Chapter 4

Macroalgae Species as Zonal Indicators of Coral Reef: A Case Study from Bet Shankhodhar Reef, India

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Additional information is available at the end of the chapter

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Abstract

Tropical coral reefs are major habitats for marine macroalgae or seaweeds. Macroalgae represent a key functional group among the coral reef communities and perform vital ecological functions like reef structure stabilisation, production of tropical sands, nutrient retention and recycling, primary productivity and trophic support. Coral reef macroalgae are comprised of three major pigment-group-based phyla: Chlorophyta (green algae), Heterokontophyta or Ochrophyta (brown algae) and Rhodophyta (red algae). Green macroalgae or Chlorophyta contain chlorophyll *a* and *b* pigments in the same proportion as that of higher plants along with β-carotene and xanthophylls and have significant industrial or commercial value. Chlorophyta members commonly inhabit the littoral zone with strong sunlight. This chapter highlights micro-level habitat preference of green macroalgae or Chlorophyta species sampled from Bet Shankhodhar Reef from the Gujarat coast of India as a unique case study. This study identifies four Chlorophyta species: *Halimeda tuna* (Ellis & Solander) Lamouroux, *Caulerpa sertularioides* (S. Gmelin) Howe *f. brevipes* (J. Agardh) Svedelius, *Valonia aegagropila* C. Agardh and *Valoniopsis pachynema* (Martens) Børgesen, as indicator species of the backreef zone. Shallow tidal pools in the backreef zone of Bet Shankhodhar Reef are preferred microhabitats for *C. sertularioides* and *V. aegagropila*.

Keywords: coral reef, macroalgae, Chlorophyta, microhabitat, indicator species

1. Introduction

Tropical coastal and near-shore marine wetlands include a wide range of habitats with different structural complexities (e.g., rock coasts, soft-sediment coasts, estuaries, mangroves, salt marshes, coral reefs and seagrass beds). The intricate, three-dimensional, underwater

landscape of coral reefs provides necessary habitat to one-third of known marine species [1] including some of the rare avifauna [2]. Coral reefs are critical eco-resources [3] to many of the maritime tropical and subtropical nations. For many of these nations, their physical foundation to national economies depend on reef-related ecosystem goods and services [4, 5].

Marine macroalgae or seaweeds occupy variety of habitats offered by the coastal and nearshore marine wetlands. Macroalgae represent a key functional group among the coral reef communities and perform vital ecological functions like reef structure stabilisation, production of tropical sands, nutrient retention and recycling, primary productivity and trophic support [6]. Coral reef macroalgae are comprised of three major pigment group-based phyla: Chlorophyta (green algae), Heterokontophyta (brown algae) and Rhodophyta (red algae). This systematic classification is based on the composition of pigments involved in photosynthesis [7]. The presence of chloroplasts and subsequent capacity to photosynthesize allow reef macroalgae to play the vital ecological role of primary producers in a reef ecosystem. Other than their ecological roles as habitat formers and primary producers, reef macroalgae are economically important. They are important sources of food, fodder, fertiliser, medicinal compounds and industrial raw materials.

Marine green algae or Chlorophyta are naturally abundant and record high biodiversity in tropical coral reefs and lagoons, often intermixed with associated seagrass habitats [6, 8]. Chlorophyta have predominantly green chlorophyll pigments: chlorophyll *a* and *b* in the same proportion as that of higher or vascular plants along with accessory carotenoid and xanthophyll pigments. Structurally, green seaweeds range from thread-like filaments to thin sheets and can be spongy, gelatinous, papery, leathery or brittle in texture [8]. Their morphological appearance is shaped through their cell division process [9]. Chlorophyta are generally siphonaceous or giant-celled forms which employ a unique cytoplasmic streaming or blade abandonment mechanism to eliminate epiphytes [8]. Certain genera of filamentous and sheet-like green algae are stress tolerant and can be potential indicators of freshwater seeps, disturbed areas of the habitat, areas of low herbivory and significant areas with an overabundance of nutrients [8].

