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Research Article

Keywords: Systematics, marine algae, intertidal zone, habitat distribution, Bay of Bengal

Posted Date: June 4th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9641569/v1

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Additional Declarations: No competing interests reported.

Intertidal algal systematics and habitat-associated distribution along the northwestern coast of the Bay of Bengal

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Abstract

Marine algal diversity along the southeastern coast of Bangladesh remains insufficiently resolved, particularly with respect to integrated assessments of macroalgal and microalgal communities. The present study aimed to provide a classical systematic account of algal diversity across selected intertidal habitats of the region, with emphasis on substrate-associated assemblages. Field sampling was conducted across three coastal sites, including St. Martin's Island and the Cox's Bazar coast, covering approximately 2 km of intertidal zones during the peak growth period (October–February). Specimens were collected through exploratory sampling across tidal gradients and identified using morphological and anatomical characteristics based on standard taxonomic literature. A total of 14 marine algal species were recorded, comprising Cyanophyta (1), Chlorophyta (5), Phaeophyta (6), and Rhodophyta (2). Species distribution showed a strong association with habitat type, with the majority of taxa occurring on rocky intertidal substrates of St. Martin's Island, while sandy coastal areas supported fewer species, primarily as washed-ashore forms. Microalgal assemblages were exclusively observed in rocky habitats, forming dense mat-like structures under relatively low turbidity and stable environmental conditions. The findings highlight the role of substrate availability and environmental stability in shaping algal community structure in tropical intertidal systems. By integrating both macroalgae and microalgae within a single survey framework, the study provides a baseline for future taxonomic and ecological investigations in the coastal waters of Bangladesh.

Keywords: Systematics, marine algae, intertidal zone, habitat distribution, Bay of Bengal,

1. Introduction

Marine algae constitute a fundamental component of marine ecosystems [1], contributing significantly to primary productivity [2] and supporting trophic dynamics [3]. In Bangladesh part of the bay of Bengal, study on marine algal diversity has historically been dominated by macroalgae (seaweeds), with a long-standing record of taxonomic documentation primarily centered on St. Martin's Island and adjacent coastal environments [4]. Foundational work by AKM Nurul Islam [5] and subsequent studies have progressively expanded the checklist of marine macroalgae, with current records exceeding 200 species. However, these efforts have largely remained confined to seaweed-based macroalgal inventories, often overlooking the broader algal assemblage.

In contrast, marine microalgae in Bangladesh have only recently begun to receive focused scientific attention, particularly in the context of the emerging blue economy framework. Recent initiatives, including those by the Bangladesh Fisheries Research Institute, have emphasized the isolation and characterization of selected commercially important taxa, namely Chlorella sp., *Nannochloropsis* sp., and *Tetraselmis* sp._[6]. Despite these advancements, taxonomic documentation of indigenous marine microalgae remained limited, and studies integrating both macro- and microalgal components within a unified ecological framework are virtually absent.

This separation has led to a fragmented understanding of algal diversity in Bangladesh, where macroalgae and microalgae are typically treated as distinct entities rather than components of

a continuous and interacting community. Globally, studies on algal communities in reef ecosystems identified three functional groups: (i) algal turfs, (ii) fleshy macroalgae or seaweeds, and (iii) crustose calcareous algae, with over 600 species documented on the Great Barrier Reef alone [7]. Encrusting coralline algae, for example, serve a structural function as one of the components of coral reefs [8]. These components provide better insight by showing how substantial some forms of seaweed can be in the composition of reefs. For example, Alacranes Reef in Mexico is dominated by coralline algae, with *Halimeda* sp. and coralline algae accounting for over 40% of the dry volume, in addition to corals, mollusks, foraminifera, and others. The recent developments, including the identification of sub-littoral reef structures 14 km west of St. Martin's Island [9] suggested the presence of previously underexplored habitats despite more than five decades of phycological research. The region may support distinct algal assemblages. However, logistical constraints, particularly limited access to subtidal environments, have resulted in a continued reliance on intertidal surveys, with many habitats and associated taxa remaining insufficiently documented.

Given this context, there remains a clear need for updated, locality-specific taxonomic assessments that incorporate both macroalgal and microalgal elements, particularly within ecologically relevant intertidal zones [10]. Such efforts are essential not only for refining existing species records but also for identifying previously unreported taxa and understanding habitat-level distribution patterns.

The present study addressed this gap by conducting a targeted survey of intertidal algal communities from selected coastal locations, including St. Martin's Island and the Cox's Bazar region. By integrating morphological and anatomical analyses, this study documented both macroalgal and microalgal taxa within a unified framework. Through this approach, the current investigation aimed to contribute to a more coherent understanding of marine algal diversity in Bangladesh and to establish a baseline for future ecological and taxonomic investigations in the region.

