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Cover: Green Bee-eater with colour pencils and watercolor wash by Elakshi Mahika Molur.

INTRODUCTION

Invasive species belonging to flora and fauna can lead to adverse effects such as altering the biodiversity and community structure (Antolić et al. 2008), and can even invade or cause mortality to flora (de Villèle & Verlaque 1995) and fauna (Žuljević et al. 2011). A study on the impact of invasive *Caulerpa taxifolia* on seagrass beds of *Posidonia oceanica* has revealed degradation of seagrass beds in the west of Menton, France (de Villèle & Verlaque 1995). Various authors have also reported the distribution of indigenous invasive species, including *Ulva fasciata*, *Cladophora sericea*, and *Dictyosphaeria cavernosa* in the Hawaiian Islands (Smith et al. 2002), and non-indigenous invasive algae, including *Caulerpa verticillata* in the Gulf of California (Perez-Estrada et al. 2013), *Lophocladia lallemandii* (Kersting et al. 2014), *Caulerpa racemosa* var. *cylindrica* and *C. taxifolia* in Mediterranean region (Žuljević et al. 2011), and *C. racemosa* in the Gulf of Arzew, Algerian coast (Bouiadjra et al. 2010). Currently, the genus *Caulerpa* has been indicated as an invasive species by the International Union for Conservation of Nature (IUCN) Centre for Mediterranean Cooperation (Otero et al. 2013).

The invasive *Caulerpa* species spread rapidly all along the Mediterranean countries (Klein & Verlaque 2008). Since then, the issue of invasive algae in other parts of the world was also undertaken in different countries, as mentioned above. Recently, studies on invasive flora from the Gulf of Mannar region are gaining more importance due to their reef damaging nature. A few studies showed the invasion of *Kappaphycus alvarezii* on coral reefs in Krusadai and Mulli Islands (Edward et al. 2015), *Caulerpa* sp. and *Halimeda* sp. in the Gulf of Mannar and Palk Bay coral reefs (Manikandan & Ravindran 2016), and *Turbinaria* in the Gulf of Mannar corals (Ramesh et al. 2019). However, there is very little information on the current distribution patterns of invasive seaweeds around the Gulf of Mannar Islands. Therefore, during coral reef monitoring, we investigated invasive species distribution in the Gulf of Mannar group of Islands.

MATERIAL AND METHODS

Reef monitoring surveys were carried out during August to November 2018, from Manoli Putti and Hare Islands under the Gulf of Mannar region, southeastern coast of Tamil Nadu, India. Several underwater dives on fringing reefs of these two islands revealed moderate

bloom forming and overwhelming growth of four green seaweeds *Caulerpa serrulata*, *C. racemosa*, *C. sertularioides*, and *C. peltata* on live and dead corals. Underwater photographs of these bloom-forming species were documented using Nikon Coolpix underwater camera. Species identification was made using standard identification keys and AlgaeBase (Guiry & Guiry 2018).

RESULTS AND DISCUSSION

Caulerpa racemosa, *C. serrulata*, *C. sertularioides*, *C. taxifolia*, *C. peltata*, and *Halimeda opuntia* are usually seen in smaller size on corals and rubbles. Their usual occurrence on reefs or rubbles used to be within the size range <5–>30 cm. However, their bloom forming nature identified by recording their overwhelming spread on corals ranged >30 cm–>1 m. Blooms of these species overwhelming on the coral reefs of Mandapam group of Islands were recorded during our study (Image 1a–h; Image 2a–f). The favourable physicochemical conditions that promote their spread in the reef area are poorly understood. These algal species have displayed a distinct distribution in the reef environment, where *C. sertularioides* and *C. racemosa* grew on rubbles, rocky substratum, and *Porites* sp.; *C. serrulata* on dead *Acropora* corals and live *Porites* species; and *C. peltata* on live *Acropora* corals. *C. taxifolia* has formed small patches on rubbles and near reef slopes, and is also found to grow mostly on *Montipora digitata* and *Porites solida* rather than on *Acropora*. Interestingly, *C. racemosa* was observed to grow on multiple species of corals such as *Porites*, *Acropora*, and *Montipora*. *C. racemosa*, *H. opuntia*, and *C. taxifolia* grew together with no inhibition activity against each other. *H. opuntia* was found to cover a few massive *Porites* coral colonies in Manoliputti Island. While its spread in seagrass beds was also observed (Image 2a–f), its actual impact on seagrass beds is yet to be studied.