In general, Chlorophyta are usually found in the littoral zone with strong sunlight. Availability of suitable substrate, light quality and quantity, availability of nutrients, intra- and interspecific competition, herbivory and grazing are major factors that delimit spatial and temporal occupancy of macroalgae in a given habitat [6]. Algal pigments and their photosynthetic capability and adaptations to different light levels lead to their depth zonation within the habitat. This chapter explores the concept of species-specific microhabitat preference of green macroalgae in a coral reef habitat of India based on field survey data.

2. Study area: Bet Shankhodhar Reef

Coral reefs provide a hard and stable habitat for algal settlers as compared to any other soft sediment coastal habitats like beaches, spits, estuaries and mudflats. India has a coastline length of 7500 km with diverse coastal habitats which support rich seaweed biodiversity [10].

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The state of Gujarat shares 1600 km of the Indian coastline and represents the northwestern most part of the peninsular India. Gujarat coast is known to harbour a rich diversity of seaweeds as its rocky segments provide suitable environment for macroalgal settlement and growth [11]. Gujarat coastline falls within the geographical limits of 20°08′–24°40′ north latitudes and 68°10′–74°28′ east longitudes. From north to south, the Gujarat coast can be divided into four major coastal ecological components: (i) Kori Creek, (ii) Gulf of Kachchh, (iii) Saurashtra coast from Okha to Porbandar and (iv) Gulf of Khambhat [12], situated in three distinct macro-geomorphological settings of a deltaic creek, two gulfs and a rocky coast.

Gulf of Kachchh (**Figure 1A** and **B**) marks the northernmost limit of reef development on the continental shelf of India [13]. Gulf of Kachchh is a funnel-shaped, east-west-oriented, seismically active indentation between the Kachchh mainland and Saurashtra/Kathiawar peninsula of Gujarat state in India [14]. This gulf occupies an area of 7350 km^2 with an average depth of 30 m [15]. Gulf of Kachchh represents a high-energy, semi-diurnal, macro-tidal environment with varying tidal amplitude of 4 m at its mouth to 7 m in the inner gulf [14]. The southern shore of the gulf is relatively smooth and has an assemblage of ecologically sensitive ecosystems including coral reefs, seagrass beds, seaweeds, mangroves and tidal flats [15].