2. Materials and Methods

2.1 Sampling & Research Design

The natural habitats of the southeastern coast (St. Martin's Island and Cox's Bazar) of Bangladesh (Fig. 1) were chosen as the study area. These two regions represent contrasting coastal environments within the northeastern Bay of Bengal. St. Martin's Island (SMI) is a coral-bearing island characterized by extensive intertidal coral and coralline rock substrates. On the other hand, the Cox's Bazar coast, including Inani and Patuartek beaches, is predominantly sandy with only limited occurrences of scattered hard substrates [11].

Field sampling was conducted at three sites across the two regions: Chera Dwip (St. Martin's Island), Inani Beach, and Patuartek Beach (Cox's Bazar). Sampling was conducted with utmost care not to destroy the habitat. These sites were selected based on field accessibility and prior local knowledge indicating the presence of algal growth. In particular, site selection was guided by observable environmental characteristics, including relatively weak wave action, clear and low-turbidity water conditions, minimal anthropogenic disturbance, and the presence of

associated biota, specifically small fishes and crabs, which collectively indicated favorable conditions for algal establishment.

Sampling was restricted to intertidal habitats and focused on substrate-associated algal communities. Surveys were carried out across approximately 2 km of intertidal zone using a systematic exploratory approach. Notably, fixed quadrat or transect-based methods were not used due to logistical constraints. Sampling proceeded along the tidal gradient from upper to lower levels of the tidal area during low tide periods, ensuring collection of recently exposed and hydrated specimens [12].

Fieldwork was conducted in three phases between October 2023 and February 2024, corresponding to the seasonal window of peak algal growth in Bangladesh coastal waters. The first survey was carried out from late October to early November, followed by a second phase in late January and a final phase in mid-February. Each field session spanned 4–6 days and was synchronized with daytime low tide cycles, as effective seaweed collection requires adequate sunlight exposure. Collections typically commenced approximately two hours prior to the lowest low tide and continued throughout the tidal cycle. Free-floating or deposited fresh masses of marine algae available in the sampling stations were grabbed; thereafter, the attached forms were scraped whenever found necessary. A solution comprising 4% buffered formaldehyde was prepared, into which the collected algal samples were preserved.

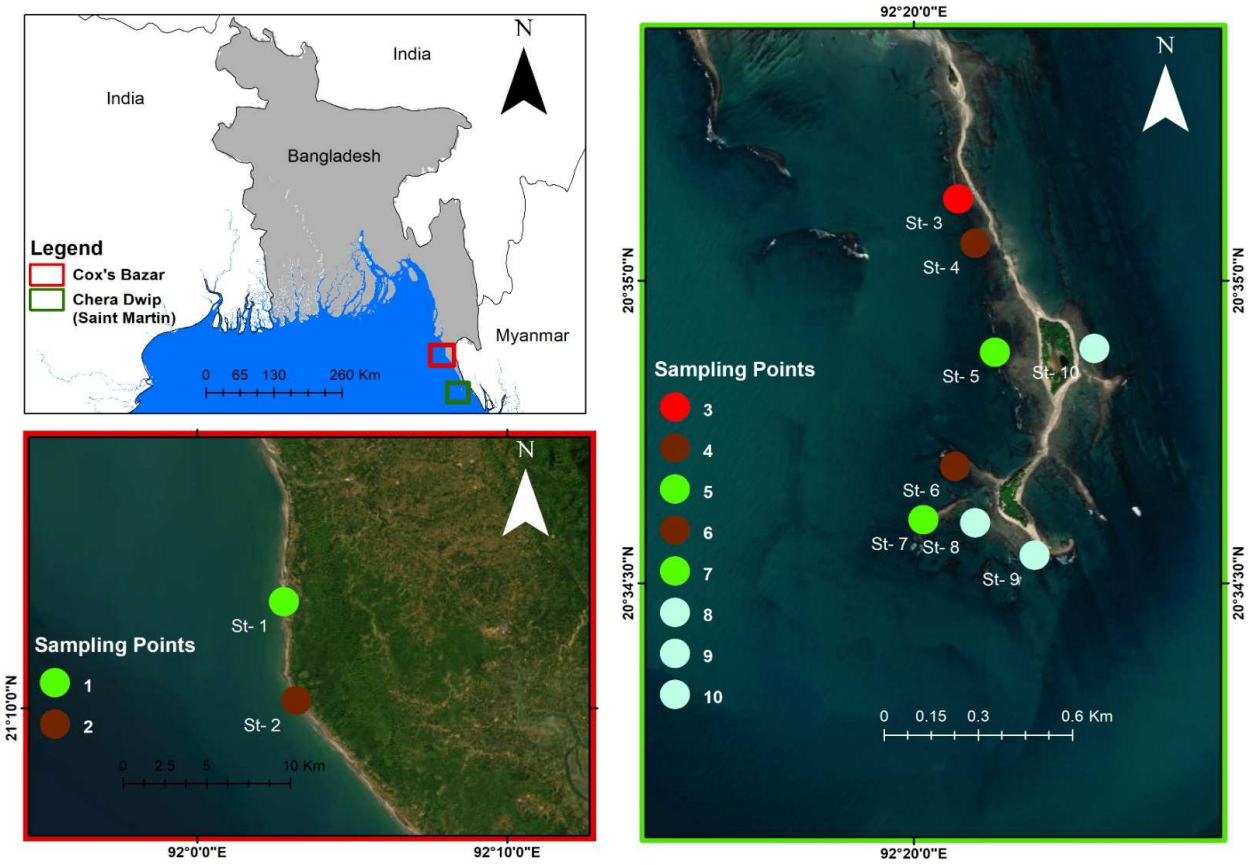


Figure 1: Location of Algal Sample Collection Areas on Southeastern coast of Bangladesh

