon *Huso Huso*. *Iranian Journal of Fisheries Sciences*, 12(3), 533-549.
- Menon, S. V., Kumar, A., Middha, S. K., Paital, B., Mathur, S., Johnson, R., Kademan, A., Usha, T., Hemavathi, K. N., Dayal, S., Ramalingam, N., Subaramaniyam, U., Sahoo, D. K., & Asthana, M. (2023). Water physicochemical factors and oxidative stress physiology in fish, a review. *Frontiers in Environmental Science*, 11. <https://doi.org/10.3389/fenvs.2023.1240813>
- Milstein, A. (1992). Ecological aspects of fish species interactions in polyculture ponds. *Hydrobiologia*, 231(3), 177-186.
- Momota, R., & Ahasan, N. S. M. (2023). Physicochemical Analysis of Water for Assessing the Feasibility of Fish Cultivation in Jessore Municipality Ponds, Bangladesh.
- Munni, M., Fardus, Z., Mia, M., & Afrin, R. (2015). Assessment of Pond Water Quality for Fish Culture: A Case Study of Santosh Region in Tangail, Bangladesh. *Journal of Environmental Science and Natural Resources*, 6(2). <https://doi.org/10.3329/jesnr.v6i2.22112>
- Rahman, M. M., Alam, M. M. M., Khalil, S. M. I., & Sumon, T. A. (2018). Prevalence of Fish Diseases in Different Aquaculture Farms in The North-Eastern Region of Bangladesh.
- Rah, B., Rs, T., & Pk, P. (2022). Alternatives to antibiotics for combating the antimicrobial resistance in aquaculture. *Indian Journal of Animal Health*. <https://doi.org/10.36062/ijah.2022.spl.01322>
- Santhosh, B., & Singh, N. P. (2007). Guidelines for water quality management for fish culture in Tripura. *ICAR research complex for NEH region, Tripura center, publication*, 29(10).
- Satpathy, K. K., Mohanty, A. K., Sahu, G., Sarguru, S., Sarkar, S. K., & Natesan, U. (2010). Spatio-temporal variation in physicochemical properties of coastal waters off Kalpakkam, southeast coast of India, during summer, pre-monsoon and post-monsoon period. *Environmental Monitoring and Assessment*, 180(1-4), 41-62. <https://doi.org/10.1007/s10661-010-1771-2>
- Serder, M. F., Islam, M. S., Hasan, M. R., Yeasmin, M. S., & Mostafa, M. G. (2020). Assessment of coastal surface water quality for irrigation purpose. *Water Practice & Technology*, 15(4), 960-972. <https://doi.org/10.2166/wpt.2020.070>
- Shaker, I., & Abdel-Aal, M. (2006). Growth Performance of Fish Reared Under Different Densities in Semi-Intensive and Extensive Earthen Ponds. *Egyptian Journal of Aquatic Biology and Fisheries*, 10(4), 109-127. <https://doi.org/10.21608/ejabf.2006.1904>
- Shefat, S. H. T. (2018). Nutritional Fish Disease and Public Health Concern. *Poultry Fisheries & Wildlife Sciences*, 06(02). <https://doi.org/10.4172/2375-446x.1000199>

- Tacon, A. G. (1996). Feed formulation and evaluation for semi-intensive culture of fishes and shrimps in the tropics. In *Feeds for small-scale aquaculture. Proc Natl Seminar-Workshop on Fish Nutrition and Feeds. SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines* (pp. 29-43).
- Wahab, M., Kadir, A., Milstein, A., & Kunda, M. (2011). Manipulation of species combination for enhancing fish production in polyculture systems involving major carps and small indigenous fish species. *Aquaculture*, 321(3–4), 289–297. <https://doi.org/10.1016/j.aquaculture.2011.09.020>
- Walker, P. J. (2004). Disease Emergence and Food Security: Global Impact of Pathogens on Sustainable Aquaculture Production. *RePEc: Research Papers in Economics*. <https://doi.org/10.22004/ag.econ.124074>
- Wang, M., & Lu, M. (2015). Tilapia polyculture: a global review. *Aquaculture Research*, 47(8), 2363–2374. <https://doi.org/10.1111/are.12708>
- Wurts, W. A. (2003). Daily pH cycle and ammonia toxicity. *World Aquaculture*, 34(2), 20-21.
- Zhang, F., Zhu, Y., & Zhou, X. (1987). Studies on the ecological effects of varying the size of fish ponds loaded with manures and feeds. *Aquaculture*, 60(2), 107–116. [https://doi.org/10.1016/0044-8486\(87\)90302-4](https://doi.org/10.1016/0044-8486(87)90302-4)



A Review on Sea Snail and its Perspective Towards Blue Economy

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Abstract

Marine resources have wide coastal and marine regions with a variety of bioresources including sea snails that have versatile functions for their various ranges of organic and inorganic bioactive compounds. Sea snail is a key candidate for coastal aquaculture system that has extremely promising opportunities to accelerate blue economy worldwide since it has increasing demand for culinary, biomaterials, cosmoceutical & pharmaceutical industries. According to global market insights, the global snail market size reached USD 647.4 million in 2024 and it's expected to grow from USD 706.7 million in 2025 to USD 1.4 billion in 2034. Therefore, it is high time to study the potentiality of sea snails and increase the production through sustainable farming. Moreover, blue economy has been a buzz word in various sectors of Bangladesh. However, there is absence of comprehensive study regarding sea snail. This review explores the intricate and diverse realm of sea snails, offering detailed insights into their ecological roles, physical characteristics, habitat preferences, conservation concerns, nutritional significance, and pharmaceutical potentials. It underscores the ecological importance of sea snails while confronting the increasing challenges they face within marine ecosystems. The current work will be a future direction for researchers, conservationists, and ecologist to explore different research areas for sea snail species. Moreover, such a review would provide critical insights for advancing the development and commercialization of sea snail based biomaterials, contributing to more sustainable, blue economy of the country.

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1. Introduction

The Earth's oceans, encompassing over 70% of the planet's surface, constitute a realm of extraordinary biodiversity. Among its myriad inhabitants, gastropod mollusks, commonly known as sea snails, represent a class (Gastropoda) of profound ecological significance. Snails are used as food either as fresh, canned, frozen, or dried for having high protein, unique texture, and other health benefits like being an oxidant, collagen, and amino acids source. Blue Economy is a marine based economy that strengthens the economic backbone of the country by rational utilization of marine resources (Mitra, Zaman, & Pramanick, 2022). Regionally, the Asia Pacific leads the market share followed by France, Spain, and Italy, which have long-consumed snails both for

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culinary and cosmetic uses. North America and Europe are also emerging regions owing to innovation in snail-derived products and the growing concern for sustainable and green production. There is also an increase in the use of snails for natural fertilizers, pet foods and other agriculture activities, which marks diversification in the market (Bouwman et al., 2011; Munywoki, 2022). About 7000 marine natural products (MNPs) were discovered from aquatic invertebrates such as leconotide from Marine snails which have various activities including antiaging, anti-analgesic activity (Ibrahim, Abdelnaby, Abouelkheir, Abo-Taleb, & Sersy, 2023). Recently, Bangladesh is focusing on blue economy aspects where the marine resources will play key role to accelerate the country's GDP. Therefore, sea snails become a good candidate to explore since it has multidisciplinary applications.

Sea snails ubiquitous across marine environments – from sunlit coral reefs and productive intertidal zones to the crushing depths of abyssal plains and hydrothermal vents – they exhibit unparalleled adaptability (De Kock et al., 1989). With estimates exceeding 60,000 described species and many more awaiting discovery, sea snails are a testament to evolutionary success and marine diversification (Johnson et al., 2015; Lambert, 2019). The ecological roles performed by sea snails are fundamental to the structure, function, and resilience of marine ecosystems. As primary consumers, many species are voracious grazers on micro- and macro-algae, directly controlling algal biomass and preventing overgrowth that could smother corals or seagrasses (Collier et al., 2016). Others act as vital detritivores, scavenging decaying organic matter and facilitating nutrient recycling within benthic food webs. Certain groups are adept burrowers, bioturbating sediments and enhancing oxygen penetration and microbial activity. Predatory sea snails regulate populations of prey species like bivalves, barnacles, and other invertebrates, while simultaneously serving as a crucial food source for higher trophic levels including fish, birds, and marine mammals (Bogan & Roe, 2008; Butler & Estrada, 2008). Collectively, these diverse behaviours—grazing, scavenging, predation, and bioturbation—contribute indispensably to nutrient cycling, habitat structuring, and the maintenance of overall ecosystem dynamics and energy flow (Duarte et al., 2022). Sea snails play important roles in different aspects including ecological, economical and industrial fields (Fig 1). The importance of sea snails transcends their ecological functions. Taxonomically, they serve as vital models for understanding evolutionary processes, speciation, and biogeographic patterns across the marine realm (Crocetta et al., 2015; Johnson et al., 2015).