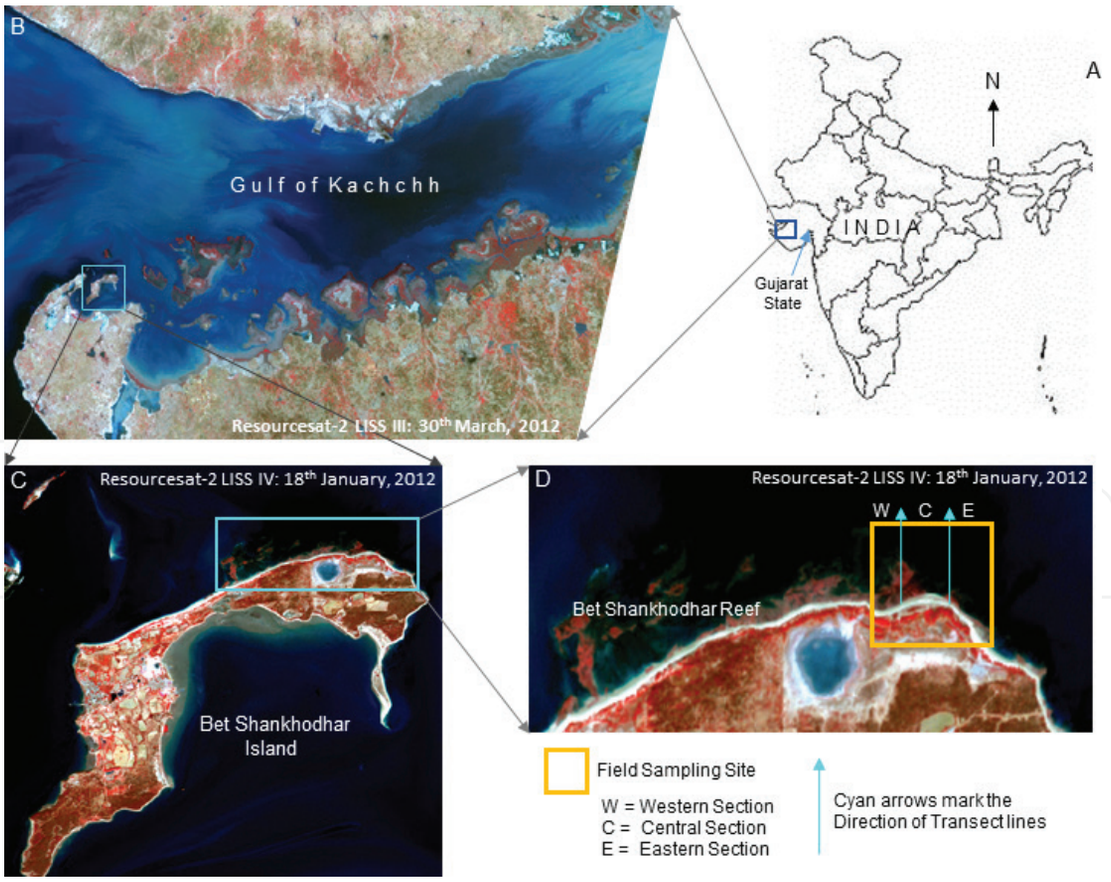

Figure 1. Location of the study site at Bet Shankhodhar Reef, India. (A) Location of Gulf of Kachchh in India, (B) location of Bet Shankhodhar Island in Gulf of Kachchh, (C) location of coral reef area in Bet Shankhodhar Island, (D) study/field sampling site at Bet Shankhodhar Reef.

The coral reefs in Gulf of Kachchh are predominantly patchy structures built up on wave-cut sandstone banks [16] on the southern shore of the gulf along with 34 adjoining islands [17]. These coral reefs are mainly comprised of fringing structure with all sub-types (i.e., platform, patch and coral pinnacles; [13]) restricted to a vast intertidal region [18]. Gulf of Kachchh coral reefs are adapted to extreme environmental conditions: high temperature ranges (10–35°C), high salinity ranges (25–40 ppt), large tidal ranges, strong tidal currents and heavy sediment loads [19]. As a result of isolation and above-mentioned extreme environmental conditions, the species diversity of corals in this region is low [20]. The coral reefs of Gulf of Kachchh are under International Union for Conservation of Nature (IUCN) Category I Marine Protected Area (MPA). Gulf of Kachchh Marine Sanctuary and Marine National Park were established in 1980 and 1982, respectively [21].

The present study was carried out in the coral reef area adjacent to Bet Shankhodhar Island (**Figure 1B** and **C**) situated to the east of Okhamandal area on the mainland coast and 2 km away from the Okha Port. The island owes its name Bet Shankhodhar to its unique shape resembling that of a conch shell [22]. Bet Shankhodhar Island has a fringing reef area (**Figure 1C**) of 28 hectares to its north [22] adjacent to a narrow strip of beach with significant exposures of beach rock [23]. This reef was selected for the present case study for its reported diversity of 120 species of macroalgae [22]. The study site on Bet Shankhodhar Reef is located within the coordinates of 22°28′36″ N–22°28′52″ N latitudes and 68°08′14″ E–69°08′40″ E longitudes and covered a survey area of 0.35 km^2 (**Figure 1D**). The survey area of the reef was further divided into three micro-zones in the north-south direction based on their topographical and geomorphological characteristics and level of tidal inundation. These three

Figure 2. Microhabitat zones of Bet Shankhodhar Reef. (A) Exposure of subtidal zone, (B) Backreef zone I and (C) Backreef zone II.

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zones (**Figure 2**) are: (i) subtidal zone or the fore reef, (ii) Backreef zone I and (iii) Backreef zone II. The subtidal zone or the fore reef was the northernmost zone which got exposed only during the spring tides while the backreef zone I or the intertidal reef flat was interspersed with large rock pools. The backreef zone II was the southernmost zone, adjacent to the beach and was characterised with coastal lapiés and smaller rock pools [23].