2.2 Microscopy, Identification and Taxonomic Delineation

Preliminary observations were conducted on fresh specimens prior to fixation to retain natural coloration and structural integrity. Detailed examination was then carried out using a stereo microscope and a research microscope (Carl Zeiss Axioscope 5, Germany) equipped with a photomicrographic system and ZEN Core software. Morphological and anatomical features were documented through direct observation and image-based measurements using calibrated scale bars.

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Macroalgal biometric data, including length, breadth, and arrangement of cells in the vegetative as well as reproductive structures of the thallus morphology, together with the shape, color, and number of chromatophores, were recorded. Selected portions of the thallus of some macroscopic algae were sectioned transversely (TS) and observed under higher magnifications (including 5x, 10x, 40x, and 100x) to study the cellular anatomy of the species. Photographs of sections of the algal samples were captured using magnifications of 40-100 × to assess vegetative and reproductive structures, including cell arrangement, cell dimensions (length and breadth), and chromatophore characteristics.

Microalgae were primarily obtained as mat-forming assemblages attached to substrate surfaces and did not require dissection. Their identification was based on microscopic examination of cell shape, filament structure, and branching patterns under higher magnifications. Multiple individuals of each taxon were examined to ensure consistency of observed characters, and representative specimens were selected for documentation.

The identification and taxonomic delineation of the collected seaweed species were conducted by referencing standard literature [5,13–17]. However, to match the arrangement of algal taxa, the classification of Bold and Wynne [18] up to algal division has been followed. Later on, the descriptive catalogue of [17] was adopted to ensure further taxonomic ranking of each species. Identifications were made to the lowest possible taxonomic level based on the availability of distinguishing morphological features. Photo-edited images to adjust sizes only were used to prepare image plates (Figs. 2-5) of the recorded species and presented. The preserved specimens have been stored in the Laboratory of Biological Oceanography, Department of Oceanography, University of Dhaka.

Given the absence of molecular analyses due to logistical and infrastructural constraints, species identification in this study is based solely on morphological and anatomical characteristics. While this approach remains standard in classical phycological studies, it may limit resolution in cases of cryptic or morphologically similar taxa.

3. Results and Discussions

3.1 Algal Systematics

In the present research, a total of 14 marine algal species has been recorded. The taxonomic description of each species, together with their habitats, has been mentioned. The species are *Lyngbya magnifica*, *Ulva lactuca*, *Cladophora echinus*, *C. patentiramea*, *Caulerpa recemosa*, *Halimeda opuntia*, *Dictyota dichotoma*, *Padina tenuis*, *Colpomenia sinuosa*, *Hydroclathrus clathratus*, *Sargassum flavicans*, *S. tenerrimum*, *Hypnea pannosa*, and *Ceramium festigiatum*.

Algal division-wise species distribution was Cyanophyta (1), Chlorophyta (6), Phaeophyta (6), and Rhodophyta (2). Distribution and occurrence of the abovementioned marine algal species in the Bay of Bengal and its coastal regions have been confirmed [5]. Above all, the present research is supported by anatomical properties of the macroalgal thalli wherever applicable. Following is a systematic presentation of the recorded algal taxa in the present research.

Division: CYANOPHYTA

Order: Oscillatoriales

Family: Oscillatoriaceae

Genus: **Lyngbya** Agardh

1. *Lyngbya magnifica* Gardner Fig. 2 A-D

([5], p. 71, Pl. 73, Fig. 430)

Plant filamentous cyanobacteria, with filaments entangled together, forming masses and trichomes covered by thick mucilaginous sheaths, stratified, biscuit-like vegetative prokaryotic cells stacked in trichomes present within the mucilage sheath. Cells 30.34 µm wide and 2.43-3.03 µm long, mucilage sheath 4.86 µm.

Collection No 12

Habitat: Rocky (formed mat on the beach rocks), Saint Martin's Island

Date of collection: 27.10.23

Genus: **Ulva** Linn.

2. *Ulva lactuca* L. Fig. 2 E-F

([5], p. 11; [15], p. 252-253)

Plant bright green in color, foliaceous, blade more or less ovate, fronds attached with the help of attenuated bases, texture delicate, blade margin smooth, individual cells with a single chromatophore with one or many pyrenoids, cells polyhedral in surface view.

Collection No. 11

Habitat: washed ashore, Inani beach, Cox's Bazar

Date of collection: 17.02.24

Order: Cladophorales

Family: Cladophoraceae

Genus: **Cladophora** Kuetz.

