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Preliminary report on the occurrence of lethal crustose (non-geniculate) coralline algae white band and white patch diseases in the coral reefs of Gulf of Kachchh, India

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This is the first report on Crustose (non-geniculate) Coralline Algae (CCA) diseases in the Gulf of Kachchh, Western India. The observation of CCA diseases was conducted in the intertidal reefs of Narara coast during August to November 2021. Two CCA diseases were identified: CCA white band disease and CCA white patch disease. Five sites were selected along the Narara intertidal reef; each site covering 200 m² area with 5 belt transects. CCA colonies intercepted within the transects were identified based on their growth form, and lesions were counted and recorded. CCA were classified into six different growth forms: encrusting, fruticose, foliose, layered, lumpy, and warty. A total of 704 CCA colonies were encountered, of which 18±2.9 % (n = 127) were identified with white band disease and 6±1.9 % (n = 42) were identified with CCA white patch disease. The encrusting growth form was predominantly affected by both CCA white band and white patch disease. CCA white band disease causes tissue loss, typically resulting in the death of CCA, subsequently colonized by endophytic green algae; whereas algal colonization was absent in the white patches. CCA white band disease was observed with a high frequency of disease occurrence (FOC) at 80 %, and white patch disease at 44 %. The spatial distribution patterns of CCA white band disease (χ^2 = 30.03; p < 0.00001) and CCA white patch disease (χ^2 = 7.98; p < 0.005) significantly differed among the growth forms of coralline algae. Present account provides baseline information on CCA growth form density and CCA disease, which would be valuable for future investigations.

[**Keywords**: Coralline algae, Growth forms, Gulf of Kachchh, White band disease, White patch disease]

Introduction

Health of the world's coral reef ecosystems has been significantly disturbed leading to a drastic degradation. Local threats such as overfishing, land-based pollution, coastal developments and other anthropogenic impacts, combined with global threats like rising sea temperatures, mass coral bleaching, and shifting weather patterns, are exerting unprecedented pressure on coral reef ecosystems around the world since the recent past[1]. Additionally, coral disease outbreaks are occurring more frequently and with greater severity, further contributing to the decline of these already vulnerable reef resources[2,3]. The increase in coral diseases over the past few decades has also led to significant changes in crucial ecosystem processes within marine habitats[4]. Diseases that affect coral species can directly harm coral reef habitats[5], posing a significant threat to their health and vitality. Simultaneously, diseases impacting other reef-associated organisms can indirectly influence coral populations by disrupting crucial biological and ecological processes, including coral recruitment, competition, and predation. Notably, the emergence of diseases among Crustose Coralline Algae (CCA) has been increasingly documented in recent times. Reports on pathogens infecting reef-building coralline red algae are most commonly found in the tropical Pacific Ocean and at several locations in the Caribbean[6-9].

Crustose (non-geniculate) coralline algae are a type of red seaweed characterized by cell walls made up of calcium carbonate. They exist in two primary forms: branched and partially calcified (geniculate corallines) or completely calcified (non-geniculate or crustose corallines). Coralline algae are versatile and can be found in various coastal habitats, from high intertidal tide pools to deep subtidal reefs, as long as there is sufficient sunlight and hard substrates for attachment. These algae serve as essential 'ecological engineers' within coral reef ecosystems, playing a significant role in stabilizing coral reefs by helping to bind the reef framework together. They actively participate in the marine food web, providing nourishment to fish and numerous benthic animals[10]. Coralline algae also play a crucial role in the global carbon cycle. Furthermore, they contribute to the habitat by offering shelter and grazing areas for a wide range of fish and invertebrate species in marine ecosystems. Apart from these ecological functions, they support to the settlement and recruitment of marine invertebrates, including corals and other sessile organisms on the reef habitat, through chemical interactions which associated with the surface of coralline algae. These chemicals are known to induce larval settlement in various species, making coralline algae a fundamental component of the complex web of life in coral reef environments[10].

Worldwide, there has been a massive know-how gap in CCA orientated research, which includes their distribution as well as diseases[11]. Field observations on CCA diseases have increased in the past decade[11-14]. CCA diseases are now prevalent worldwide, with reports in the Atlantic[15], Caribbean[16,17], Pacific[7,11,12,18], Mediterranean Sea[19], Indian Ocean[20,21], and the Red Sea[22]. In spite of the numerous studies in various regions of the Gulf of Kachchh, the Arabian Sea pays an exception. There are numerous studies disbursed on the corals in The Gulf of Kachchh, but the information about CCA is very sparse. The present account reports the occurrence of lethal diseases affecting the CCA in the Gulf of Kachchh reefs, India.