3. Field data collection and analysis

3.1. Field sampling of seaweeds/macroalgae

The study area of Bet Shankhodhar Reef was divided into three sections in the west-east direction, as: (i) western, (ii) central and (iii) eastern sections (**Figure 1D**) for systematic field sampling and equal representation of the reef habitat. Seaweed sampling was routinely carried out for 2 years: from April 2013 to April 2015 with sampling exercise coinciding with the annual cycles of seaweed abundance and growth, that is, local seasons of post-monsoon (October-November), winter (December-February), spring (March) and summer (April-June), respectively. Field surveys/samplings were carried out during low-tide exposures of the reef following line intercept transects (LITs). For quantitative assessment of the seaweeds in the given area, the GPS-tagged, LITs were laid perpendicular to the coast in a seaward direction with the help of a 50-m-long rope [24]. The length of the transect essentially depended on the tidal exposure of the reef during the field surveys. The minimum and maximum transect lengths surveyed were 52 and 372.5 m, respectively. The maximum depth of the subtidal zone sampled for the present study is 1 m. Quadrats of 1 m^2 were positioned over the transects for quantitative seaweed sampling wherever macroalgal growth, density and diversity were visibly high. A total of 182 GPS-tagged quadrats was sampled for the seaweeds over a total of 23 transects on the reef site.

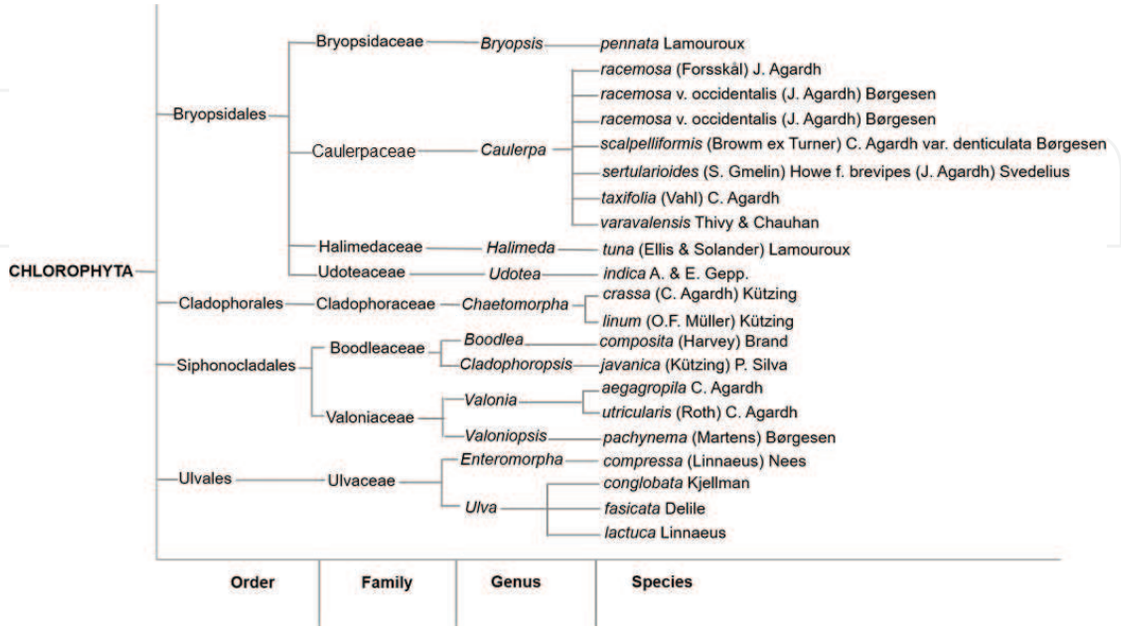

Figure 3. Cladogram of Chlorophyta species sampled from Bet Shankhodhar Reef.

3.2. Field data analysis

Macroalgae samples collected from the field were taken to laboratory for herbarium preparation and sample identification. Morphological criteria and reproductive structures of the algae specimens were analysed for taxa identification. A cladogram (**Figure 3**) was prepared for the sampled Chlorophyta in order to generate classification statistics, that is, number of genera and species pertaining to different families and genera.