3. *Cladophora echinus* (Bias.) Kuetz. Fig. 2 H-L

([5], p. 15, pl. 3, figs. 23-24)

Plant filamentous, branched, grass-green in color; cells cylindrical and long, branching irregularly dichotomous; cell wall thick; cells broader, vegetative cells nearly 75.72 µm long and 9.54 µm in diameter, branch tip attenuated, 8.34 µm in diameter, cell wall 0.37 µm in diameter.

Collection No. 7
Habitat: Rocky intertidal zone (formed dense mat on the beach rocks), Saint Martin's Island
Date of collection: 27.10.23

4. *C. patentiramea* (Mont.) Kuetz. Fig. 3 A-D
([5], p. 15, pl. 3, fig. 20)

Plant an aggregated mass, floating freely in a small creek, with branches small, sparse, and sometimes bent or dumbbell-shaped, and cells slender, attached to the substratum with single-celled holdfasts. Vegetative cells 17.64 µm in diameter and 411.60 µm long.

Collection No. 6
Habitat: Rocky intertidal zone (formed dense mat on the beach rocks), Saint Martin's Island
Date of collection: 27.10.23

Order: Siphonales
Family: Caulerpaceae
Genus: **Caulerpa** Lamour.

5. *Caulerpa racemosa* var. *clavifera* (Turner) W. v. Bosse Fig. 2 G
([5], p. 20, Pl. 5, Fig. 46-48; [17], p. 152, pl. 17, fig. 7)

Plants with coarse branching stolons, erect axis and branchlet terete, broadly clavate, densely entangled, often crowded, 3-10 cm long, the globular summit of branches 2-3 mm in dia., bright green, occur in masses.

Collection No. 10
Habitat: Washed ashore, Saint Martin's Island
Date of collection: 28.10.23

Family: Codiaceae
Genus: **Halimeda** Lamx.

6. *Halimeda opuntia* (L.) Lamour. Fig. 3 E
([5] p. 24, Pl. 13, Fig. 96; [15] 2002, p. 202, fig. 12)

The plant body is arranged in segments of more or less moniliform, cylindrical, or discoid shape; each segment is connected by a short stipe to the next, is flat or somewhat contorted and frequently ribbed, and may be variable and oblong in shape; the young stage of the thalli looks bright green, but the older thallus is whitish and encrusted with lime deposition by the plant itself. Each lobe is 4 mm long and around 7 mm broad.

Collection No. 8
Habitat: Rocky Surface, Saint Martin's Island
Date of collection: 28.10.23

Division: PHAEOPHYTA
Order: Dictyotales
Family: Dictyotaceae
Genus: **Dictyota** Lamx

7. *Dictyota dichotoma* (Hunds) Lamx. Fig. 4 G-K, 5 H
([5], p. 36, Pl. 39, Fig. 241;[15], p. 142, fig. 3)

Thallus pale to dark brown in color, robust, irregularly and dichotomously branched, each with a lens shaped apical cell, thallus anatomy reveals one to more layers of cortical cells, main thallus body 440 µm wide, branches 93.33-239.94 µm in width.

Collection No. 13
Habitat: Washed Ashore, Patuartyek beach, Cox's Bazar
Date of collection: 18.01.24

Genus: **Padina** Adanson

8. *Padina tenuis* Bory Fig. 3 F-H
([5], p. 39, Pl. 43, Fig. 253)

Plant dark brown, approx. 10 cm in height, 5 cm broad, fan-shaped, basal attachment a rhizoidal disc, stipe short, fronds radiated with concentric rings, lateral margins of the frond smooth, rows of hairs are present on the thallus, and rows of hairs alternate.

Collection No. 3
Habitat: Rocky (Attached to benthic rock surface), Saint Martin's Island
Date of collection: 28.10.23

Order: Punctariales
Family: Punctariaceae
Genus: **Colpomenia** Derbes & Solier

9. *Colpomenia sinuosa* (Roth) Derb. Fig. 5 E-G
([5], p. 43, Pl. 42, Fig. 250)

Thallus ball like vesicle, golden to dark brown, surface smooth convoluted, thallus anatomy shows a single layer short epidermal rectangular cell, sometimes with crypto-stomata. Whole plant body measures 5-8 cm.

Collection No. 14
Habitat: Washed Ashore, Patuartyek beach, Cox's Bazar
Date of collection: 18.01.24

Genus: **Hydroclathrus** Bory

10. *Hydroclathrus clathratus* (Ag.) Howe. Fig. 5 A-D
([5], p. 44, Pl. 42, Fig. 249)

Thallus body golden to dark brown, clathrate, densely perforated, window arms interlocked, slightly flattened, whole plant body 40-60 mm in dia., arm anatomy reveals single layer epidermal cell, short, rectangular, cells below small.

