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Species composition of seaweed biofoulers in fish cage aquaculture in Bongao Channel, Tawi-Tawi, Philippines

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Abstract

The excessive growth of seaweeds (macroalgal biofouling) on submerged cage structures is a severe operational constraint for fish cage aquaculture in tropical environments. This study investigated the species composition of macroalgal biofouling growing on the submerged structures of the fish cage aquaculture in Bongao Channel, Tawi-Tawi, Philippines, via a qualitative survey (e.g., snorkeling around the cage systems). The primary objective was to provide a taxonomic inventory of the colonizing seaweed species to understand the biological makeup of the fouling community. Through morphological examination of the collected samples, a total of 26 species belonging to 16 distinct genera were identified, representing the three major algal divisions: Chlorophyta (green algae) exhibited the highest generic richness, including *Boergesenia*, *Caulerpa*, *Chaetomorpha*, *Cladophora*, *Halimeda*, *Boodlea*, and *Ulva*. Rhodophyta (red algae) were represented by *Acanthophora*, *Actinotrichia*, *Chondrophycus*, *Yonagunia*, *Gracilaria*, *Hypnea*, and *Endosiphonia*, while Ochrophyta (brown algae) included *Padina* and *Sargassum*. The presence of various taxa, particularly filamentous *Chaetomorpha* and stoloniferous *Caulerpa*, identifies these groups as the key structural components of the biofouling community on the cage nets. Additionally, the inventory recorded the occurrence of economically valuable red algae (e.g., *Gracilaria* and *Hypnea*) and ecologically significant brown algae (e.g., *Sargassum*) within the assemblage. These findings establish a critical taxonomic baseline, providing the essential species-level data required to develop targeted mitigation strategies and sustainable management practices for the floating cage aquaculture in Tawi-Tawi.

Keywords: Aquaculture, Biofouling, Macroalgae, Seaweeds

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1. Introduction

Aquaculture is a critical pillar of global food security, evolving through intensive production systems to meet the rising demand for aquatic products (Bostock et al., 2010; Verdegem et al., 2023; Tahiluddin et al., 2025). Among these systems, cage culture remains a cornerstone of Asian aquaculture, originating from traditional practices in the Mekong Basin and evolving into a sophisticated global industry (De Silva & Phillips, 2007). Floating net cages are particularly advantageous in tropical regions because they utilize natural water currents for oxygenation and waste removal, theoretically eliminating the need for active water-quality management (Nagler et al., 2003; Alcantara & Noro, 2006).

However, the continuous immersion of aquaculture infrastructure in nutrient-rich tropical waters facilitates the rapid colonization of submerged surfaces by a wide array of organisms. This phenomenon, known as biofouling, represents one of the most significant operational constraints in the aquaculture industry (Bannister et al., 2019). Macroalgal biofouling, specifically, creates a physical barrier on nets, ropes, and frames. The accumulation of these seaweeds restricts water exchange, increases hydrodynamic drag on the structures, and may lead to localized depletions of dissolved oxygen (Madin et al., 2010; Fitridge et al., 2012; Mascorda Cabre et al., 2021). Furthermore, heavy fouling can decrease the effective volume of the cage by causing net deformation, thereby increasing stocking density and stressing the cultured fish (Fitridge et al., 2012).

Tawi-Tawi, located at the heart of the Coral Triangle in the southern Philippines, is a region of immense marine biodiversity (Muallil et al., 2020). The Bongao Channel serves as a vital waterway in this province, supporting a high richness of wild fish, corals, and macroalgae. While the cage culture industry in Tawi-Tawi has expanded gradually over the last two decades (Imlani et al., 2022), it faces persistent challenges from local biofouling communities. At the Mindanao State University–Tawi-Tawi College of Technology and Oceanography (MSU-TCTO) experimental floating cages, seaweed colonization is a visible and constant factor affecting cage maintenance.