4. Results and discussion

Twenty-one species of Chlorophyta (**Table 1**) were identified based on the field survey data collected for 2 years: April 2013 to April 2015. These species belonged to 4 orders, 7 families and 11 genera as shown in the cladogram (**Figure 3**). As the Chlorophyta species distribution is tagged with the zonal morphology of the Bet Shankhodhar Reef as a part of this study, it is found that the sampled species can be classified into five major groups as per their zonal or microhabitat occurrences. These five groups are: (i) subtidal and Backreef zone I species, (ii) Backreef zone I species, (iii) Backreef zone I and zone II species, (iv) ubiquitous species and (v) chance factor species. The taxonomic details of the species classified under these five major groups are mentioned below.

i. Subtidal and Backreef zone I species: the subtidal and backreef zone I species include four Chlorophyta species from two families: Caulerpaceae and Udoteaceae. *Caulerpa racemosa* v. *occidentalis* (J. Agardh) Børgesen and *Caulerpa scalpelliformis* (Brown ex Turner) C. Agardh var. *denticulata* Børgesen and *Caulerpa taxifolia* (Vahl) C. Agardh belong to the Caulerpaceae family while *Udotea indica* A. & E. Gepp represents the Udoteaceae family.

ii. Backreef zone I species: Backreef zone I species include four members from three families: Caulerpaceae, Halimedaceae and Valoniaceae. *Caulerpa sertularioides* (S. Gmelin) Howe *f. brevipes* (J. Agardh) Svedelius represents the Caulerpaceae family while *Halimeda tuna* (Ellis & Solander) Lamouroux belongs to the Halimedaceae family. *Valonia aegagropila* C. Agardh and *Valoniopsis pachynema* (Martens) Børgesen are members of the Valoniaceae family.

iii. Backreef zone I and zone II species: the backreef zone I and zone II species again include four species representing three families: Boodleaceae, Ulvaceae and Valoniaceae. *Boodlea composita* (Harvey) Brand and *Cladophoropsis javanica* (Kützing) P. Silva represent the first family while *Ulva conglobata* Kjellman belongs to the Ulvaceae family. *Valonia utricularis* (Roth) C. Agardh is the other species identified in the backreef zone I and zone II. These four species were found in both the backreef zones from all three sections of Bet Shankhodhar Reef and were absent in the subtidal zone.

iv. Ubiquitous species: Chlorophyta species found in all the three reef zones were considered as ubiquitous species. For Bet Shankhodhar Reef, ubiquitous species included five Chlorophyta species representing three families. *Caulerpa veravalensis* Thivy & Chauhan belonged to Caulerpaceae family while *Chaetomorpha crassa* (C. Agardh) Kützing belonged

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to Cladophoraceae family. The other three species: *Enteromorpha compressa* (Linnaeus) Nees, *Ulva fasciata* Delile and *Ulva lactuca* Linnaeus are members of the Ulvaceae family.

v. Chance factor species: the Chlorophyta species encountered only once during the two-year field sampling are considered as chance factor species. In the case of Bet Shankhodhar