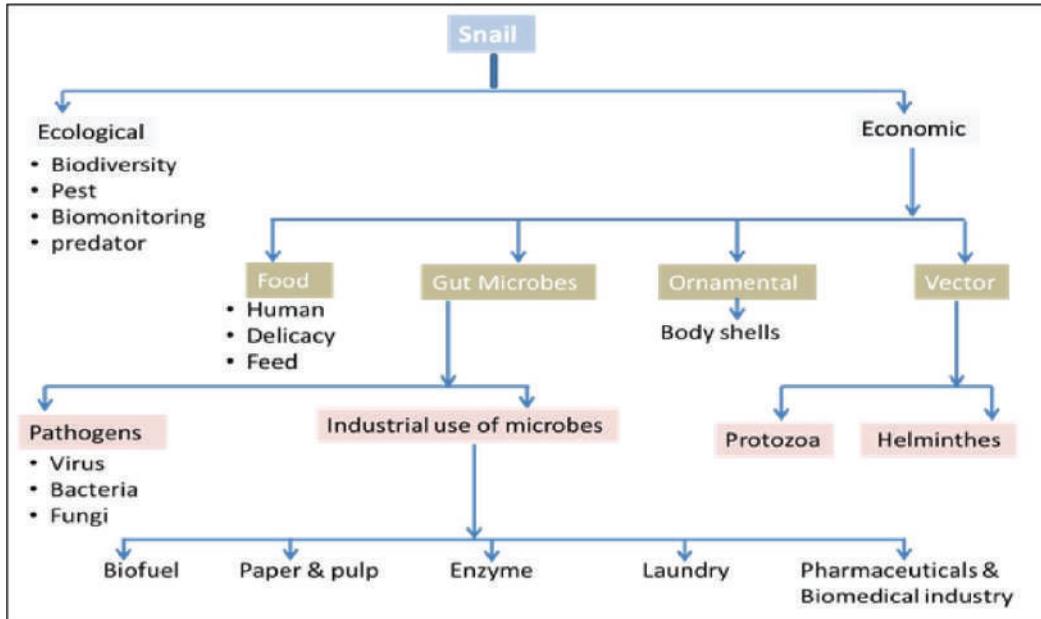


Figure 1. Ecological, economical, pathogenic hosting and industrial application of sea of snail

Their unique morphological and physiological adaptations, such as the biomechanics of shell formation, the efficiency of their radular apparatus, or their tolerance to extreme conditions (e.g., hydrothermal vents), inspire research in biomimicry and offer potential for biotechnological applications. Economically, numerous sea snail species underpin valuable fisheries and aquaculture industries globally (Cowie, 1995). Iconic species like abalone (*Haliotis* spp.), queen conch (*Lobatus gigas*), and whelks (*Buccinum* spp.) are harvested intensively for their prized meat, decorative shells, and in some cases, pearls, providing critical livelihoods and food security for coastal communities and contributing significantly to international seafood markets. Culturally, sea snails hold deep significance, featuring prominently in the art, mythology, folklore, and traditional practices of diverse societies worldwide; their shells have historically served as currency, adornment, ritual objects, and artistic mediums (Dhiman & Pant, 2021).

Despite their ecological, scientific, economic, and cultural value, sea snails face escalating anthropogenic threats that imperil their populations and the integrity of the ecosystems they support. Habitat destruction and degradation, driven by coastal development, destructive fishing practices (e.g., bottom trawling), and pollution (including plastics, heavy metals, and nutrient runoff), directly reduce available niches and alter community structures (Collier et al., 2016). Overexploitation through unregulated or unsustainable harvesting for food, the ornamental shell trade, and curios has driven numerous species towards local extirpation or global endangerment. Furthermore, the pervasive impacts of climate change — manifesting as ocean warming, acidification, deoxygenation, and altered current patterns—pose severe

physiological stresses, disrupt reproductive cycles, impair shell formation (especially under acidified conditions), and shift species distributions (Collier et al., 2016). These cumulative pressures jeopardize not only the survival of individual species but also the stability and resilience of entire marine ecosystems and the services they provide to humanity (Parkyn & Newell, 2013).

Moreover, heliciculture is pivotal to providing an uninterrupted supply of snails to fulfill the demands of food or feed industries. Consequently, a comprehensive understanding of sea snail biology, ecology, current conservation status, and future prospects is not merely an academic pursuit but an urgent imperative (Beltramino et al., 2015; Bogan & Roe, 2008). Recent technological advancements in molecular genetics, deep-sea exploration, and remote sensing, coupled with a resurgent scientific appreciation for their ecological centrality, have revitalized research efforts (Schweizer et al., 2019). However, there is no such comprehensive review to study sea snails thoroughly. This review synthesizes current knowledge on the classification, morphological diversity, physiological adaptations, habitat requirements, and complex ecological interactions of sea snails. It critically examines the multifaceted threats they confront and evaluates ongoing conservation strategies by integrating insights from taxonomy, ecology, physiology, and conservation science, and identifying critical knowledge gaps to prioritize future research horizon. This review aims to illuminate the fascinating world of sea snails, underscore their irreplaceable roles in maintaining ocean health and biodiversity, and catalyze effective, science-based actions to ensure their persistence and the integrated role in blue economy.

2. Taxonomy and Morphology of the Sea Snail

The term comes from the Latin word molluscus, which means soft body. It is the second biggest invertebrate phylum after the Arthropoda, with over 400,000 species (Brown & Lydeard, 2010).

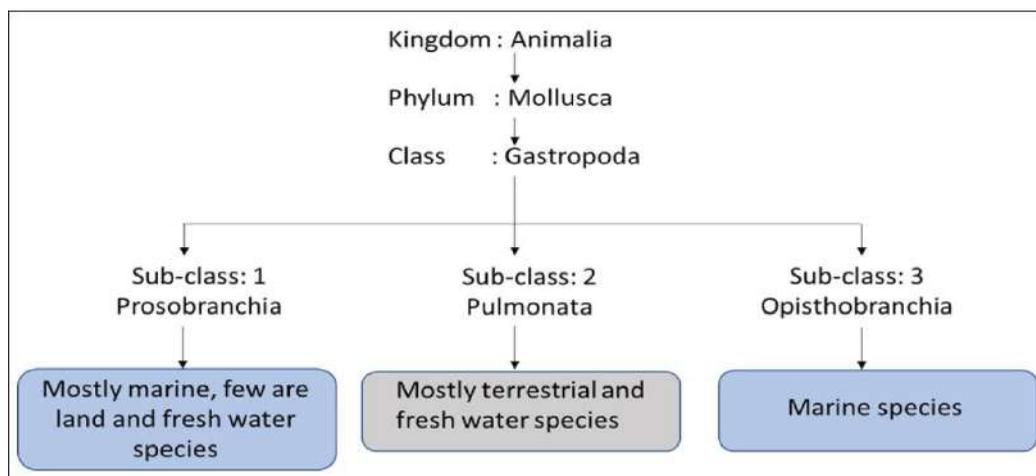


Figure 2: Classification of Snail

Sea snails, a diverse group of mollusks belonging to the class Gastropoda, which is further sub classified into three groups (Fig 2): Prosobranchia (mostly marine and few are fresh water or land dwellers), Pulmonata (mostly terrestrial and fresh water) and Opisthobranchia (marine species) (Ibrahim et al., 2021). Sea snails exhibit remarkable morphology and adaptations that enable them to thrive in various marine habitats. Sea snails have a muscular foot used for locomotion, attachment to substrates, and grazing on surfaces (Ravinet, 2018). The head region contains sensory organs (tentacles with eyes) and the mouth, equipped with a radula (rasping tongue) used for feeding (Fig.3). Internal organs, includes digestive, reproductive, and respiratory systems, protected by the shell. Sea snail shells vary widely in shape, ranging from conical (e.g., cone snails) to coiled (e.g., spiral shells of many gastropods) or flattened (e.g., limpets) (Berger & Kharazova, 1997). Shells are typically composed of calcium carbonate and may be smooth, ribbed, spiny, or ornamented, providing protection against predators and environmental stresses (Chiba, 2009). The opening of the shell (aperture) may have specialized structures (e.g., operculum in some species) for sealing the shell when the snail withdraws into it (Ravinet, 2018). These snails ranged in size from small to medium-sized. An adult *Acmea nana*, measuring just 0.79 millimetres, is the tiniest known snail in the entire world. The *Achatina achatina*, an African giant snail, is the largest known land gastropod. The largest specimen measured 39.3 cm in length from snout to tail when fully stretched, and its shell was 27.3 cm (Ibrahim et al., 2021). Their iconic coiled shells, far from mere aesthetic features, serve as critical protective armor against predation and environmental stressors, while also facilitating buoyancy control in pelagic species. However, their biological sophistication extends far beyond the shell; specialized radulae for diverse feeding modes, complex reproductive strategies encompassing both broadcast spawning and brooding, and refined sensory systems enabling navigation and chemoreception underpin their ecological dominance (Giokas et al., 2005a; Ravinet, 2018).

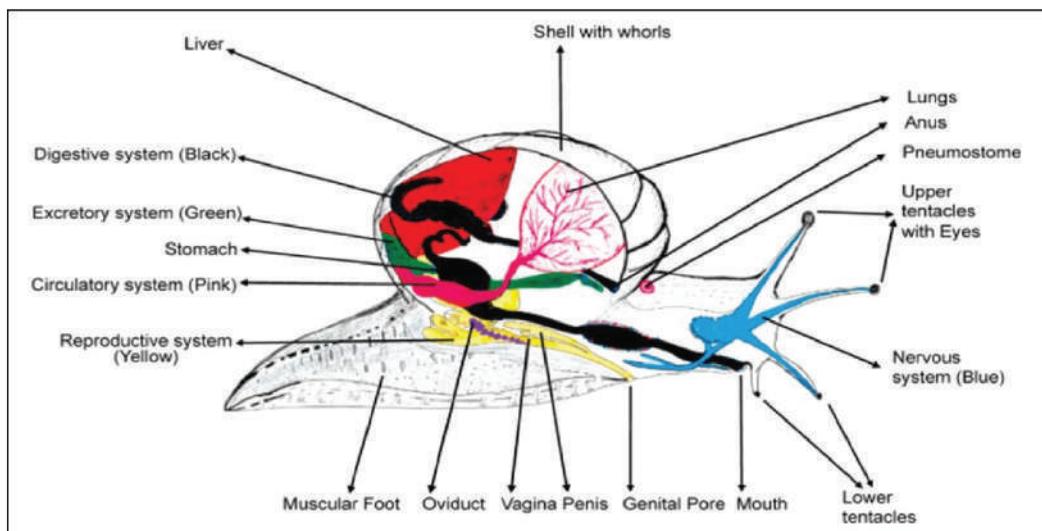


Figure 3: Significant body parts of snail (adapted from Gupta & Khanal, 2024).