Despite the clear operational impacts of biofouling, there is a notable lack of site-specific data regarding the taxonomic makeup of these communities in Tawi-Tawi. Understanding the species composition is a prerequisite for any mitigation strategy, as different seaweed taxa (e.g., filamentous vs. leathery algae) have varying rates of growth and impacts on water flow. Currently, baseline information on the macroalgal biofoulers of the Bongao Channel remains fragmented.

The present study aimed to address this knowledge gap by documenting the species composition and generic richness of macroalgal biofoulers on the MSU-TCTO floating fish cages. By establishing this taxonomic baseline, this research provides the essential biological data needed to develop sustainable management practices and effective fouling mitigation strategies for the burgeoning aquaculture industry in the region.

2. Material and Method

2.1. Study area

The study was conducted at the experimental floating fish cage facility of MSU-TCTO, situated within the Bongao Channel, Tawi-Tawi, southern Philippines (Figure 1). This area is characterized by high marine biodiversity and constant water exchange, making it a representative site for tropical small-scale cage aquaculture.

2.2. Sample collection

A qualitative survey of attached seaweeds was conducted via snorkeling to document the species composition on various submerged substrates, including nets, mooring ropes, and floating HDPE drums.

This study was designed as a preliminary taxonomic baseline assessment to provide a high-resolution snapshot of the fouling community during September, e.g., the wet season. While macroalgal communities exhibit seasonal shifts, this single-event sampling focused on achieving a comprehensive inventory of the taxa present during peak fouling periods to establish a primary reference for the region. Collected specimens were placed in labeled polyethylene bags with ambient seawater and transported immediately to the Seaweed Post-Harvest Laboratory, College of Fisheries, for processing. To maintain the study's focus on taxonomic richness, environmental parameters were not recorded, as the primary objective was the establishment of a species-level checklist.

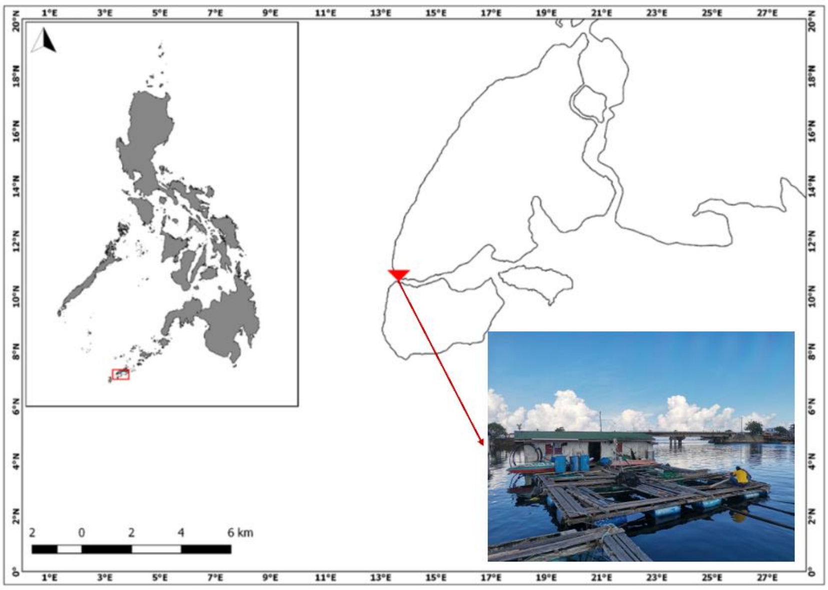

Figure 1. Map of Bongao, Tawi-Tawi, Philippines showing the MSU-TCTO floating fish cage

2.3. Laboratory procedures and species identification

Sorting and cleaning

Upon arrival at the laboratory, the macroalgal samples were allowed to acclimate in seawater for 30 minutes to maintain tissue integrity. The specimens were then meticulously cleaned of debris, sediment, and mobile epifauna using filtered seawater, followed by a brief rinse in distilled water to remove external salts.