Sr. No.	Chlorophyta species	Field site: Bet Shankhodhar Reef								
		Months								
		O	N	D	J	F	M	A	M	J
1	*Boodlea composita* (Harvey) Brand	×	×	√	√	√	×	×	×	×
2	*Bryopsis pennata* Lamouroux	×	×	×	√	×	×	×	×	×
3	*Caulerpa racemosa* (Forsskål) J. Agardh	×	×	×	×	×	√	×	×	×
4	*Caulerpa racemosa* (Forsskål) J. Agardh *V. macrophysa* (Sonder ex Kützing) Taylor	×	×	×	√	×	×	×	×	×
5	*Caulerpa racemosa v. occidentalis* (J. Agardh) Børgesen	×	×	√	√	√	×	√	×	×
6	*Caulerpa scalpelliformis* (Brown ex Turner) C. Agardh var. *denticulata* Børgesen	×	×	×	×	×	√	√	×	×
7	*Caulerpa sertularioides* (S. Gmelin) Howe *f. brevipes* (J. Agardh) Svedelius	×	×	√	√	√	×	×	×	×
8	*Caulerpa taxifolia* (Vahl) C. Agardh	×	×	√	√	√	√	√	×	×
9	*Caulerpa veravalensis* Thivy & Chauhan	√	×	√	√	×	×	×	×	×
10	*Chaetomorpha crassa* (C. Agardh) Kützing	×	×	×	√	√	√	√	×	×
11	*Chaetomorpha linum*(O. F. Müller) Kützing	×	×	×	×	×	√	×	×	×
12	*Cladophoropsis javanica* (Kützing) P. Silva	×	×	×	×	√	√	√	×	×
13	*Enteromorpha compressa* (Linnaeus) Nees	×	×	√	√	√	√	×	×	×
14	*Halimeda tuna* (Ellis & Solander) Lamouroux	√	×	×	×	×	×	√	×	×
15	*Udotea indica* A. & E. Gepp.	×	×	×	×	√	×	√	×	√
16	*Ulva conglobata* Kjellman	×	×	√	√	×	×	×	×	×
17	*Ulva fasciata* Delile	×	×	×	×	√	√	√	×	×
18	*Ulva lactuca* Linnaeus	×	×	√	√	√	√	√	×	×
19	*Valonia aegagropila* C. Agardh	×	×	√	×	√	×	×	×	×
20	*Valonia utricularis* (Roth) C. Agardh	×	×	√	√	×	×	√	×	×
21	*Valoniopsis pachynema* (Martens) Børgesen	×	×	√	√	×	×	×	×	×

The calendar months are denoted with the first letter, for example, O = October, starting with October and continuing up to June indicating local post-monsoon, winter, spring and summer seasons; √ denotes presence and x denotes absence of the species.

Table 1. Chlorophyta species observed during different months at Bet Shankhodhar Reef.

Reef, four species were found as chance factor species. These species include *Bryopsis pennata* Lamouroux from the Bryopsidaceae family. This species was found in the fore reef zone of the western section of the reef. Two species of *Caulerpaceae*: *Caulerpa racemosa* (Forsskål) J. Agardh and *Caulerpa racemosa* (Forsskål) J. Agardh v. *macrophysa* (Sonder ex Kützing) Taylor were encountered in the subtidal zone of the western section and the backreef zone I of the central section, respectively. The remaining species, *Chaetomorpha linum* (O. F. Müller) Kützing, member of Cladophoraceae family, was also observed for once in the subtidal zone of the western section of the reef.

From the preceding classification of the 21 Chlorophtya species, as per their spatial occurrences on the reef, the following 4 species: *Caulerpa sertularioides*, *Halimeda tuna*, *Valonia aegagropila* and *Valoniopsis pachynema,* are found exclusive to the back reef zone 1 of Bet Shankhodhar Reef.

The establishment of seaweeds or marine macroalgae within a habitat zone involves complex physical interactions as well as biological, ecological and chemical processes at the microscale [25]. These processes include release of propagules by reproductive adults, migration of propagules to suitable substrates, initial adhesion to the substratum surface, permanent attachment and further growth and development [25]. Availability of suitable substrate, light quantity and quality and nutrients are three major abiotic factors that control the settlement and growth of macroalgal communities within an ecosystem [6].

Halimeda is a globally significant, calcifying, green macroalgae genera strongly associated with tropical coral reef habitats [26]. *Halimeda* species are widely distributed across the reefs indicating different reef conditions and are considered important primary producers of the backreef and lagoon habitats [6]. These species prefer moderate energy environments like shallow backreef and lagoon habitats, while in the fore-reef zone, *Halimeda* species may occur in large populations even at greater depths beyond 100 m [26]. Approximately 75% of *Halimeda* species prefer consolidated or gravelly habitats such as against sand or mud substratum [6] and the same was experienced with *H. tuna* at Bet Shankhodhar Reef (**Figure 4**: Plate A: 1A and 1B).