Materials and Methods

Study area

The Gulf of Kachchh is a shallow, east-west oriented bay, situated in the Arabian Sea along the north-western coast of India. It encompasses an area of 7300 km² and features 42 islands with fringing reefs. To assess the incidence of CCA diseases, current study was conducted between August and November 2021 along the intertidal reefs of Narara coast (22°27.912" N; 69°40.714" E) within the Marine National Park, Jamnagar, along the Gujarat coast in India (Fig. 1). Narara Island boasts a well-developed coral reef and mangrove ecosystem, along with its associated biodiversity[23]. It is located in close proximity to Vadinar village, which is well-connected to the mainland and surrounded by oil terminals and jetties.

Methodology

The CCA disease prevalence in the reef sites was assessed at 5 spatially distinct sites around the Narara Island following the methodology outlined by English *et al*.[24] to evaluate both the overall disease prevalence and the disease prevalence specific to each growth form of CCA on the reefs of Narara. A total of 25 belt transects were laid on exposed reefs during the low-tides through reef-walking. All transects were laid parallel to the reef crest. Each transect measured 20 × 2 meters, with a 1-meter width on each side, and a five-meter gap between them. Along each belt transect, all the CCA colonies were meticulously identified categorizing them by their respective

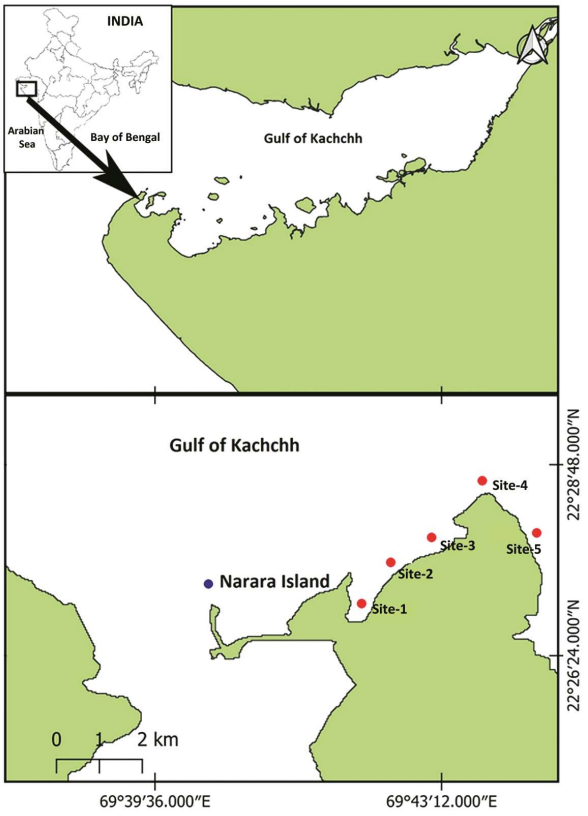

Fig. 1 — A geographic map showing the study area in Narara, Gulf of Kachchh, India

growth forms and enumerating their populations. Disease lesions were identified based on their characteristics, in accordance with the methodology as detailed by Work & Abey[25]. To document the findings comprehensively, field-photographs of all CCA colonies and disease lesions were taken using a Nikon COOLPIX AW130 camera.

Statistical analyses

The frequency of disease occurrence (FOC) serves as a measure of how CCA diseases spread across the reefs. FOC was calculated using the formula:

FOC = (the number of transects with both CCA and CCA diseased lesions) / (the total number of transects surveyed at each site).

To analyze the distribution of diseased versus healthy colonies among different CCA growth forms infected with the disease, a Chi-square (χ^2) goodness-of-fit test was employed. This statistical analysis allowed comparing and assessing the distribution patterns of the diseased and healthy colonies within each growth form.

Results and Discussion

Globally there are 10 different growth forms of non-geniculate coralline algae[26] have been described; and out of these, six (encrusting, fruticose, foliose, layered, lumpy, warty) have been observed in current study location. Non-geniculate coralline algae were noticed on the arduous substrate wherever light enters[27]. Among the different growth forms of the CCA, encrusting, lumpy and fruticose CCA were recorded as dominant growth forms as 72.3±2.4 %, 14.5±2.2 % and 10.4±2 %, respectively; whereas, the least mean percentage was observed in other growth forms such as layered (1.7±0.8 %), foliose (0.6±0.3 %), and warty (0.4±0.2 %). In all the observed 5 sites, encrusting growth form was high, followed by lumpy, fruticose and others. Warty growth form was the least and was observed only in 3 sites (Fig. 2). CCA act as a solid substrate and serves as a space for coral larval settlement[28,29]. When this surface becomes clogged, it directly leads to a decrease in coral cover and the creatures that depend on it.