We did not observe any grazers that preferred to feed on these *Caulerpa* species. Although *C. taxifolia* was found in the reef flats but were not seen to occur profusely. These algal blooms appear to be unsuitable for the development of corals due to their proliferation, smothering the corals. Also, overwhelming algal growth inhibits light penetration required for zooxanthellae to generate energy for polyps. These reasons appear to inhibit the growth of coral polyps and restrict juvenile corals' settlement on the dead reefs or rubble in the Gulf of Mannar reefs.

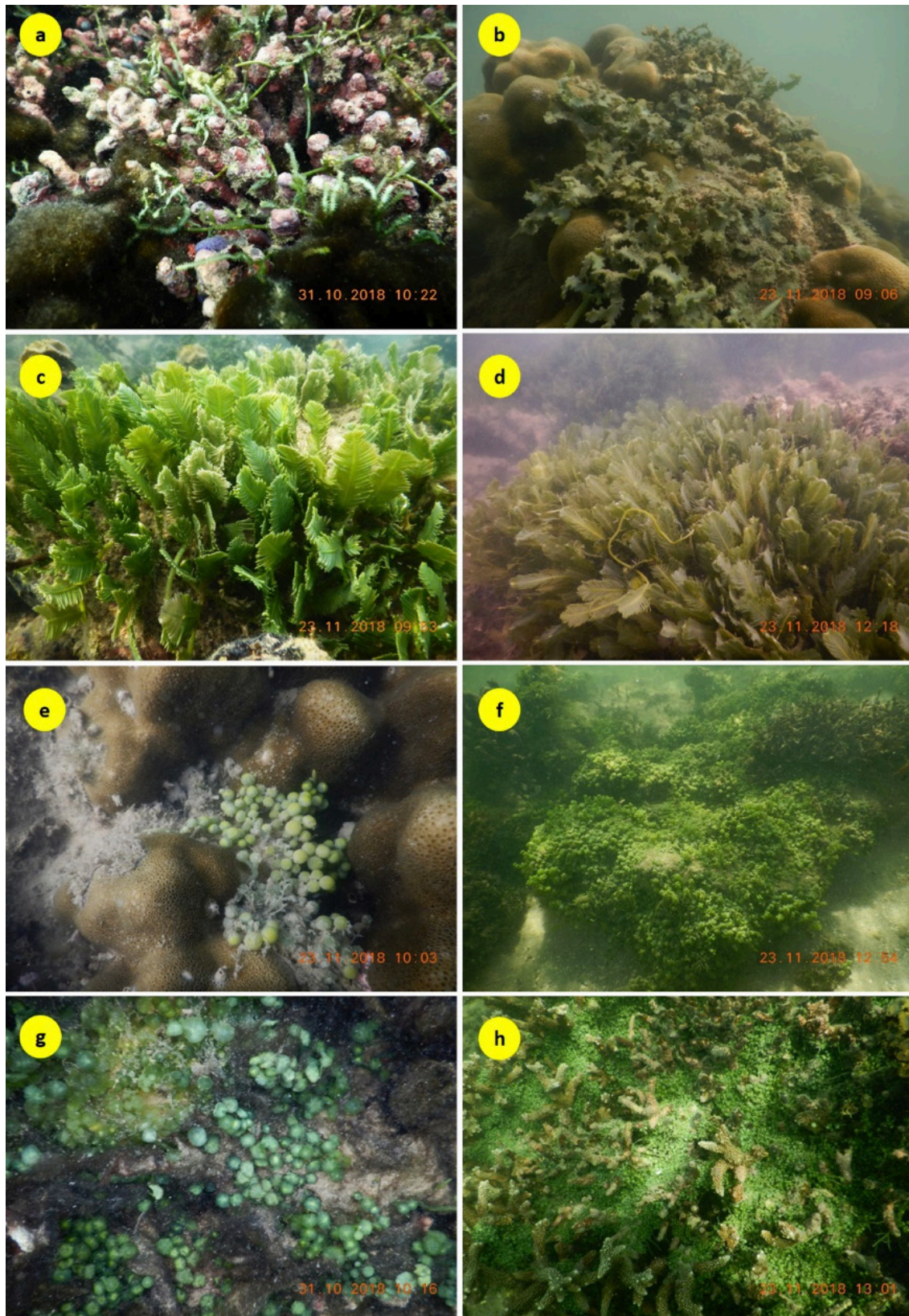


Image 1. a—Invasive and bloom-forming *Caulerpa serrulata* on dead *Acropora* reef | b—its overwhelming growth on *Porites* | c—*Caulerpa sertularioides* usual occurrence | d—canopy formation on the upper surface of *Porites* sp., dead corals and coral rubbles | e—*C. racemosa* in normal condition | f—its algal mat formation on *Porites* sp., dead corals and rubbles | g—*C. peltata* on dead *Acropora* coral | h—its algal mat formation on *Acropora* coral. © Ramesh Ch.