Caulerpa is another major Chlorophyta genus, commonly found in the tropical and subtropical coastal waters throughout the world [27]. *Caulerpa* species generally occur in the intertidal and subtidal zones and prefer sandy and rocky reef substrates. They are also important primary producers of the backreef zone and lagoon habitats similar to that of *Halimeda* genera [6]. *C. sertularioides* is rather considered as a secondary metabolite which yields different potentially bioactive compounds, both toxic and non-toxic [27]. This chemically defended species inhabits tropical reefs with high fish populations [27] and prefers unconsolidated sand or soft mud substratum in the shallow tidal pools [28]. In Bet Shankhodhar Reef, this species is found in abundance in the tidal pools (**Figure 4**: Plate A: 2A and 2B) in the backreef zone I along with other *Caulerpa* species.

Valonia aegagropila species from the Valoniaceae family was also found in the backreef zone I of Bet Shankhodhar Reef (**Figure 5**: Plate B: 1A and 1B) during the field surveys. This species is identified as a lower mid-littoral zone species, inhabiting shallow tidal pools and prefers

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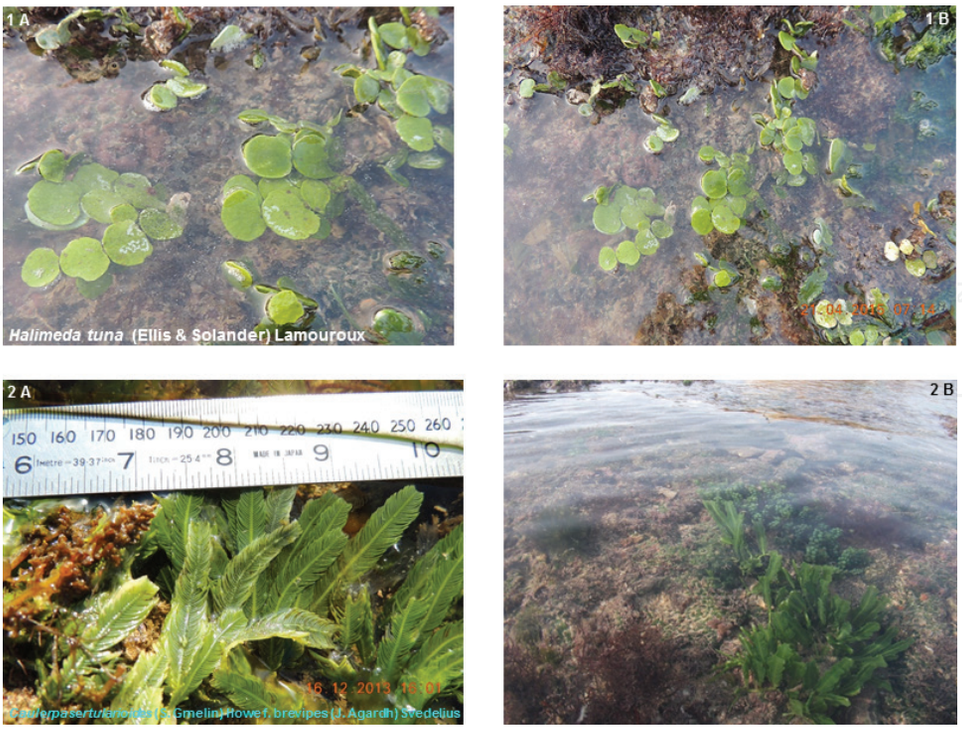

Figure 4. Indicator Chlorophyceae species of Backreef zone I of Bet Shankhodhar Reef: Plate A (1A: *Halimeda tuna* species and 1B: *H. tuna* in its habitat; 2A: *Caulerpa sertularioides* species and 2B: *C. sertularioides* in shallow tidal pool).