3. Distribution and Physiological Adaptations of Sea Snail

Mollusca live on all continents except Antarctica. They lived in a variety of ecosystems, including terrestrial, marine, and freshwater habitats, but their diversity and distribution patterns differed among regions (Ibrahim et al., 2021). These preferences are affected by factors such as environmental conditions, substrate type, food availability, and interactions with other organisms (Evans et al., 2011). Marine mollusks comprised around 23% of all marine species (Wolfe et al., 2025).

Many sea snail species appear on intertidal zones, where they are revealed to alternating periods of submersion and emersion due to tides. Intertidal sea snails may be adapted to face desiccation and wave action also some species preferring rocky shores (e.g., limpets) and others favoring sandy or muddy substrates (Kiko et al., 2008). Numerous sea snail species dwell in subtidal zones, extending from shallow coastal waters to deeper offshore environments. Different subtidal habitats endeavor a diverse range of substrates which include reefs, seagrass beds, and soft sediments, each hosting specific snail swarms adapted to local conditions (Ng et al., 2017). Specifically certain sea snail species are closely connected with coral reefs, where they play roles in grazing algae, swallowing coral polyps, and contributing to reef dynamics (Beltramino et al., 2015). Moreover snails in reef environments may exhibit specialized adaptations to navigate complex reef structures specifically to interact with other reef-dwelling organisms (De Kock et al., 1989).

More precisely sea snails have a worldwide distribution, occupying diverse marine and freshwater habitats across different latitudes and oceanic regions. As a result distribution patterns of sea snails are influenced by ocean currents, temperature gradients, and biogeographic barriers (Beltramino et al., 2015). Therefore snail populations can vary in abundance and diversity within specific habitats due to localized factors such as predation pressure, competition, and habitat complexity (De Kock et al., 1989).

Powerful foot muscles enable sea snails to crawl or glide over substrates, using mucus for lubrication and adhesion. Certain sea snails possess an operculum, a hard plate that can seal the shell opening to protect the soft body during retraction (Ravinet, 2018).

A specialized feeding structure unique to mollusks, the radula is a ribbon-like structure with rows of tiny teeth used for scraping algae, detritus, or prey from surfaces (Yamamori & Kato, 2018). Herbivorous sea snails have adaptations for grazing on algae or plant material, while carnivorous species may have venomous harpoons or proboscises for capturing prey (Kiko et al., 2008). The shell provides physical protection against predators, with some species having thick or spiny shells to deter predators. Certain sea snails produce toxic compounds or secrete defensive mucus to deter predators (Chiba, 2009). Sea snails typically have gills for gas exchange, adapted to extract oxygen from water. Many sea snails are simultaneous hermaphrodites, possessing both male and female reproductive organs, facilitating efficient mating.

Some snails produce protective egg capsules that may be attached to surfaces or released into the water column (Chiba, 2009). Some sea snails are nocturnal, reducing exposure to diurnal predators. Burrowing sea snails can retract into substrates for protection during low tide or to avoid predators (Hollander et al., 2006; Ravinet, 2018). Sea snails exhibit adaptations to specific temperature ranges, with some species inhabiting intertidal zones that experience temperature fluctuations (Kiko et al., 2008). Sea snails showcase a range of morphological features and adaptations that highlight their evolutionary diversity and ecological versatility. These adaptations enable sea snails to occupy diverse marine habitats, from rocky shores and coral reefs to deep-sea environments, contributing to their ecological success as important components of marine ecosystems (Chiba, 2009; Yamamori & Kato, 2018).

3. Major Threats to Sea Snails

Comprehensive conservation assessments for many sea snail species remain hindered by limited data availability and insufficient research efforts. Despite these knowledge gaps, numerous species are classified as threatened or endangered, primarily due to documented population declines and habitat loss. These endangered populations encounter substantial threats, including overexploitation driven by the shell trade, habitat destruction, pollution, and the escalating impacts of climate change (Lambert, 2019). Anthropogenic habitat degradation is a significant pressure, with coastal development—encompassing urbanization, industrial activities, and infrastructure expansion—leading directly to habitat destruction and fragmentation (Lai et al., 2015). Furthermore, targeted commercial exploitation for purposes such as the shell trade, traditional medicine, or food consumption poses a severe risk, particularly to slow-growing or low-density species; overharvesting can rapidly deplete populations and disrupt ecological balances (Dhiman et al., 2020). Marine pollution, originating predominantly from land-based sources (e.g., sewage discharge, agricultural runoff, plastic debris), exerts negative impacts through water contamination and broader habitat degradation, adversely affecting sea snail health, reproductive success, and ecosystem function (Dang et al., 2015). Concurrently, climate change presents profound challenges through rising sea temperatures, ocean acidification, and altered current patterns. These changes threaten sea snails directly and indirectly, notably by degrading essential habitats such as coral reefs, which are highly vulnerable to climate-related stressors and host numerous reef-associated snail species (Malhi et al., 2020). Finally, the introduction and proliferation of invasive marine species, including predatory or competing snails, can disrupt native snail populations and alter critical ecological interactions (Beltramino et al., 2015).

4. Ecological Role of the Sea Snail

Sea snails, a diverse group of gastropod molluscs, execute various ecological functions within marine ecosystems (Floyd et al., 2020). A major percentage of species act as herbivores, grazing on epilithic algae, seagrass, or coral reef substrates. This feeding

strategies regulates algal growth, preventing blooms that would otherwise suffocate the host organisms like corals and seagrasses, thereby maintaining ecological balance and promoting biodiversity (Ravinet, 2018). Furthermore, certain species contribute to seed dispersal; ingested fruits or seeds deposited after passage through the digestive system facilitate the spread and colonization of marine plants in new areas (Simonová et al., 2016). Burrowing species, such as members of the Naticidae family, enhance sediment dynamics through bioturbation. Their activities aerate substrates, promote nutrient cycling, and redistribute organic matter, significantly influencing benthic community structure and composition (Zheng et al., 2011). Additionally, the calcium carbonate shells produced by sea snails constitute vital habitat structures. Accumulations of these shells on the seafloor form complex microhabitats and shell beds, providing essential refuge and substrate for colonization by diverse organisms including small invertebrates, bacteria, and algae (Rick, 2024; Tluste & Birkhofer, 2021). Sea snails also represent a crucial trophic link, serving as prey for numerous predators such as fish, crabs, and birds; their abundance and distribution directly impact predator populations and broader food web dynamics (Ellis et al., 2005). Notably, predatory snails, including species within the Muricidae family, play important control over populations of coral-devouring crown-of-thorns starfish (*Acanthaster* spp.), mitigating outbreak impacts and contributing to coral reef health and resilience (Cowan et al., 2017; Kayal et al., 2012). Finally, the presence, abundance, and condition of specific sea snail populations serve as valuable bioindicators, reflecting environmental changes such as shifts in water quality, temperature regimes, or habitat degradation (Min et al., 2022). Collectively, these diverse roles—spanning herbivory, nutrient cycling, habitat engineering, trophic interactions, and environmental indication—underscore the integral contribution of sea snails to the structure, function, and conservation of marine environments (Bishop et al., 2017).

5. Nutritional Value of Sea Snail

Snail meat is recognized as a nutritionally valuable food source. Proximate analysis (Ab Lah et al., 2017) shows it constitutes high-protein, low-fat dietary, and minerals contributes to its popularity as a food worldwide. The quality of snail meat is similar to conventional meat sources (Anthony et al., 2010). A comparative meat value from various sources along with sea snails has shown in Table 1. Beyond direct human consumption, snails offer economic advantages in farming due to efficient feed conversion – approximately half a kilogram of feed can yield one kilogram of consumable giant snail meat (Sika Piba et al., 2015). Snail farming is gaining popularity as an alternative to traditional livestock farming due to its short duration of growth, lower investment, and minimal space requirements with higher profitability (Munywoki, 2022). In livestock farming, feed conversion ratio (FCR) is one of the most critical components of livestock management. Sea snails (*Rapana* species) have FCR of 4.7–6.3 whereas 6.0–10.0 for beef, 2.7–5.0 for pigs and 5–6 for sheep which

demonstrate the higher efficiency of sea snails for feed conversion (Bouwman et al., 2011; Fry, Mailloux, Love, Milli, & Cao, 2018).

Furthermore, byproducts like powdered snail shell serve as a valuable calcium source in animal feeds for cattle, small animals, broilers, and layers (Gupta & Khanal 2024). Some sources also attribute therapeutic benefits to snail flesh. However, it is important to note that various studies have detailed potential microbiological and toxicological hazards to human health associated with consuming snail meat and its byproducts (Hatzioannou, et al., 2014; Nkansah et al., 2021).