Collection No. 15
Habitat: Washed Ashore, Patuartyek beach, Cox's Bazar
Date of collection: 18.01.24

Order: Fucales
Family: Sargassaceae
Genus: **Sargassum** C. A. Agardh

11. *Sargassum flavicans* J. Ag. Fig. **3 M**
([5], p. 47, Pl. 30, Fig. 203)

Plant macroscopic, bushy, radially symmetrical, densely contained by laterals of ultimate and limited growth. Ultimate branchlets modified into vesicles and/or racemose-type branched receptacles. Fronds of the lower portion are relatively larger than the uppermost fronds, simple or divided, broad to filiform, entire or serrate or dentate, with a more or less prominent midrib. Fronds 15-17 mm long and 5-6 mm broad.
Collection No. 1
Habitat: Washed Ashore, Saint Martin's Island
Date of collection: 28.10.23

12. *Sargassum tenerrimum* (Turner) C. Ag.
([5], p. 47, Pl. 30, Fig. 202) Fig. **3 N**

Plant macroscopic, robust, branching pattern bushy, fronds prominent with clear dentition in the margin, branching distinct, arising from stolon-like organs, lower fronds large, gas vesicles prominent. Fronds 25-30 mm long, 8-12 mm broad.

Collection No. 2
Habitat: Washed Ashore, Saint Martin's Island
Date of collection: 28.10.23

Division: RHODOPHYTA
Order: Gigartinales
Family: Hypneaceae
Genus: **Hypnea** Lamx.

13. *Hypnea pannosa* J. Ag. Fig. 3 I-L
([5], p. 55; [15], p. 210-211)

Plants form bushy, tufted masses; individual fronds may be 40 cm long, with slender, spreading, and terete branchlets with spinulose branchlets, often crozier tips, and sometimes short, curved, or bent lateral branchlets may be present, which are often fusiform. Vegetative branch's cross section shows medullary cells with lenticular thickenings in their cell wall.

Collection No. 3
Habitat: Washed Ashore, Saint Martin's Island
Date of collection: 28.10.23

Order: CERAMIALES
Family: CERAMIACEAE
Genus: **Ceramium** Roth

14. *Ceramium fastigiatum* Harvey Fig. 4 A-F
([5], p. 59, Pl. 54, Fig. 317-318)

Plant bushy, forming a tufted mass, rose-red color, dichotomously branched, basal plant parts prostrate, branchlets tip incurved, nodes with 2-3 tiers of cells, cells of upper part relatively larger than the lower parts, around 80 µm in diameter, cells of internode around 200 µm long.

Collection No. 4
Habitat: Rocky intertidal zone Saint Martin's Island
Date of collection: 28.10.23