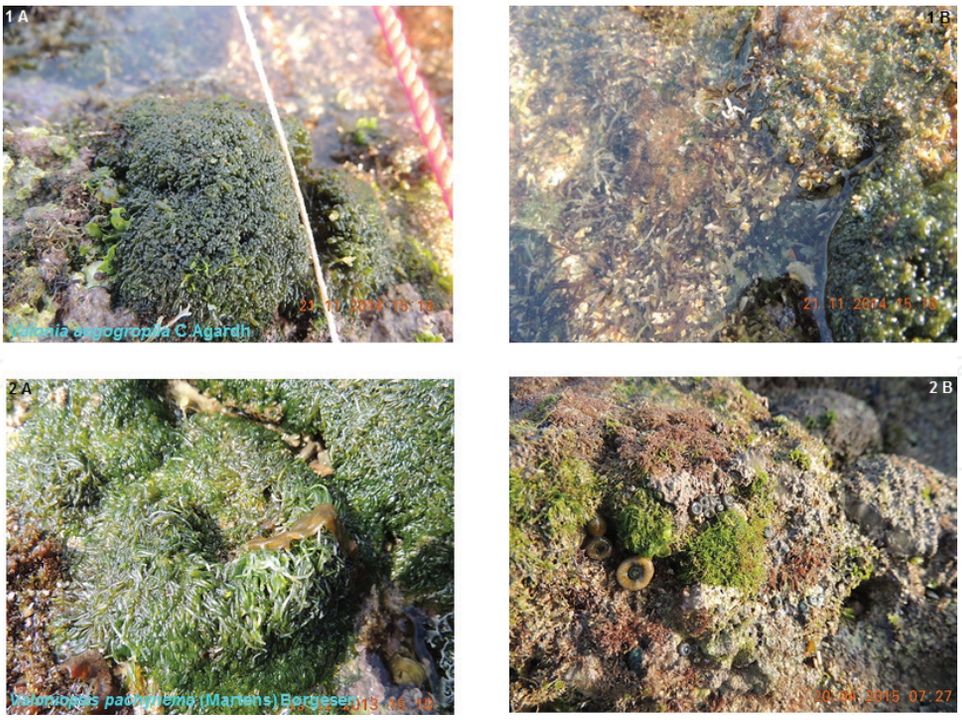

Figure 5. Indicator Chlorophyceae species of Backreef zone I of Bet Shankhodhar Reef: Plate B (1A: *Valonia aegagropila* species and 1B: *V. aegagropila* in its habitat; 2A: *Valoniopsis pachynema* species and 2B: *V. pachynema* on rocky substratum).

intertidal rocks and coralline stones as suitable substratum [10]. Other species from the same genus have been reported from reef front zones of shelf-edge atolls of northwestern Australia [29]. Occurrence of this species is reported from the rocky substratum at the intertidal sampling sites of Uran coast of Navi Mumbai, Maharashtra, India [30].

Valoniopsis pachynema is another Valoniaceae family member which forms stiff cushions or spongy mats on intertidal rocks of coralline origin [10]. This is a common tropical sea species and prefers hard substratum like intertidal rocks and dead corals. It forms green, hairy clumps and appears as turfs in littoral zones dominated by high wave actions. In our study site, this species was found in the backreef zone I, on the dead reef substrate in association with invasive zootaxa: *Zoanthus* (**Figure 5**: Plate B: 2A and 2B).

5. Conclusions

This study has identified four Chlorophyta species: *Caulerpa sertularioides*, *Halimeda tuna*, *Valonia aegagropila* and *Valoniopsis pachynema,* exclusive to the backreef zone I of Bet Shankhodhar Reef. *H. tuna* generally occurs in the sub-littoral zone and the infra-littoral fringe while rest of the Chlorophyta species occurs in the mid-littoral zone. Two of the species, *C. sertularioides* and *V. aegagropila,* prefer shallow tidal pools as their microhabitat within the backreef zone. All the four species grow on intertidal rocks having a calcareous or coralline origin. However, *C. sertularioides* prefers a thin veneer of fine sediments on the intertidal rocks as a suitable substrate to settle and grow. Thus, *C. sertularioides* prefers soft sediment substratum as compared to other three species. Since *Halimeda* and *Caulerpa* genera are well-known primary producers in backreef habitats, presence of these four species indicates backreef zone or environment for the Bet Shankhodhar Reef. Presence of chlorophyll *a* and chlorophyll *b* as the main accessory pigment in these species restricts the distribution of these sub- and mid-littoral species to relatively shallow depths of the reef with strong sunlight as compared to other reef algae belonging to other pigment groups.

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