Table 1: Food value of Snail meat compared to other meats (Acham et al., 2018)

Food Items	Carbohydrate	Protein	Fat	Ash	Water
1.Snail Meat	2.93	20.7	1.21	1.49	73.7
2.(a)Beef	--	17.5	22.0	0.9	60.0
(b)Pork	--	11.9	45.0	0.6	42.0
(c)Lamb	--	15.7	27.7	0.8	56.0
3.Poultry					
(a)Chicken	--	20.2	12.6	1.0	81.8
(b)Duck	--	16.2	30.0	1.0	68.6
(c)Turkey	--	20.2	20.2	1.0	79.3
(d)Dried fish	--	60.0	21.0	15.0	4.0
4.Milk					
(a) Cow (whole milk)	5.0	3.5	3.8	0.7	87.3
(b) Goat	4.5	3.8	4.8	0.8	86.4
5.Eggs					
(a)White of egg	10.5	Small amount	1.0	88.0	
(b)Yolk of egg	15.5	33.5	1.0	49.5	

6. Pharmaceutical and Biomedical Potential of Sea Snail

The pharmaceutical and cosmetic industries are in continuous pursuit of novel bioactive molecules to develop formulations that are safe and non-toxic for human use. In this context, sea snails represent a valuable source, as their hemolymph and other tissues contain diverse bioactive compounds, including glycans, peptides, and other molecules (Dhiman & Pant, 2021a). Snail extracts typically consist of glycans, proline-rich antimicrobial peptides with glycopeptides, hemocyanins, lectins, allantoin, and glycolic acid. A landmark achievement was the 2004 U.S. Food and Drug Administration (USFDA) approval of ziconotide (Prialt), the first marine-derived medication, for pain treatment (Pope & Deer, 2013). This synthetic compound, analogous to the naturally occurring ω -conotoxin MVIIA peptide, blocks N-type calcium channels. Originally isolated and refined from the venom of the fish-hunting marine snail *Conus magus*, ziconotide represents an analgesic with an innovative mechanism of action (Mayer et al., 2010). Marine snails (gastropods) are increasingly

valuable models in biomedical research (Pati et al., 2015). Like all marine organisms, they harbor potential for producing antimicrobial secondary metabolites—such as sterols, polypropionates, alkaloids, terpenes, fatty acid derivatives, and macrolides (Dang et al., 2015; Kaviarasan et al., 2012)—which, along with fungal extracts, exhibit diverse pharmaceutically relevant bioactivities. These include anticancer, antibiotic, antiviral, antimicrobial, antioxidant, antibiofilm, larvicidal, snailicidal, antiaflatoxicogenic, neurotoxic, and anti-inflammatory properties (Ibrahim et al., 2021). However, secondary metabolites have been investigated in only a tiny proportion (<1%) of molluscan species (Benkendorff, 2010; Benkendorff, et al., 2015). *Aplysia californica* serves as an excellent neurological model due to its simple brain, large, positionally defined nerve cells, and identifiable synaptic connections facilitating studies on learning and memory (Akhmedov et al., 2014). Antimicrobial activity against bacterial and fungal strains is demonstrated by crude tissue extracts from *Babylonia spirata* (Periyasamy et al., 2012). Antiviral properties are prominent, often attributed to glycopeptides or peptides within extracts (Dang et al., 2015). Examples include *Buccinulum corneum* Kellletin A inhibiting viral transcription and DNA/RNA synthesis (Ibrahim et al., 2021), acidic extracts from whelks acting against human viruses (Defer et al., 2009), Littorerin (from *L. littorea*) exhibiting antiviral and antibacterial properties, aqueous extracts of abalone (*Haliotis laevis/rubra*) showing activity against poliovirus, influenza A virus, and polyomavirus (Benkendorff, 2010), and *Tegula gallina* extracts displaying antibacterial and antiviral activities (Dang et al., 2015). Furthermore, the Muricidae family, historically known for producing the dye Tyrian purple used in traditional remedies, yields extracts with antibacterial, anti-inflammatory, anticancer, muscle-relaxing, and analgesic properties (Benkendorff, et al., 2015). Beyond their pharmaceutical potential, sea snails are a source of gelatin. This unique protein fraction has been investigated for its functional properties as a potential emulsifier, stabilizer, or foaming agent (Zarai et al., 2011). Gelatin characteristics of snails have comparatively at good candidacy than other mammalian or marine species (Pissia et al., 2021). The immunostimulatory properties of molluscan hemocyanins are attributed to their highly unique monosaccharide compositions. Hemocyanin derived from *Rapana venosa*, for instance, comprises at least 28 distinct heterogeneous mixtures of glycan structures. This structural complexity underpins its significant antiviral activity, primarily inhibiting viral transcription or preventing virus adhesion against human pathogens (Dolashka-Angelova et al., 2009). The diverse medical and biomedical applications of sea snail-derived compounds, including conotoxins, are summarized in Figure 4.

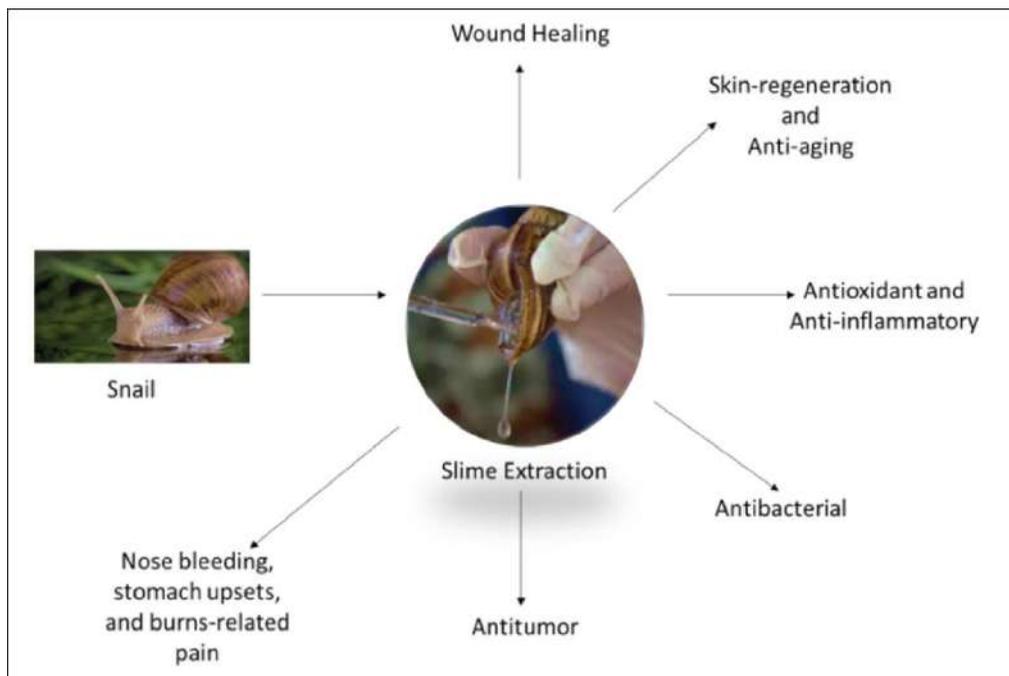


Figure 4: Different medical and biomedical applications of sea snail

There are approximately 500 species of predatory cone snails within the genus *Conus*. It has been estimated that the venom of each *Conus* species has between 50 and 200 components. These highly constrained sulfur rich components or conotoxins represent a unique arsenal of neuropharmacologically active peptides that have been evolutionarily tailored to afford unprecedented and exquisite selectivity for a wide variety of ion-channel subtypes (Jones & Bulaj, 2000). With over 850 species of cone snails, each with unique venom concoctions, cone snail venom is a valuable source of novel pharmacological probes and potential drug leads, nicotinic acetylcholine receptors (nAChRs), and the most ubiquitous venom components across the *Conus* genus. Ligands of nAChRs are clinically important for addiction, cognitive disorders, neurodegenerative diseases, and pain (Grandal, 2020).

The marine snail *Conus magus* employs venom to immobilize prey. This venom contains conotoxins, peptides characterized by internal disulfide bonds. Conotoxins exert their effect by targeting neurological pathways, evidenced by their ability to cause paralysis in humans (Becker & Terlau, 2008). Due to this specific neural targeting, several conopeptides are now under investigation as potential analgesics for treating neuropathic pain (Layer & McIntosh, 2006). Various sea snails have diverse biomedical applications of with their promising bioactive compounds (Table 2).

Table 2: Bioactive compounds and biomedical applications of sea snail

Sl No.	Scientific Name of sea snails	Active compound	Use/Application	Reference
1.	<i>Aplysia californica</i>	Aplysianins, Dolabellinin, Cyplasin	These glycoproteins exhibit antitumor and bactericidal activity.	(Akhmedov et al., 2014)
2.	<i>Babylonia spirota</i>	CRiSPs and metalloproteinases,	Tissue extract of this species showed antimicrobial activity against bacterial and fungal strains.	(Periyasamy et al., 2012)
3.	<i>Buccinulum corneum</i>	Kelletin A	An antiviral extract which inhibits viral transcription and DNA/RNA synthesis (i.e., by inhibition of virus DNA polymerase α and reverse transcriptases)	(Benkendorff et al., 2015)
4.	<i>Buccinum undatum</i>	SPE fraction	Entire organism demonstrated antiviral activity.	(Ibrahim et al., 2021)
5.	<i>Haliotis laevis</i> and <i>Haliotis rubra</i>	Hemocyanin	Aqueous extract has antiviral activity against polyomavirus, influenza A virus, and poliovirus.	(Benkendorff, 2010)
6.	<i>Littorina littorea</i>	Littorein	Peptide extract from whole organism showed antiviral activity	(Ibrahim et al., 2021)
7.	<i>Rapana venosa</i>	Hemocyanin	Showed antiviral activity by preventing virus of the attachment to cells and inhibited the replication of Epstein-Barr virus and Herpes simplex virus type 1.	(Benkendorff et al., 2015)
8.	<i>Tegula gallina</i>	Hemocyanin	Their extracts showed antiviral activity.	(Dang et al., 2015)
9.	<i>Haliotis rufescens</i>	Omega-3 and Omega-6 fatty acids	Important for heart health, brain function, and reducing inflammation.	(Benkendorff, 2010)
10.	<i>C. geographus</i>	Contulakin-G σ -GVIIIA	Its venom contains the Con-Ins G1 receptor, which binds to the human insulin receptor and shows promise for improved diabetes treatment. Helps in N-methyl-D-aspartate receptor blockade and act as a neuroprotection agent.	(Olivera et al., 2017)