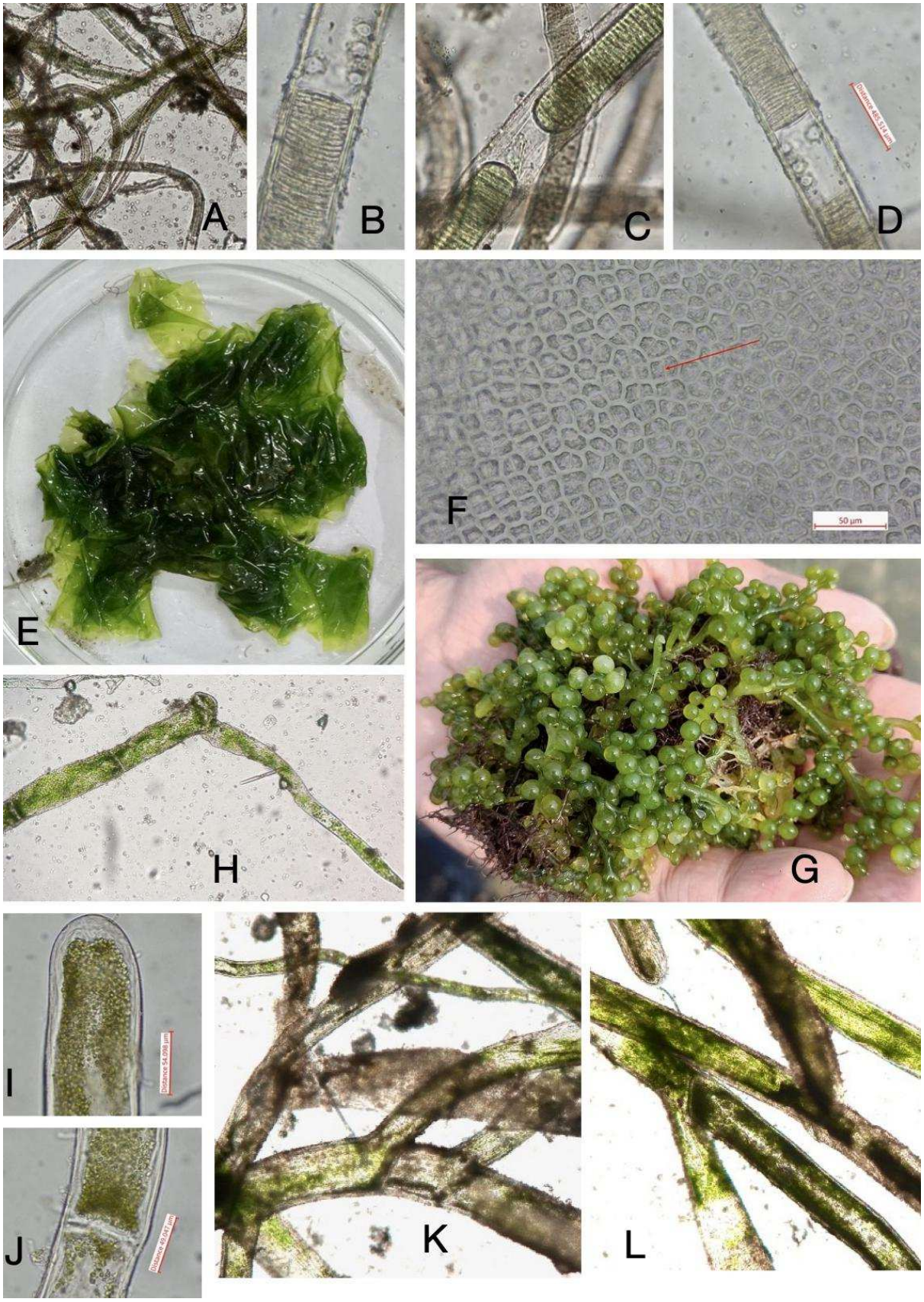
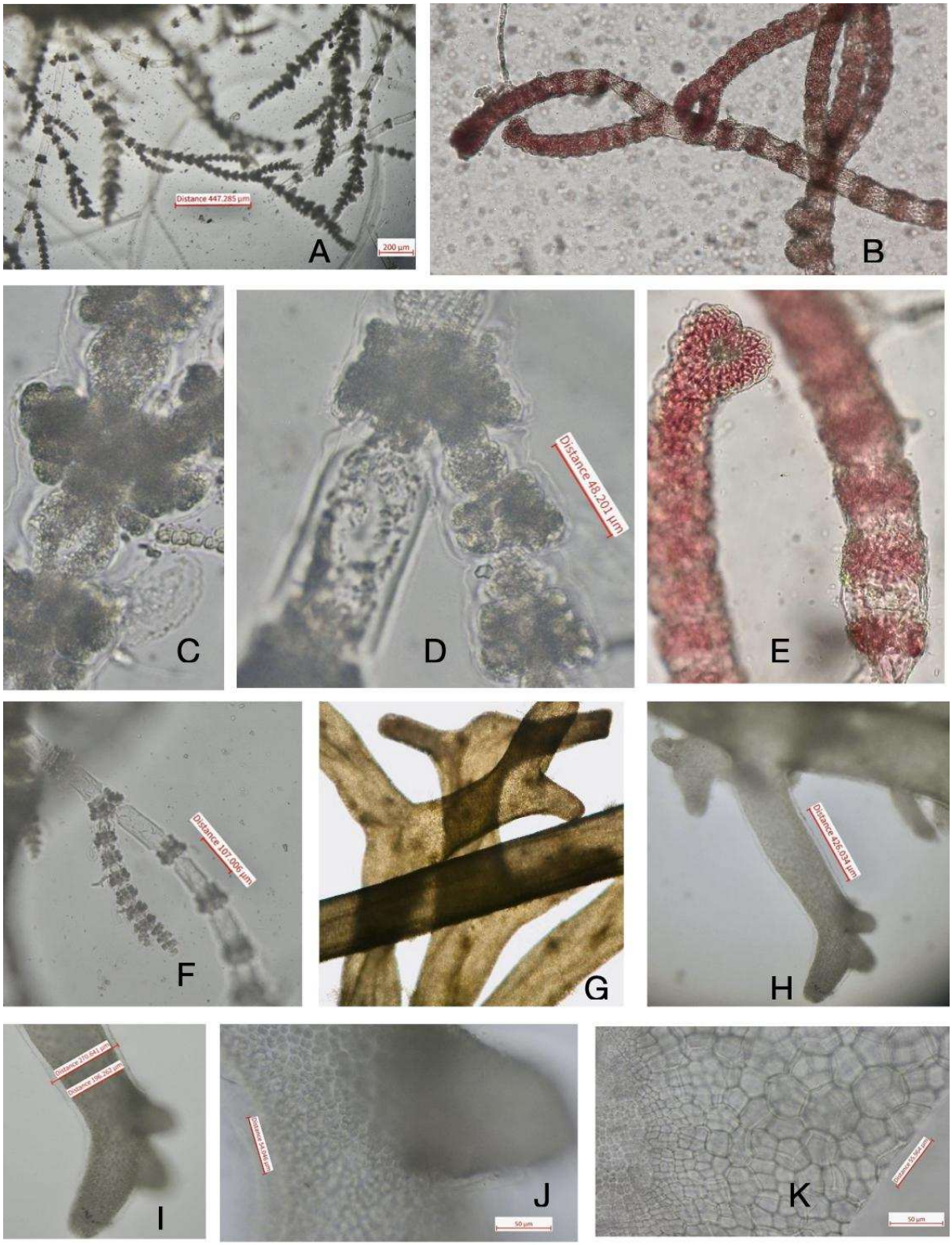


Fig. 2A-L. A-D, *Lyngbya magnifica*; E-F, *Ulva lactuca*; G, *Caulerpa racemosa* var. *clavifera*; H-L, *Cladophora echinus*.