A total of six types of CCA diseases have been identified worldwide[30]. Among these, the present study observed the occurrence of two CCA diseases, namely, CCA white band disease and CCA white patch disease, which were noted with high prevalence in the reefs of Narara. The CCA white band disease is detected as diffuse, circular, and semi-circular lesions on the CCA with a band of white coloration along the edge of the injury between diseased and healthy tissues (Fig. 3). The disease lesion CCA white band disease is observed as an acute and sub-acute tissue loss. In contrast, CCA white patches are characterized by the occurrence of various distinct white patches on the wholesome CCA, suggesting rapid loss of diffuse, circular lesions and also irregular tissue loss (Fig. 4). CCA white band disease causes tissue loss followed by colonization of green algae typically resulting in the death of CCA; whereas colonization by endophytic green algae in the category of white patches was absent (Fig. 3). During the present study, the CCA white band disease was observed at all the five studied sites and white patches disease was

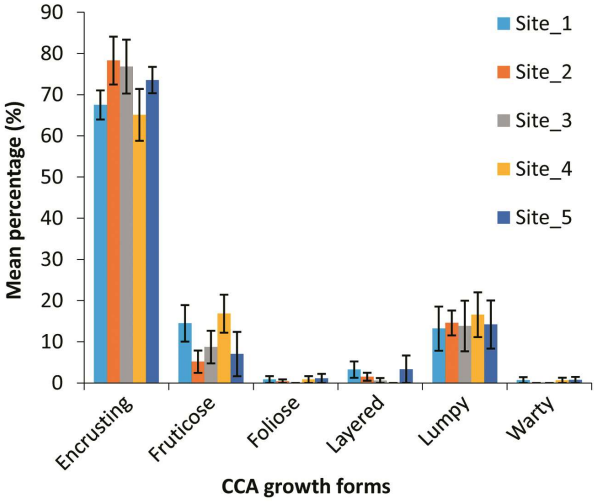

Fig. 2 — Mean percentage coverage (%) of Crustose Coralline Algae (CCA) growth forms (Mean±SE)

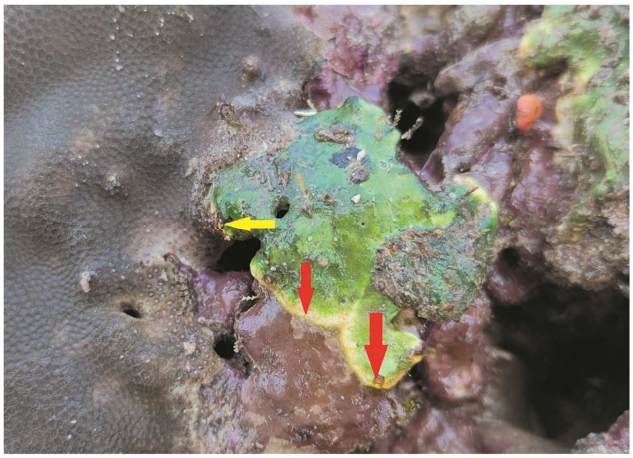

Fig. 3 — CCA white band disease (red arrow shows the white band disease; yellow arrow shows the fused margin showing concerned pathogen is not affecting the live coral *Porites* sp.

Fig. 4 — CCA white patch disease (red arrow shows the white patch disease)

observed only among the three studied reefs sites of Narara.

During the present study, overall CCA white band disease prevalence was noted as 18±2.9 % (n = 127) and was observed in all the 5 sites of Narara reef. Among them, encrusting (23.3±4.2 %) was observed as a high prevalence growth form in all 5 sites, followed by fruticose (8.7±1.9 %) and lumpy (1.9±0.7 %). The affected encrusting growth with the recent tissue loss (white bands) was in a range between 1 to 5 mm wide. Lumpy and fruticose growth forms ranged between 1 – 2 mm wide. The lumpy was observed as the least growth form and noted only in 2 sites, whereas the fruticose form was observed in 4 sites of Narara reef. Foliose, layered and warty growth forms were not affected by CCA white band disease (Fig. 5). The CCA white band disease was observed at 20 out of 25 transects (FOC = 80 %) and had an overall prevalence of 18 %. Prevalence of CCA white band disease significantly differed among the coralline algae growth forms (χ^2 = 30.03, *df* = 3, $p < 0.00001$).

In the case of CCA white patch disease, overall prevalence was recorded as 6±1.9 % (n = 42) and was found affecting 3 out of 5 sites. Only two growth forms were affected by CCA white patch disease, *viz.* encrusting (7.5±2.8 %) and lumpy (3.7±2 %) and were observed in 3 sites of Narara reef (Fig. 6). The affected encrusting and lumpy growth forms with the fresh tissue loss (white patches) were in a range between 0.5 to 3 cm in diameter. CCA patch band disease was observed at 11 out of 25 transects (FOC = 44 %), with an overall prevalence of 6 %. Prevalence of CCA white band disease significantly differed among the coralline algae growth forms (χ^2 = 7.98, *df* = 2, $p < 0.005$).