11.	<i>C. ermenius</i>	δ -EVIA	Helps in sodium channel activity blockade in mammals and used in neuro related health issues.	(Catterall and Swanson, 2015)
12.	<i>C. victoriae</i>	α -Vc1.1	Known for its antinociceptive activity and used to cure chronic visceral pain.	(Krishnarjuna, et al., 2023)
13.	<i>C. marmoreus</i>	μ O-MrVIB Xen2174	A hydrophobic peptide known for its Na ⁺ current blockade in neural ganglia of mammals and mollusks. It interferes with norepinephrine mechanism in organism's body, known for its allodynic activity.	(Prashanth, et al., 2014)
14.	<i>C. striatus</i>	μ -SIIIA	Blocks the sodium ion conductance by inhibiting voltage gated sodium channel, having analgesic properties	(Wang et al., 2006).
15.	<i>C. radiatus</i>	Contryphan-R	This peptide causes central nervous system stimulation of mammals and plays its role in excitotoxic shock response in CNS.	(Pallaghy, et al., 1999)
16.	<i>C. tulipa</i>	ρ -TIA	Act as antagonist that target mammalian receptors, helps in developing inhibitor drugs for diseases treatment.	(Dutt, et al., 2019)
17.	<i>C. textile</i>	Conus Peptide	These peptides show its potency in central nervous system of mammals, thus have therapeutic potential.	(Tayo, et al, 2010)
18.	<i>C. spurius</i>	Conorfamide	This peptide blocks the voltage dependent K ⁺ ions in the brain and plays important role in regulation and modulation of pain, weight and food consumption.	Campos-Lira, et al., 2017)
19.	<i>C. magus</i>	Conodipine ω -MVIIA	It shows catalytic action and target enzymes on specific sites. Highly active peptide toxin that acts as calcium channel inhibitor helps in cancer pain treatment.	(Layer & McIntosh, 2006)

20.	<i>Conus regius</i>	α -conotoxin	Significant medical potential for the treatment of cancer and addiction.	(Margiotta, et al., 2022)
21.	<i>Cenchritis muricatus</i>	Cm-p1	This peptide fragment possesses notable physicochemical properties and shows strong potential as an antifungal agent.	(López-Abarrategui, et al., 2015)

Research insights, gained from studying of natural products, the peptidic components of cone snail venoms have multiple medical applications (Olivera et al., 2017). μ -conotoxins identified from the fish-hunting cone snails *Conus geographus* (μ -conotoxin GIIIA, GIIIB and GIIC) and *C. purpurescens* (μ -conotoxin PIIIA) are capable of occluding the outer pore of sodium channels, and compete with TTX and STX to bind the site I within the P-loop region of α subunit. The former three conotoxins preferentially block the skeletal muscle-type but not neuronal VGSCs (Wang et al., 2006).

7. Potential applications of Sea Snail Shell

In the last decade, research on snail shells has grown almost exponentially. They have been the basis for certain study in biology, chemistry, and engineering. A significant environmental hazard with little to no economic value is posed by snail shells, which are the bio-shell debris that is abandoned from restaurants, eateries, or snail vendors. Researchers are in a race to develop value-added products from natural renewable sources and discarded waste materials. Therefore, using snail shells effectively can result in great economic gain (Fig 5). Snail shells have been used to cleanse wastewater and purify aqueous solutions (Buranyi, 2015). They have been employed to create biomaterials and bio fertilizer (Kolawole et al., 2017). They are commonly utilized as reinforcing phases in the manufacture of composite materials. Other industries that use snail shells as engineering raw materials include chemical, construction, and automobile (Ferguson et al., 2018).

To produce metal matrix composites (MMCs) with thermal resistance for use in automobile components like pistons and connecting rods, snail shells provide an appropriate reinforcement material. (Das et al., 2023) investigated the process of optimizing biodiesel production using farm waste (Snail Shell) as a highly active nano-catalyst. In their work, they described the trans-esterification of soyabean oil to biodiesel.

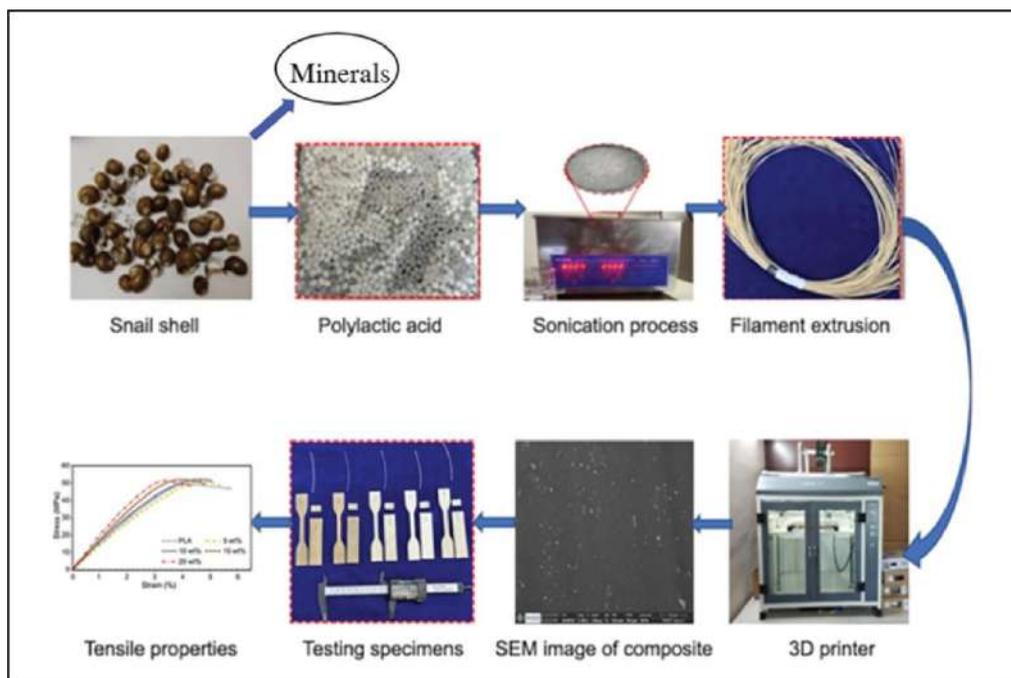


Figure 5: Advancements of reusing the snail shells for value added products (modified from Thamilarasan & Kamaraj, 2025).

These shells have demonstrated potential in a wide range of applications, including in biomedicine, construction, environmental remediation, and agriculture. Snail shell powder-filled polylactic acid composites: filler content and mechanical properties using simple calcium oxides nano-catalysts derived from snail shells by dehydration and sequential calcination (Gupta & Khanal, 2024). The need for new sustainable engineering materials using polymer composites is evolving every day. Interestingly, sea snail *Pomacea lineata* was of interested in bone engineering or substitution (Clarke & Walsh 2014). Additionally, Snail shells can be used as fillers in the paper industry to improve the paper capacity or in the cosmetic industries as face powder (Tobins, et al., 2018).

8. Future Prospects of Sea Snail

Sea snails are fundamental components of marine ecosystems, playing diverse and critical ecological roles. Their distribution patterns, habitat preferences, and interactions with other marine organisms highlight the intricate and interconnected nature of marine biodiversity. They contribute to nutrient cycling, serve as food sources for various predators and along with playing role in food industry, biomaterials, pharmaceuticals and cosmoceuticals industry and thereby influencing economy of the country. However, there are many horizon to explore that can be considered as research areas such as threatened by various conservation challenges specific causes of habitat loss, pollution, overexploitation for commercial purposes, introduction of

invasive species, and the impacts of climate change pose significant risks to sea snail populations worldwide. To address these challenges and ensure the conservation and sustainable management of sea snail populations, a multifaceted approach is required. This approach involves coordinated efforts across scientific, management, and policy domains. Through extensive research and monitoring, scientists can deepen their understanding of sea snail ecology, population dynamics, and responses to environmental stressors. This knowledge serves as the foundation for evidence-based conservation strategies aimed at mitigating threats and promoting the recovery of sea snail populations. Key conservation measures include prioritizing habitat protection through the establishment of marine protected areas, implementing sustainable resource management practices to prevent overharvesting, and fostering community engagement to promote stewardship of marine ecosystems. Education and outreach initiatives can enhance public awareness about the importance of sea snails and their role in maintaining marine biodiversity. Future research directions should focus on population studies to assess the status of different sea snail species, conduct ecological assessments to identify critical habitats and potential conservation priorities, investigate strategies for enhancing climate change resilience, and explore innovative conservation technologies such as artificial habitats or breeding programs. Engagement with local communities and collaboration with international stakeholders are essential components of successful conservation efforts. By integrating scientific knowledge with practical conservation actions and increasing community involvement, we can ensure the long-term conservation of sea snails and their habitats for the benefit of future generations. Protecting sea snails is not only vital for preserving marine ecosystem health but also contributes to broader goals of biodiversity conservation and sustainable economic development.

Sea snails contribute to the blue economy as a food source, a material for crafts and jewelry, and as a resource for biotechnology and waste management (Heller & Kurts, 2015). Their shells can be repurposed into calcium supplements, construction materials, and catalysts for biodiesel production, while some species are harvested for food, supporting aquaculture and traditional industries. Sea snails' ecological roles as consumers and nutrient recyclers in marine ecosystems also support overall ocean health, a fundamental aspect of a sustainable blue economy.

The familiarity and popularity of sea snail for multiple purposes in Bangladesh is still at low scale though the trade market is increasing worldwide. Invertebrate welfare is an issue that has not gained much attention within the effective altruism community regarding studying snails. Further research may uncover specific welfare measures on behalf of these animals. Other important causes might be misconception of snail consumption and the lack of sustainable management of seafood market. Furthermore, scientific literature and official data on snail farming and collection are remarkably scarce.