Fig. 3A-N. A-D, *Cladophora patentiramea*; E, *Halimeda opuntia*; F, *Padina tenuis*; G, *P. tenuis*, surface view of the thallus; H, *P. tenuis*, cross section of thallus; *Cladophora echinus*. I-K, *Hypnea pannosa*; L. *H. pannosa*, cross section of thallus; M, *Sargassum flavicans*; N. *S. twnerrimum*.



345

346 **Fig. 4A-K.** A-F, *Ceramium festigiatum*; G-J, Dictyota *dichotoma;* K, *D. dichotoma,* transverse
347 section of thallus.

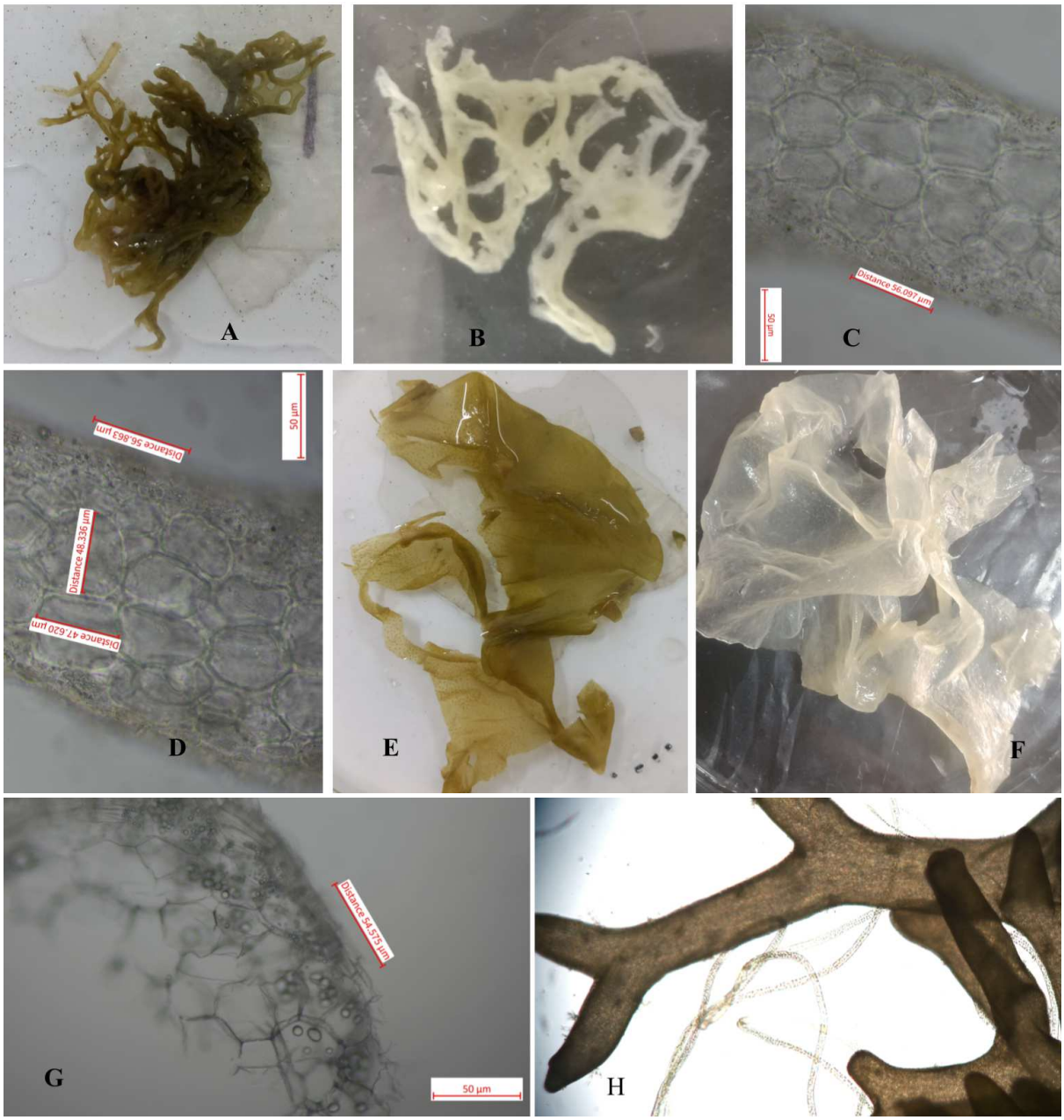


Fig. 5A-I. A-B, *Hydroclathrus clathratus* (a part of a broken thallus); C-D, *H. clathratus*, cross section of a thallus part; E-F, *Colpomenia sinuosa* (a part of the burst-out vesicle); G, *C. sinuosa*, transverse section of a thallus part; *H*, *Dictyota dichotoma*;

3.2 Algal Biodiversity and Distribution

The observed distribution indicates a comparable representation of green and brown algae within the study area, while red algae and cyanobacteria were comparatively less abundant. This pattern reflects the dominance of Chlorophyta and Phaeophyta in intertidal coastal habitats of the northeastern Bay of Bengal.