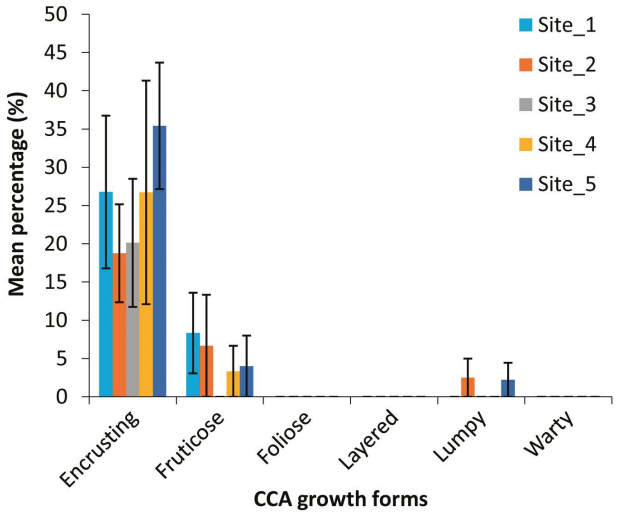

Fig. 5 — CCA white band disease prevalence recorded at the Narara reef

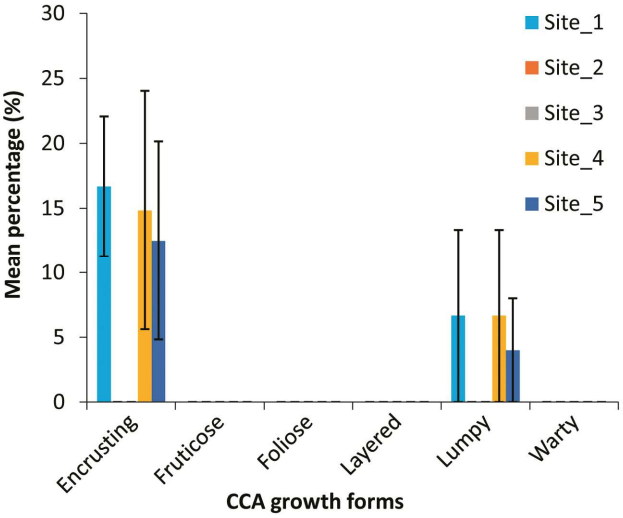

Fig. 6 — CCA white patch disease prevalence recorded at the Narara reef

The specific triggering mechanism for CCA white patches and white band diseases remains unknown[29]. However, it is established that other CCA diseases are directly linked to bacterial and fungal pathogens[30,31]. These CCA diseases can have severe consequences for coral reefs and their associated communities. They directly impact CCA tissues and lead to a reduction in calcium deposition rates, which ultimately results in the death of the affected areas[32]. Incidents of CCA white band syndrome have been correlated with elevated temperatures[14]. In the Gulf of Kachchh (GoK) region, which experiences average tides

ranging from 0 to 7 m, CCA are entirely submerged during the high tide and exposed to direct sunlight with extreme temperatures of up to 35 °C during the low tide[33]. Notably, the margin of CCA white band disease lesions was observed to be fused with healthy coral tissue, indicating that the microbes affecting the CCA do not affect the live *Porites* sp.[15]. Nonetheless, CCA diseases have the potential to directly impact coral larval settlement and inhibit coral recruitment[13].

In addition to the diseases mentioned above, the coral reefs face significant threats due to the detrimental consequences of human-induced stress[34,35]. Temperature anomalies have had a notably negative impact, causing severe damage to the reef structure in the Gulf of Kachchh[36,37]. The recognition of CCA diseases in the reefs of the Gulf of Kachchh adds another layer of concern and underscores the need for conservation efforts to protect these reefs. Mounting global climate changes is expected to play a pivotal role in the outbreak of CCA syndromes. Pathogenic virulence becomes more sensitive to environmental conditions, which can lead to CCA disease outbreaks. Nonetheless, long-term studies are crucial to fully understand the temporal dynamics of CCA status and associated diseases. This study further emphasizes the importance of conservation and restoration efforts for coral reefs and associated ecosystems. Further in-depth research is warranted to gain a comprehensive understanding of these diseases prevalence trends in the coming years.

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Conflicts of Interest

The authors declare that they have no conflicts of interests.

Ethical Statement

The author agreed to the ethical principles.

Author Contributions

MSB & RC: Disease investigation, data collection, and manuscript preparation; RC & RS: Review, editing and language correction; KR & VPPT: Data analysis; MP: CCA identification; NRC, RR & CS: Final reviewing the manuscript.

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