By working together to implement effective conservation measures and promote environmental stewardship, we can strive towards a future where sea snails thrive in healthy, resilient marine environments, supporting the intricate web of life that sustains our planet. The development of pharmaceutical products from marine natural resources has seen a notable resurgence. As the potential of snails as an alternative source of feed for animals is promising, future research efforts are necessary to heliculture (Segade et al., 2011) ensure the safe and responsible use of snails for the benefit of human, animal, and environmental health. Future research must focus on filling the gaps by undertaking comprehensive studies that consider all applications, assess environmental and economic impacts, and investigate novel processing technologies of sea snails. This will assist in realizing the full potential of sea snail and contribute to their integration into a blue economy, providing a sustainable alternative to traditional materials in several industries.

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References :

- Ab Lah, R., Smith, J., Savins, D., Dowell, A., Bucher, D., & Benkendorff, K. (2017). Investigation of nutritional properties of three species of marine turban snails for human consumption. *Food Science & Nutrition*, 5(1), 14–30. <https://doi.org/10.1002/fsn3.360>
- Acham, I. O., Kundam, D. N., & Girgih, A. T. (2018). A Review on potential of some Nigerian local food as source of functional food and their health promoting benefits. *Asian Food Science Journal*, 2(4), 1–15. <https://doi.org/10.9734/AFSJ/2018/41784>
- Akhmedov, E. T., Minter, S., Nicolini, P., & Singleton, D. (2014). Experimental tests of quantum gravity and exotic quantum field theory effects. *Advances in High Energy Physics*, 2014, 1–2. <https://doi.org/10.1155/2014/192712>
- Anthony, A. A., Adebayo-Tayo, C., Inyang, U., Aiyegoro, A., & Komolafe, O. A. (2010). Snails as meat source: Epidemiological and nutritional perspectives. *Journal of Microbiology and Antimicrobials*, 2(1), 001–005.
- Bouwman, A. F., Pawłowski, M., Liu, C., Beusen, A. H. W., Shumway, S. E., Glibert, P. M., & Overbeek, C. C. (2011). Global Hindcasts and Future Projections of Coastal Nitrogen and Phosphorus Loads Due to Shellfish and Seaweed Aquaculture. *Reviews in Fisheries Science*, 19(4), 331-357. doi: 10.1080/10641262.2011.603849
- Becker, S., & Terlau, H. (2008). Toxins from cone snails: Properties, applications and biotechnological production. *Applied Microbiology and Biotechnology*, 79, 1–9.
- Benkendorff, K. (2010). Molluscan biological and chemical diversity: Secondary metabolites and medicinal resources produced by marine molluscs. *Biological Reviews*, 85(4), 757–775. <https://doi.org/10.1111/j.1469-185X.2010.00124.x>
- Benkendorff, K., Rudd, D., Devi Nongmaithem, B., Liu, L., Young, F., Edwards, V., Avila, C., & Abbott, C. A. (2015). Are the traditional medical uses of Muricidae molluscs substantiated by their pharmacological properties and bioactive compounds? *Marine Drugs*, 13(8), 5237–5275.

- Beltramino, A. A., Vogler, R. E., Gutiérrez Gregoric, D. E., & Rumi, A. (2015). Impact of climate change on the distribution of a giant land snail from South America: Predicting future trends for setting conservation priorities on native malacofauna. *Climatic Change*, *131*(4), 621–633. <https://doi.org/10.1007/s10584-015-1405-3>
- Bishop, M. J., Mayer-Pinto, M., Airolidi, L., Firth, L. B., Morris, R. L., Loke, L. H. L., Hawkins, S. J., Naylor, L. A., Coleman, R. A., Chee, S. Y., & Dafforn, K. A. (2017). Effects of ocean sprawl on ecological connectivity: Impacts and solutions. *Journal of Experimental Marine Biology and Ecology*, *492*, 7–30. <https://doi.org/10.1016/j.jembe.2017.01.021>
- Böhm, M., Dewhurst-Richman, N. I., Seddon, M., Ledger, S. E. H., Albrecht, C., Allen, D., Bogan, A. E., Cordeiro, J., Cummings, K. S., Cuttelod, A., Darrigran, G., Darwall, W., Fehér, Z., Gibson, C., Graf, D. L., Köhler, F., Lopes-Lima, M., Pastorino, G., Perez, K. E., ... Collen, B. (2021). The conservation status of the world's freshwater molluscs. *Hydrobiologia*, *848*(12–13), 3231–3254. <https://doi.org/10.1007/s10750-020-04385-w>
- Bogan, A. E., & Roe, K. J. (2008). Freshwater bivalve (Unioniformes) diversity, systematics, and evolution: Status and future directions. *Journal of the North American Benthological Society*, *27*(2), 349–369. <https://doi.org/10.1899/07-069.1>
- Brown, K. M., & Lydeard, C. (2010). Mollusca: gastropoda. In *Ecology and classification of North American freshwater invertebrates* (pp. 277-306). Academic Press.
- Buranyi, S. (2015). Snail shells are inspiring tomorrow's toughest materials. *MOTHERBOARD, McGill University Press. London.*
- Butler, R., & Estrada, A. (2008). Tropical Conservation Science, Mongabay.com E-Journal. *Tropical Conservation Science*, *1*(1), 1–5. <https://doi.org/10.1177/194008290800100101>
- Campos-Lira, E., Carrillo, E., Aguilar, M. B., Gajewiak, J., Gómez-Lagunas, F., & López-Vera, E. (2017). Conorfamide-Sr3, a structurally novel specific inhibitor of the Shaker K⁺ channel. *Toxicon*, *138*, 53–58. <https://doi.org/10.1016/j.toxicon.2017.07.024>
- Catterall, W. A., & Swanson, T. M. (2015). Structural basis for pharmacology of voltage-gated sodium and calcium channels. *Molecular pharmacology*, *88*(1), 141–150. <https://doi.org/10.1124/mol.114.097659>
- Chiba, S. (2009). Morphological divergence as a result of common adaptation to a shared environment in land snails of the genus *Hirasea*. *Journal of Molluscan Studies*, *75*(3), 253–259. <https://doi.org/10.1093/mollus/eyp020>
- Clarke, S. A., & Walsh, P. (2014). Marine organisms for bone repair and regeneration. In *Bone substitute biomaterials* (pp. 294-318). Woodhead Publishing
- Cobbinah, J. R., Vink, A., & Onwuka, B. (2008). *Snail Farming: Production, processing and marketing. Agromisa.*
- Collier, K. J., Probert, P. K., & Jeffries, M. (2016). Conservation of aquatic invertebrates: Concerns, challenges and conundrums. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(5), 817–837. <https://doi.org/10.1002/aqc.2710>

- Cowan, Z.-L., Pratchett, M., Messmer, V., & Ling, S. (2017). Known predators of Crown-of-Thorns Starfish (*Acanthaster* spp.) and their role in mitigating, not preventing, population outbreaks. *Diversity*, 9(1), 7. <https://doi.org/10.3390/d9010007>
- Cowie, R H. (1995). Variation in species diversity and Shell shape in Hawaiian Land Snails: in situ speciation and ecological relationships. *Evolution*, 49(6), 1191–1202. <https://doi.org/10.1111/j.1558-5646.1995.tb04446.x>
- Crocetta, F., Poursanidis, D., & Tringali, L. P. (2015). Biodiversity of sea slugs and shelled relatives (Mollusca: Gastropoda) of the Cretan Archipelago (Greece), with taxonomic remarks on selected species. *Quaternary International*, 390, 56–68. <https://doi.org/10.1016/j.quaint.2015.02.061>
- Dang, V. T., Benkendorff, K., Green, T., & Speck, P. (2015). Marine snails and slugs: A great place to look for antiviral drugs. *Journal of Virology*, 89(16), 8114–8118. <https://doi.org/10.1128/JVI.00287-15>
- Das, Shikhasmita, Anal, Jasha Momo H., Kalita, Pranjal, Saikia, Lakshi, Rokhum, Samuel Lalthazuala, & Bhuyar, Prakash. (2023). Process Optimization of Biodiesel Production Using Waste Snail Shell as a Highly Active Nanocatalyst. *International Journal of Energy Research*, 1-26. doi: 10.1155/2023/6676844
- De Kock, K. N., Joubert, P. H., & Pretorius, S. J. (1989). Geographical distribution and habitat preferences of the invader freshwater snail species *Lymnaea columella* (Mollusca: Gastropoda) in South Africa. *The Onderstepoort Journal of Veterinary Research*, 56(4), 271–275.
- Defer, D., Bourgoignon, N., & Fleury, Y. (2009). Screening for antibacterial and antiviral activities in three bivalve and two gastropod marine molluscs. *Aquaculture*, 293(1–2), 1–7. <https://doi.org/10.1016/j.aquaculture.2009.03.047>
- Dhiman, V., & Pant, D. (2021a). Environmental biomonitoring by snails. *Biomarkers*, 26(3), 221–239. <https://doi.org/10.1080/1354750X.2020.1871514>
- Dhiman, V., & Pant, D. (2021b). Human health and snails. *Journal of Immunoassay and Immunochemistry*, 42(3), 211–235. <https://doi.org/10.1080/15321819.2020.1844751>
- Dhiman, V., Pant, D., Sharma, D. K., & Prakash, P. (2020). A review on persisting threats to snail's diversity and its conservation approaches. *Archives of Agriculture and Environmental Science*, 5(2), 205–217. <https://doi.org/10.26832/24566632.2020.0502019>
- Dolashka-Angelova, P., Lieb, B., Velkova, L., Heilen, N., Sandra, K., Nikolaeva-Glomb, L., Dolashki, A., Galabov, A. S., Beeumen, J. V., & Stevanovic, S. (2009). Identification of glycosylated sites in *Rapana* hemocyanin by mass spectrometry and gene sequence, and their antiviral effect. *Bioconjugate Chemistry*, 20(7), 1315–1322. <https://doi.org/10.1021/bc900034k>
- Duarte, C., Jahnsen-Guzmán, N., Quijón, P. A., Manríquez, P. H., Lardies, M. A., Fernández, C., Reyes, M., Zapata, J., García-Huidobro, M. R., & Lagos, N. A. (2022). Morphological, physiological and behavioral responses of an intertidal snail, *Acanthina monodon* (Pallas), to projected ocean acidification and cooling water conditions in upwelling