A clear habitat-based variation in species occurrence was observed between St. Martin's Island and the Cox's Bazar coast. The majority of recorded species were associated with rocky intertidal substrates, particularly coralline rocks of St. Martin's Island, where dense algal

assemblages were observed. In contrast, the sandy beaches of Cox's Bazar, including Inani and Patuartek, supported comparatively fewer species, with all the occurrences represented by washed-ashore specimens in contrast to Saint Martin Island. This difference strongly suggests that substrate availability plays a critical role in structuring algal communities [19], as attached macroalgae and mat-forming microalgae require stable surfaces for establishment and growth.

Microalgal assemblages were exclusively recorded from St. Martin's Island and were primarily associated with intertidal coral and coralline rock substrates. These taxa, including filamentous forms, were observed to form dense mat-like structures, particularly during the winter months. Such growth patterns indicate favorable environmental conditions, including relatively stable salinity and reduced wave disturbance, which collectively support the development of cohesive algal mats. In contrast, the higher turbidity and predominantly sandy substratum of Cox's Bazar likely limit microalgal attachment and persistence, thereby reducing their observable abundance.

Seasonal variation was also evident during the sampling period. Algal growth was comparatively lower during October–November, while a marked increase in abundance and biomass was observed during December to February. This trend corresponds with the dry winter season in Bangladesh, characterized by minimal precipitation (relatively stable salinity) and calmer sea conditions. Field observations further indicated that several macroalgal taxa, including *Sargassum* sp. and *Hypnea* sp., were frequently encountered as washed ashore biomass during peak winter months, suggesting seasonal detachment or increased productivity in adjacent subtidal zones.

Overall, the present study highlighted the importance of substrate type, water transparency, and seasonal stability in shaping algal community structure along the southeastern coast of Bangladesh. By integrating both macroalgal and microalgal components within a single survey framework, the study provides a more unified perspective on algal diversity and emphasizes the need for further ecological and taxonomic investigations, particularly in underexplored intertidal and subtidal habitats.

4. Conclusion

The present study provided a localized and systematic account of marine algal diversity from the southeastern coast of Bangladesh, documenting a total of 14 species across four major algal divisions. Systematic accounts have proven to be an effective approach for species-level identification and contribution to algal taxonomy. Algal morphology combined with anatomical feature analysis was utilized in this regard. The findings indicate a clear influence of habitat characteristics on species distribution, with the majority of taxa occurring on rocky intertidal substrates of St. Martin's Island, whereas the sandy coasts of Cox's Bazar supported comparatively fewer species, primarily represented by washed ashore forms. This pattern emphasized the importance of substrate availability and water transparency in structuring algal communities in the region. The study further highlighted that microalgal assemblages, particularly filamentous and mat-forming taxa, are closely associated with stable intertidal rocky habitats and remain underrepresented in previous studies from Bangladesh. By integrating both macroalgae and microalgae within a single survey framework, the present

work provides a more unified understanding of algal community structure, which has traditionally been studied separately. Its presence in intertidal rocky habitats suggests that similar overlooked taxa may exist in comparable environments, particularly where microalgal communities have not been systematically investigated. A weak factor in the classic approach of morphoanatomy is the absence of the reproductive structures in some samples. More advanced approaches like DNA barcoding and molecular-level identification are recommended for precise identification and conservation. Despite this resource constriction, this study successfully documented a number of known and unknown species from the region. A comprehensive checklist of macro and micro-algal species and their distribution patterns is critical for future studies, conservation, and comprehensive utilization of algal diversity. These efforts will contribute to conserving algal diversity and fostering sustainable utilization, ensuring the long-term benefits of seaweed resources for ecological and economic purposes.

Acknowledgements

The authors express their gratitude to the local people of St. Martin's Island and Cox Bazar for helping them guiding to the zones of marine algae.

Author contributions

Swachsa Rahman: Research Design, Filed Sampling, Assistance in Lab Analysis, Manuscript Writing; **Moniruzzaman Khondker:** Algae Identification, Research Supervision, Manuscript Review and Editing; **Hasibul Hasan**: Field Sampling, Map Generation; **Trisha Paul:** Manuscript Writing, Assistance in Lab Analysis, **Mahmudul Hasan**: Manuscript Review, Research Supervision

Funding

This research was part of Master's Thesis of One of the authors. The research received fund from the National Science and Technology Fellowship (Master's), 2023 offered by Ministry of Science and Technology (MOST), Bangladesh**.**

Availability of data and materials

All data analyzed during this study are included in this article.

Conflict of interests

The authors declare no competing interests.

Ethics approval

Not Applicable.

Consent to participate

Not Applicable.

Consent for publish

Not Applicable.

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