The samples were processed into herbarium vouchers following standard phycological techniques (Tsuda & Abbott, 1985). Specimens were air-dried at room temperature (25-27 °C) for approximately one hour before being arranged on acid-free paper. The specimens were then pressed using a traditional wooden plant press, with blotting paper and corrugated cardboard changed every 24 hours to prevent fungal growth and ensure rapid desiccation. This process was maintained for three to five days until the specimens were fully dehydrated.

Taxonomic identification

The identification of the macroalgal biofoulers was based on a detailed examination of morphological and vegetative characters. Diagnostic features such as branching patterns, thallus structure, and specialized attachment organs (holdfasts) were analyzed. Taxonomic nomenclature and classification were verified using the following authoritative references: AlgaeBase (Guiry & Guiry, 2025) for current valid names and authorities, and Field Guide and Atlas of the Seaweed Resources of the Philippines (Trono, 1997) for regional morphological variations.

3. Results and Discussion

A total of 26 macroalgal species belonging to 16 genera were identified from the MSU-TCTO floating fish cage facility (Table 1). Chlorophyta (green algae) exhibited the highest taxonomic richness with 14 species (54% of the total), followed by Rhodophyta (red algae) with 8 species (31%), and Ochrophyta (brown algae) with 4 species (15%).

The Chlorophyta group was represented by seven genera: *Boergesenia*, *Caulerpa*, *Chaetomorpha*, *Cladophora*, *Halimeda*, *Boodlea*, and *Ulva*. As illustrated in Figure 2, these taxa ranged from stoloniferous forms to filamentous mats. Notably, *Caulerpa* and the filamentous *Chaetomorpha* were the most prominent genera observed colonizing the ropes and nets of the aquaculture structure.

The Ochrophyta were represented by two genera, *Padina* and *Sargassum* (Figure 3). These brown algae are characterized by their larger, more complex thalli compared to the green algae found on the site. Finally, the Rhodophyta displayed a diverse generic composition with seven identified genera: *Acanthophora*, *Actinotrichia*, *Chondophycus*, *Yonagunia*, *Gracilaria*, *Hypnea*, and *Endosiphonia* (Figure 4).

The prevalence of Chlorophyta in the Bongao Channel suggests a highly productive environment characterized by shallow depths and high light penetration. Genera such as *Caulerpa*, *Ulva*, and *Halimeda* are ubiquitous in tropical reef-associated ecosystems in the Philippines (Trono, 1997), where stable substrates—in this case, aquaculture infrastructure—allow for rapid colonization (Mineur et al., 2012). The presence of a taxonomically rich assemblage, including climax-stage genera like *Sargassum*, indicates relatively stable environmental conditions and minimal anthropogenic disturbance within the channel (Littler & Littler, 1984; Steneck & Dethier, 1994; Schaffelke et al., 2007).

While biofouling communities can act as natural filtration systems, their proliferation on aquaculture systems poses significant technical risks. As noted by Fitridge et al. (2012), the primary concerns involve the restriction of water exchange and the potential for cage deformation under increased hydrodynamic loads.

Table 1. Taxonomic checklist of seaweed biofoulers in the MSU-TCTO floating fish cage

No.	Phylum	Genus	Species
1	Chlorophyta	*Boergesenia*	*Boergesenia forbesii*
2		*Caulerpa*	*Caulerpa brachypus*
3			*Caulerpa nummularia*
4			*Caulerpa oligophylla*
5			*Caulerpa racemosa*
6		*Chaetomorpha*	*Chaetomorpha linum*
7			*Chaetomorpha crassa*
8		*Cladophora*	*Cladophora* sp.
9		*Halimeda*	*Halimeda cuneata*
10			*Halimeda discoidea*
11			*Halimeda copiosa*
12		*Boodlea*	*Boodlea composita*
13		*Ulva*	*Ulva reticulata*
14			*Ulva lactuca*
15	Ochrophyta	*Padina*	*Padina gymnospora*
16		*Sargassum*	*Sargassum aquifolium*
17			*Sargassum oligocystum*
18			*Sargassum polycystum*
19	Rhodophyta	*Acanthophora*	*Acanthophora spicifera*
20		*Actinotrichia*	*Actinotrichia fragilis*
21		*Chondrophycus*	*Chondrophycus* sp.
22		*Yonagunia*	*Yonagunia millardii*
23		*Gracilaria*	*Gracilaria salicornia*
24			*Gracilaria corticata*
25		*Hypnea*	*Hypnea musciformis*
26		*Endosiphonia*	*Endosiphonia* sp.