- ecosystems. *Environmental Pollution*, 293, 118481. <https://doi.org/10.1016/j.envpol.2021.118481>
- Dutt, M., Giacomotto, J., Ragnarsson, L., Andersson, Å., Brust, A., Dekan, Z. & Lewis, R. J. (2019). The α 1-adrenoceptor inhibitor p-TIA facilitates net hunting in piscivorous *Conus tulipa*. *Scientific Reports*, 9(1), 17841.
- Ellis, J. C., Chen, W., O'Keefe, B., Shulman, M. J., & Witman, J. D. (2005). Predation by gulls on crabs in rocky intertidal and shallow subtidal zones of the Gulf of Maine. *Journal of Experimental Marine Biology and Ecology*, 324(1), 31–43. <https://doi.org/10.1016/j.jembe.2005.04.001>
- Evans, J., Borg, J. A., & Schembri, P. J. (2011). Distribution, habitat preferences and behaviour of the critically endangered Maltese top-shell *Gibbula nivosa* (Gastropoda: Trochidae). *Marine Biology*, 158(3), 603–611. <https://doi.org/10.1007/s00227-010-1584-4>
- Evanson Inyang, U. (2018). Comparative study on the chemical composition and amino acid profile of Periwinkle and Rock Snail meat powders. *International Journal of Food Science and Biotechnology*, 3(2), 54. <https://doi.org/10.11648/j.ijfsb.20180302.13>
- Felici, A., Bilandžić, N., Magi, G. E., Iaffaldano, N., Fiordelmondo, E., Doti, G., & Roncarati, A. (2020). Evaluation of Long Sea Snail *Hinia reticulata* (Gastropod) from the Middle Adriatic Sea as a possible alternative for human consumption. *Foods*, 9(7), 905. <https://doi.org/10.3390/foods9070905>
- Ferguson H., T., Oladiran. K, A., Raseed.A, M., & Salawu. A, A. (2018). Snail shell as an inspiring engineering material in science and technology development: A review. *International Journal of Contemporary Research and Review*, 9(03), 20408–20416. <https://doi.org/10.15520/ijcrr/2018/9/03/473>
- Floyd, M., Mizuyama, M., Obuchi, M., Sommer, B., Miller, M. G., Kawamura, I., Kise, H., Reimer, J. D., & Beger, M. (2020). Functional diversity of reef molluscs along a tropical-to-temperate gradient. *Coral Reefs*, 39(5), 1361–1376. <https://doi.org/10.1007/s00338-020-01970-2>
- Fry, Jillian P., Mailloux, Nicholas A., Love, David C., Milli, Michael C., & Cao, Ling. (2018). Feed conversion efficiency in aquaculture: do we measure it correctly? *Environmental Research Letters*, 13(2), 024017. doi: 10.1088/1748-9326/aaa273
- Giokas, S., Pafilis, P., & Valakos, E. (2005). Ecological and physiological adaptations of the land snail *Albinaria caerulea* (pulmonata: Clausiliidae). *Journal of Molluscan Studies*, 71(1), 15–23. <https://doi.org/10.1093/mollus/eyi001>
- Grandal, M. K. (2020). Venomics as a drug discovery platform: Identifying conopeptides with pharmacological activity. Doctoral dissertation, Department of Drug Discovery and Biomedical Sciences, *Medical University of South Carolina*, USA.
- Gupta, A., & Khanal, P. (2024). The potential of snails as a source of food and feed. *Journal of Agriculture and Food Research*, 18, 101330. <https://doi.org/10.1016/j.jafr.2024.101330>

- Hatzioannou, M., Issari, A., Neofitou, C., Aifadi, S., & Matsiori, S. (2014). Economic analysis and production techniques of snail farms in southern Greece. *World Journal of Agricultural Research*, 2(6), 276–279.
- Heller, Joseph, & Kurtz, Tuviyah. (2015). *Sea snails*: Springer.
- Hollander, J., Adams, D. C., & Johannesson, K. (2006). Evolution of adaptation through allometric shifts in a marine snail. *Evolution*, 60(12), 2490–2497. <https://doi.org/10.1111/j.0014-3820.2006.tb01884.x>
- Ibrahim, Hassan A. H., Abdelnaby, Hanan M., Abouelkheir, Samia S., Abo-Taleb, Hamdy A., & Sersy, Nermeen A. El. (2023). Blue economic potency of marine invertebrates for bio-drug discovery. *Blue Economy*, 1(2). doi: 10.57241/2805-2994.1008
- Johnson, S. B., Warén, A., Tunnicliffe, V., Dover, C. V., Wheat, C. G., Schultz, T. F., & Vrijenhoek, R. C. (2015). Molecular taxonomy and naming of five cryptic species of *Alviniconcha* snails (Gastropoda: Abysochrysoidea) from hydrothermal vents. *Systematics and Biodiversity*, 13(3), 278–295. <https://doi.org/10.1080/14772000.2014.970673>
- Kaviarasan, T., Siva, S. R., & Yogamoorthi, A. (2012), Antimicrobial secondary metabolites from marine gastropod egg capsules and egg masses. *Asian Pacific Journal of Tropical Biomedicine*, 2(11), 916–922. doi: 10.1016/S2221-1691(12)60253-6
- Kayal, M., Vercelloni, J., Lison De Loma, T., Bosserelle, P., Chancerelle, Y., Geoffroy, S., Stievenart, C., Michonneau, F., Penin, L., Planes, S., & Adjerdoud, M. (2012). Predator Crown-of-Thorns Starfish (*Acanthaster planci*) outbreak, mass mortality of Corals, and cascading effects on reef fish and benthic communities. *PLoS ONE*, 7(10), e47363. <https://doi.org/10.1371/journal.pone.0047363>
- Kemencei, Z., Farkas, R., Páll-Gergely, B., Vilisics, F., Nagy, A., Hornung, E., & Sólymos, P. (2014). Microhabitat associations of land snails in forested dolinas: Implications for coarse filter conservation. *Community Ecology*, 15(2), 180–186. <https://doi.org/10.1556/ComEc.15.2014.2.6>
- Kiko, R., Kramer, M., Spindler, M., & Wägele, H. (2008). *Tergipes antarcticus* (Gastropoda, Nudibranchia): Distribution, life cycle, morphology, anatomy and adaptation of the first mollusc known to live in Antarctic sea ice. *Polar Biology*, 31(11), 1383–1395. <https://doi.org/10.1007/s00300-008-0478-0>
- Kolawole, M. Y., Aweda, J., & Abdulkareem, S. (2017). *Archachatina marginata* bio-shells as reinforcement material in metal matrix composites. *International Journal of Automotive and Mechanical Engineering*, 14(1), 4068–4079. <https://doi.org/10.15282/ijame.14.1.2017.18.0328>
- Lai, S., Loke, L. H. L., Hilton, M. J., Bouma, T. J., & Todd, P. A. (2015). The effects of urbanisation on coastal habitats and the potential for ecological engineering: A Singapore case study. *Ocean & Coastal Management*, 103, 78–85. <https://doi.org/10.1016/j.ocecoaman.2014.11.006>
- Lambert, J. (2019). Ocean snail is first animal to be officially endangered by deep-sea mining. *Nature*, 571(7766), 455–456. <https://doi.org/10.1038/d41586-019-02231-1>

- Layer, R. T., & McIntosh, J. M. (2006). Conotoxins: Therapeutic potential and application. *Marine Drugs*, 4(3), 119–142. <https://doi.org/10.3390/md403119>
- Ibrahim, A. M., Hamed, A. A., & Ghareeb, M. A. (2021). Marine, freshwater, and terrestrial snails as models in the biomedical applications. *Egyptian Journal of Aquatic Biology & Fisheries*, 25(3), 23–38. DOI: 10.21608/ejabf.2021.172142
- Jones, R. M., & Bulaj, G. (2000). Conotoxins-new vistas for peptide therapeutics. *Current Pharmaceutical Design*, 6(12), 1249–1285. <https://doi.org/10.2174/1381612003399653>
- Krishnarajuna, B., Sunanda, P., Seow, J., Tae, H. S., Robinson, S. D., Belgi, A., ... & Norton, R. S. (2023). Characterisation of elevenin-Vc1 from the venom of *Conus victoriae*: A structural analogue of α -conotoxins. *Marine Drugs*, 21(2), 81. <https://doi.org/10.3390/md21020081>.
- Lambert, Jonathan. (2019). Ocean snail is first animal to be officially endangered by deep-sea mining. *Nature*, 571(7766), 455-457.
- López-Abarrategui, C., McBeth, C., Mandal, S. M., Sun, Z. J., Heffron, G., Alba-Menéndez, A. & Otero-González, A. J. (2015). Cm-p5: an antifungal hydrophilic peptide derived from the coastal mollusk *Cenchritis muricatus* (Gastropoda: Littorinidae). *The FASEB Journal*, 29(8), 3315.
- Luo, F., Xing, R., Wang, X., Peng, Q., & Li, P. (2017). Proximate composition, amino acid and fatty acid profiles of marine snail *Rapana venosa* meat, visceral mass and operculum. *Journal of the Science of Food and Agriculture*, 97(15), 5361–5368. <https://doi.org/10.1002/jsfa.8425>
- Malhi, Y., Franklin, J., Seddon, N., Solan, M., Turner, M. G., Field, C. B., & Knowlton, N. (2020). Climate change and ecosystems: Threats, opportunities and solutions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 375(1794), 20190104. <https://doi.org/10.1098/rstb.2019.0104>
- Margiotta, F., Micheli, L., Ciampi, C., Ghelardini, C., McIntosh, J. M., & Di Cesare Mannelli, L. (2022). *Conus regius*-derived conotoxins: Novel therapeutic opportunities from a marine organism. *Marine Drugs*, 20(12), 773. <https://doi.org/10.3390/md20120773>
- Mason, S. L., Shi, J., Bekhit, A. E.-D., & Gooneratne, R. (2014). Nutritional and toxicological studies of New Zealand *Cookia sulcata*. *Journal of Food Composition and Analysis*, 36(1–2), 79–84. <https://doi.org/10.1016/j.jfca.2014.08.002>
- Mayer, A. M. S., Glaser, K. B., Cuevas, C., Jacobs, R. S., Kem, W., Little, R. D., McIntosh, J. M., Newman, D. J., Potts, B. C., & Shuster, D. E. (2010). The odyssey of marine pharmaceuticals: A current pipeline perspective. *Trends in Pharmacological Sciences*, 31(6), 255–265. <https://doi.org/10.1016/j.tips.2010.02.005>
- Min, F., Wang, J., Liu, X., Yuan, Y., Guo, Y., Zhu, K., Chai, Z., Zhang, Y., & Li, S. (2022). Environmental factors affecting freshwater Snail intermediate hosts in Shenzhen and adjacent region, South China. *Tropical Medicine and Infectious Disease*, 7(12), 426. <https://doi.org/10.3390/tropicalmed7120426>