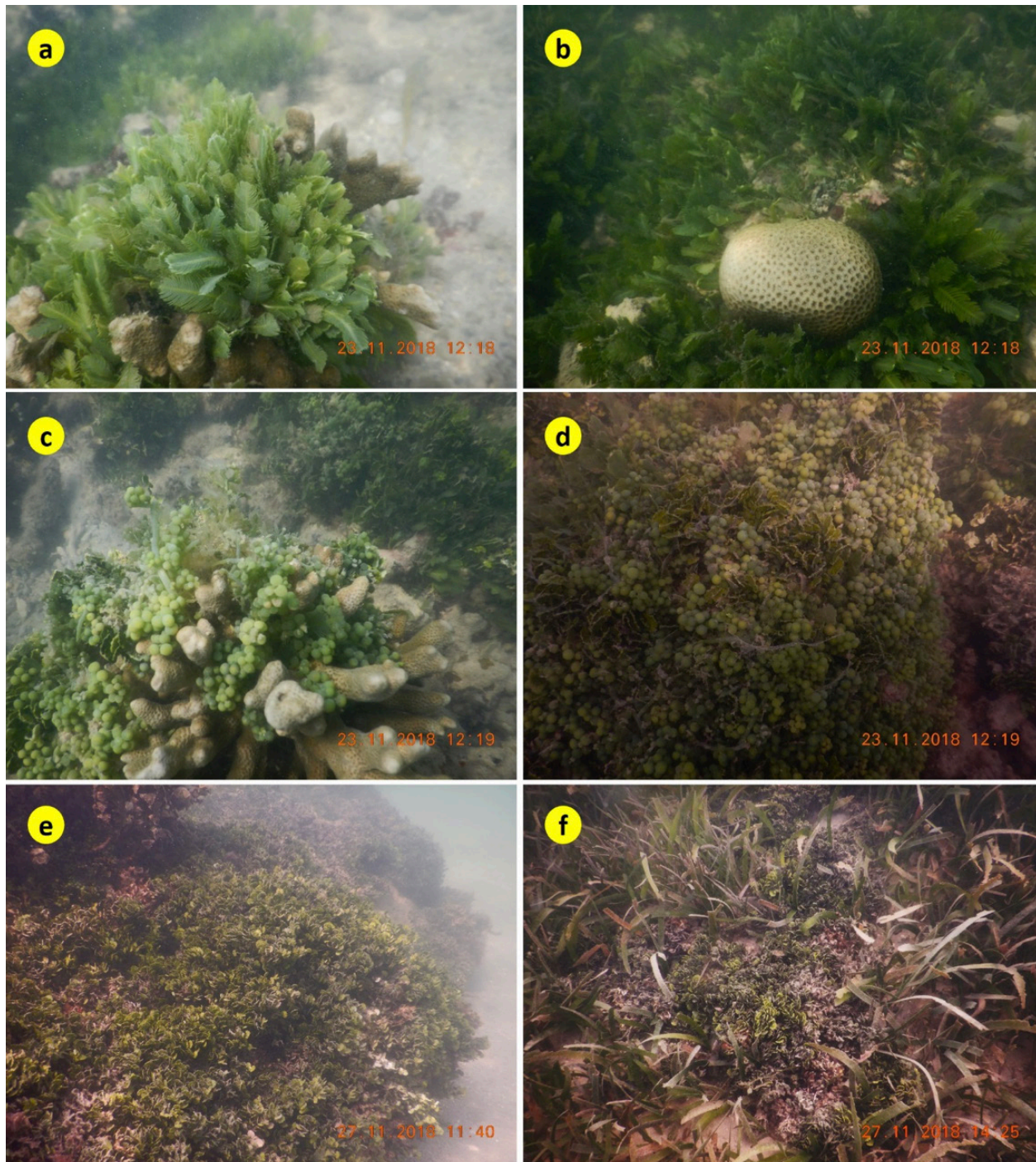


Image 2. a—*Caulerpa taxifolia* invasion on *M. digitata* | b—around a newly recruited *P. solida* | c—*C. racemosa* invading on *M. digitata* | d—its interaction with *Halimeda opuntia* and *C. sertularioides* (top left) | e—profuse growth of *H. opuntia* on *P. luteus* | f—its propagation in seagrass bed. © Ramesh Ch.