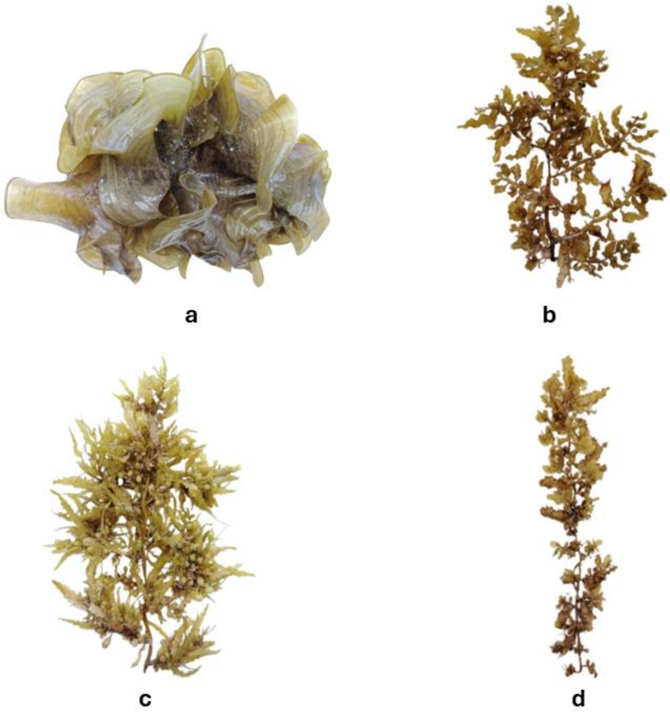

Figure 2. Ochrophyta, the brown seaweeds. a) *Padina gymnospora*, b) *Sargassum aquifolium*, c) *Sargassum oligocystum*, and d) *Sargassum polycystum*