- Mitra, Abhijit, Zaman, Sufia, & Pramanick, Prosenjit. (2022). Blue Economy: An Overview *Blue Economy in Indian Sundarbans: Exploring Livelihood Opportunities* (pp. 1-83). Cham: Springer International Publishing.
- Munywoki, Gilbert Ndotu. (2022). Snail farming (Heliciculture): Benefits, economic viability, challenges and prospects. *International Journal of Research in Agronomy* 5(1), 09-11.
- Ng, T. P., Lau, S. L., Seuront, L., Davies, M. S., Stafford, R., Marshall, D. J., & Williams, G. A. (2017). Linking behaviour and climate change in intertidal ectotherms: insights from littorinid snails. *Journal of Experimental Marine Biology and Ecology*, 492, 121–131.
- Nkansah, M. A., Agyei, E. A., & Opoku, F. (2021). Mineral and proximate composition of the meat and shell of three snail species. *Heliyon*, 7(10), e08149. <https://doi.org/10.1016/j.heliyon.2021.e08149>
- Olivera, B. M., Safavi-Hemami, H., Raghuraman, S., Teichert, R. W., Newman, D. J., Cragg, G. M., & Grothaus, P. G. (2017). Cone Snail venom peptides and future biomedical applications of natural products. In *Chemical Biology of Natural Products* (pp. 425-489). CRC Press
- Özogul, Y., Özogul, F., & Olgunoglu, A. I. (2005). Fatty acid profile and mineral content of the wild snail (*Helix pomatia*) from the region of the south of the Turkey. *European Food Research and Technology*, 221(3–4), 547–549. <https://doi.org/10.1007/s00217-005-1191-7>
- Parkyn, J., & Newell, D. A. (2013). Australian land snails: A review of ecological research and conservation approaches. *Molluscan Research*, 33(2), 116–129. <https://doi.org/10.1080/13235818.2013.782793>
- Pati, S., Swain, S., Hussain, M. A., Van Den Akker, M., Metsemakers, J., Knottnerus, J. A., & Salisbury, C. (2015). Prevalence and outcomes of multimorbidity in South Asia: A systematic review. *BMJ Open*, 5(10), e007235. <https://doi.org/10.1136/bmjopen-2014-007235>
- Pallaghy, P. K., Melnikova, A. P., Jimenez, E. C., Olivera, B. M., & Norton, R. S. (1999). Solution structure of contryphan-R, a naturally occurring disulfide-bridged octapeptide containing D-tryptophan: comparison with protein loops. *Biochemistry*, 38(35), 11553–11559. <https://doi.org/10.1021/bi990685j>
- Periyasamy, N., Arularasan, S., & Gayathri, S. (2012). Antibacterial activity of the tissue extracts of *Conus betulinus* and *Conus inscriptus* Linnaeus, 1758 (Mollusca: Gastropoda) from Nagapattinam, Southeast coast of India. *Asian Pacific Journal of Tropical Disease*, 2, S914–S919. [https://doi.org/10.1016/S2222-1808\(12\)60291-6](https://doi.org/10.1016/S2222-1808(12)60291-6)
- Pissia, M. A., Matsakidou, A., & Kiosseoglou, V. (2021). Raw materials from snails for food preparation. *Future Foods*, 3, 100034. <https://doi.org/10.1016/j.fufo.2021.100034>
- Pope, J. E., & Deer, T. R. (2013). Ziconotide: a clinical update and pharmacologic review. *Expert Opinion on Pharmacotherapy*, 14(7), 957–966. <https://doi.org/10.1517/14656566.2013.784269>

- Prashanth, J. R., Brust, A., Jin, A. H., Alewood, P. F., Dutertre, S., & Lewis, R. J. (2014). Cone Snail Venomics: From Novel Biology to Novel Therapeutics. *Future Medicinal Chemistry*, 6(15), 1659–1675.
- Ravinet, M. (2018). Notes from a snail island: Littorinid evolution and adaptation. *Molecular Ecology*, 27(13), 2781–2789. <https://doi.org/10.1111/mec.14730>
- Rick, T. C. (2024). Shell Midden Archaeology: Current trends and future directions. *Journal of Archaeological Research*, 32(3), 309–366. <https://doi.org/10.1007/s10814-023-09189-9>
- Schweizer, M., Triebkorn, R., & Köhler, H. (2019). Snails in the sun: Strategies of terrestrial gastropods to cope with hot and dry conditions. *Ecology and Evolution*, 9(22), 12940–12960. <https://doi.org/10.1002/ece3.5607>
- Segade, P., Crespo, C., García, N., García-Estévez, J. M., Arias, C., & Iglesias, R. (2011). *Brachylaima aspersae* n. sp. (Digenea: Brachylaimidae) infecting farmed snails in NW Spain: morphology, life cycle, pathology, and implications for heliculture. *Veterinary Parasitology*, 175(3–4), 273–286.
- Sika Piba, N., Karamoko, M., Adou, C., Otchoumou, A., & Kouassi, K. (2015). Effet du régime et de la teneur en protéines brutes alimentaires sur le rendement en viande de l'escargot *Achatina fulica* (Bowdich, 1720). *International Journal of Biological and Chemical Sciences*, 8(5), 2296. <https://doi.org/10.4314/ijbcs.v8i5.31>
- Simonová, J., Simon, O. P., Kapic, Š., Nehasil, L., & Horsák, M. (2016). Medium-sized forest snails survive passage through birds' digestive tract and adhere strongly to birds' legs: More evidence for passive dispersal mechanisms. *Journal of Molluscan Studies*, 82(3), 422–426. <https://doi.org/10.1093/mollus/eyw005>
- Tayo, L. L., Lu, B., Cruz, L. J., & Yates III, J. R. (2010). Proteomic analysis provides insights on venom processing in *Conus textile*. *Journal of proteome research*, 9(5), 2292–2301.
- Thamilarasan, K., & Kamaraj, M. (2025). Snail shell powder-filled polylactic acid composites: filler content and mechanical properties. *Iranian Polymer Journal*, 1–14.
- Tluste, C., & Birkhofer, K. (2021). Shells of the Roman snail are important microhabitats for soil invertebrates. *Soil Organisms*, 93(3), 141–152. DOI: <https://doi.org/10.25674/so93iss3id167>.
- Tobins, F. H., Abubakre, O. K., Muriana, R. A., & Abdulrahman, A. S. (2018). Snail shell as an inspiring engineering material in science and technology development: a review. *International Journal of Contemporary Research and Review*, 9(3), 20408–20416. <https://doi.org/10.15520/ijcrr/2018/9/03/473>
- Wang, C., Zhang, H., Jiang Hui, Lu, Wuyuan, Zhao, Zhi-Qi, Chi Cheng-Wu (2006). A novel conotoxin from *Conus striatus*, μ -SIIIA, selectively blocking rat tetrodotoxin-resistant sodium channels, *Toxicon*, 47(1), 122–132, ISSN 0041-0101, <https://doi.org/10.1016/j.toxicon.2005.10.008>.
- Wolfe, Barrett W., Champion, Curtis, Gaston, Troy, Brown, Joshua, Coleman, Melinda A., Davis, Tom R., Pecl, Gretta T. (2025). Continental-scale assessment of climate-driven marine

species range extensions using a decade of citizen science data. *Diversity and Distributions*, 31(4), e70022. doi: 10.1111/ddi.70022

Yamamori, L., & Kato, M. (2018). Morphological and ecological adaptation of limpet-shaped top shells (Gastropoda: Trochidae: Fossarininae) to wave-swept rock reef habitats. *PLOS ONE*, 13(8), e0197719. <https://doi.org/10.1371/journal.pone.0197719>

Zarai, Z., Frikha, F., Balti, R., Miled, N., Gargouri, Y., & Mejdoub, H. (2011). Nutrient composition of the marine snail (*Hexaplex trunculus*) from the Tunisian Mediterranean coasts. *Journal of the Science of Food and Agriculture*, 91(7), 1265–1270. <https://doi.org/10.1002/jsfa.4309>

Zheng, Z., Lv, J., Lu, K., Jin, C., Zhu, J., & Liu, X. (2011). The Impact of Snail (*Bellamya aeruginosa*) Bioturbation on Sediment Characteristics and Organic Carbon Fluxes in a Eutrophic Pond. *CLEAN–Soil, Air, Water*, 39(6), 566–571. <https://doi.org/10.1002/clen.201000212>



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