Previous reports indicated that *C. racemosa* and *C. taxifolia* could inhabit the entire reef area, which would ultimately undermine the resilience of corals (Hoey et al. 2011). The impact of these *Caulerpa* species on Gulf of Mannar's reef environment is yet to be studied in detail. However, the present study observations are

challenging the issues related to the algal destruction and conservation of corals and coral reef biodiversity from invasive algae.

A recent study revealed that a feeding deterrent activity assay on green algae *C. peltata*, *C. sertularioides*, and *C. taxifolia* species display highest deterrent

activity of >80% (Rajan & Padmakumar 2017). While *C. cupressoides* and *C. fergusonii* showed moderate deterrent activity, *C. scalpelliformis* and *C. microphysa* exhibited negligible deterrent activity (Rajan & Padmakumar 2017). Experimental studies also show that grazing on *C. taxifolia* resulted in the loss of spines and less gonosomatic ratios in sea urchin *Paracentrotus lividus* (Boudouresque et al. 1996). Later it was observed that high production of toxic and repellent chemical metabolite 'caulerpenyne' in summer causes sea urchins to avoid *C. taxifolia* (Lemee et al. 1996). The deterrent activity exhibited by *C. taxifolia* might be the reason that restricts grazers not to feed on it.

Whereas the same compound produced by *C. racemosa* had not displayed any deterrent activity towards herbivorous surgeon fish *Zebrasoma flavescens* (Wylie & Paul 1988), and it was highly preferred by both juvenile and adult rabbitfish *Siganus argenteus* (Paul et al. 1990). In this study, we have not found any grazers feeding on these *Caulerpa* species during our underwater observations. A recent study also indicated that *C. racemosa* distribution could drastically change over time by spreading from deep water to the shallow waters, as observed in the Columbretes Islands, Mediterranean Sea (Kersting et al. 2014). A study also suggested that overgrowth of *C. racemosa* via chemotropism results in smothering or even death of sponge *Sarcotragus spinosulus* (Žuljevic et al. 2011).

Caulerpa species are well known as edible seaweeds in eastern Asian countries such as China, Japan, Korea, Philippines; southeastern Asian countries like Indonesia, Vietnam; and Indo-Pacific regions (Kaliaperumal & Chennubhotla 2017). In India, *C. lentillifera* is cultured on the Gulf of Mannar coast (Mary et al. 2009). But utilization of these six species in India has not been implemented so far. Hence, they remain an untapped and unutilized food resource from the Indian Coast. Thus, *Caulerpa* species can be considered a potential natural edible seafood to the increasing population in India.

Crustose coralline algae are well known as they support the settlement of coral polyps (Tebben et al. 2015). Although we have found very few coralline algae in our surveys at Hare Island and Manoli Island, the coral recruitment was appreciable on the dead corals free from these algae. However, there is high competition for substrata between algae and corals, similar to previous reports (McCook et al. 2001). Therefore, monitoring the bloom-forming invasive seaweeds in terms of their reproductive strategies and favourable conditions that promote their propagation is essential for developing

remedies. Reports evidenced that ease dispersion and spread of *Caulerpa* species is mostly due to fishing nets, anchors, boats, and aquaria (Otero et al. 2013). Studies from the Mediterranean Sea have shown the rapid spread of invasive *C. taxifolia* by fragment mechanism (Ceccherelli & Cinelli 1999; Smith & Walters 1999). Therefore, further investigations are important to understand the temporal and spatial expansion of *C. racemosa*, *C. serrulata*, *C. sertularioides*, *C. taxifolia*, and *C. peltata* in these Islands. Also, multidisciplinary approaches are essential to address issues related to invasive species distribution dynamics, impacts, management, and utilization in the Gulf of Mannar. Also, the impact of environmental factors such as light, temperature, and water quality in different seasons should be analysed in future studies to understand bloom dynamics.

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