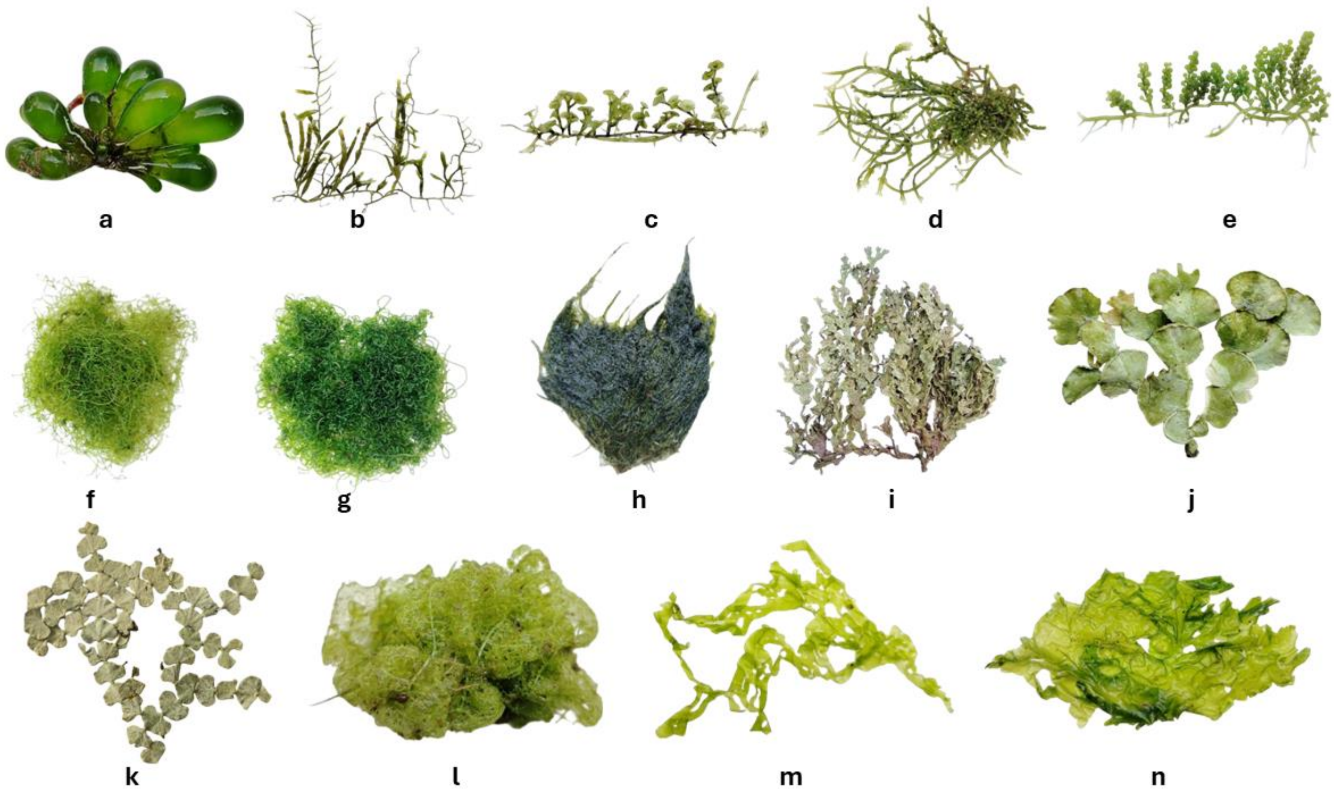

Figure 3. Chlorophyta, the green seaweeds. a) *Boergesenia forbesii*, b) *Caulerpa brachypus*, c) *Caulerpa nummularia*, d) *Caulerpa oligophylla*, e) *Caulerpa racemosa*, f) *Chaetomorpha linum*, g) *Chaetomorpha crassa*, h) *Cladophora* sp., i) *Halimeda cuneata*, j) *Halimeda discoidea*, k) *Halimeda copiosa*, l) *Boodlea composita*, m) *Ulva reticulata*, and n) *Ulva lactuca*

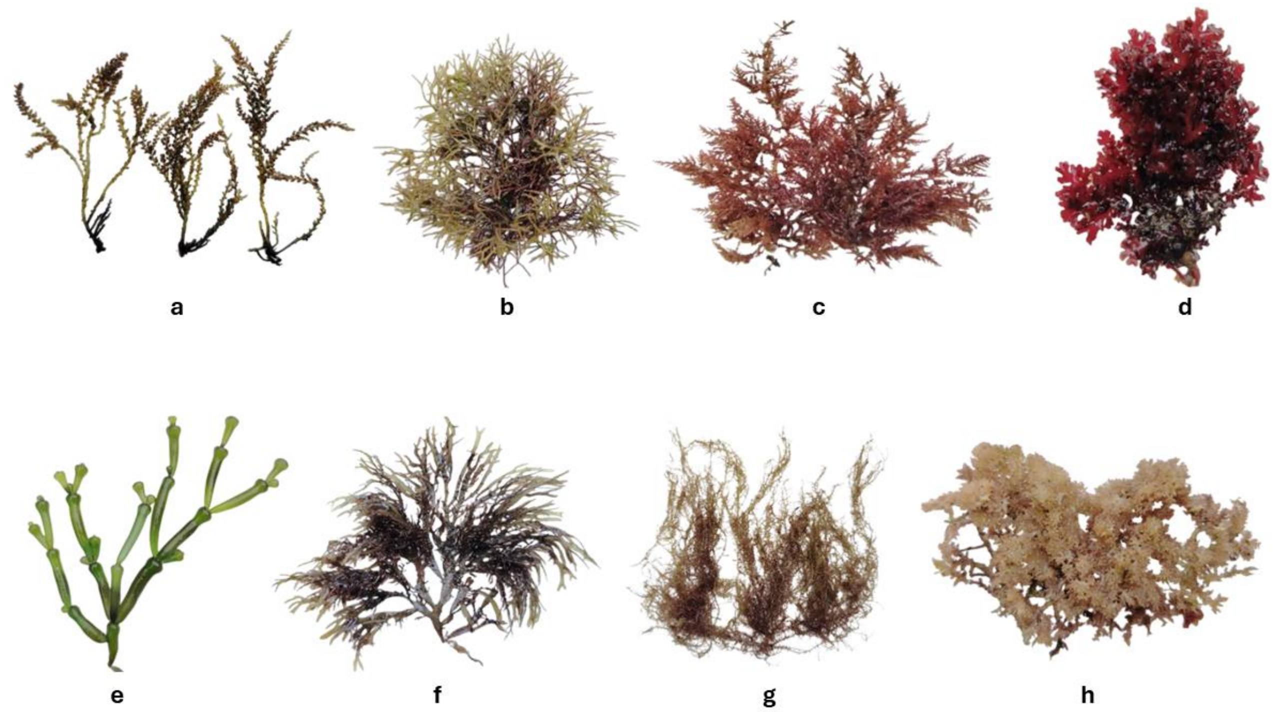

Figure 4. Rhodophyta, the red seaweeds. a) *Acanthophora spicifera*, b) *Actinotrichia fragilis*, c) *Chondrophycus* sp., d) *Yonagunia millardii*, e) *Gracilaria salicornia*, f) *Gracilaria corticata*, g) *Hypnea musciformis*, and h) *Endosiphonia* sp.

Observations from cage personnel at the MSU-TCTO facility confirm that while seaweed attachment does not appear to directly inhibit fish growth, it significantly reduces the effective culture volume. This “occupational fouling” can lead to localized reductions in water flow, hindering the removal of metabolic wastes and potentially facilitating the transmission of pathogens by providing a biological substrate for viral or bacterial hosts (Fitridge et al., 2012).

Conversely, the fouling community provides several ecosystem services that enhance the sustainability of the floating cage system. The identified *Sargassum* species are ecologically vital, acting as complex three-dimensional habitats and nursery grounds for juvenile fish and invertebrates (Casazza & Ross, 2008). These brown algae concentrate prey resources and offer protection from predators, effectively turning the aquaculture site into a localized biodiversity hotspot.

Furthermore, the documentation of Rhodophyta genera such as *Gracilaria*, *Hypnea*, and *Acanthophora* underscores the economic potential of the Bongao Channel. These taxa are high-value sources of agar and carrageenan, polysaccharides with increasing demand in the global food and industrial sectors (McHugh, 2003; Bixler & Porse, 2011; Jayakody et al., 2022). The natural abundance of these red algae suggests that the biofouling present on aquaculture structures could be viewed not just as a waste product, but as a potential secondary resource for sustainable seaweed farming ventures in the region.

4. Conclusion

This study provides the first comprehensive taxonomic checklist of seaweed biofoulers in the MSU-TCTO floating fish cage facility in Bongao Channel, Tawi-Tawi, Philippines. A total of 26 species were identified, with Chlorophyta being the most taxonomically diverse group. The results confirm that the fouling community is composed of a mix of opportunistic green algae, ecologically significant brown algae, and economically valuable red algae. As a baseline inventory, these findings provide the necessary biological data for local aquaculture managers to design targeted mitigation strategies, such as mesh size adjustments or scheduled mechanical cleaning, to maintain optimal cage performance in the Bongao Channel.

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Conflict of interest

The authors declare no conflict of interest.

Ethical Approval

This arcticle does not require ethics committee approval.

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