without a detailed understanding of serpentine species and their spatial O and H isotopic distribution. This necessitates further detailed study for better characterizing the serpentinization process in the Rakhabdev–Kherwara region constrained along the Rakhabdev Lineament.


Grazing of seaweed tissues by herbivores causes inconsistent crop yields that make commercial seaweed farming a less economically viable venture. In most situations, about 10% of available seaweed biomass is removed near the herbivores. To identify the seaweeds that are preferred by the herbivores, a study was carried out near the experimental seaweed farming site at Krasadi Island (9°14.823′N; 79°12.921′E), southeast coast of India. Abundant populations of grazer fishes, namely Siganus javus (Rabbit fish), Acanthurus sp. (Surgeon fish), Cetoscarus sp. (Parrot fish) and sea urchin Tripneustes sp. were observed near this site. Twenty different seaweed species tested for this study include Caulerpa racemosa, C. taxifolia, Halimeda gracilis, H. macroloba (all Chlorophyceae), Sargassum wightii, Turbinaria conoides, Dictyota dichotoma, Padina boergeseni, Pocockiella valegata, (all Phaeophyceae), Hypnea musiformis, H. valentiae, Champia parvula, Acanthophora spicifera, Gelidiella acerosa, Gracilaria crassa, G. edulis, G. dura, G. corticata, Laurencia papillosa and Kappaphycus alvarezhii (all Rhodophyceae). Among these, only five species of Rhodophyceae were grazed. G. edulis was the preferred choice of herbivores and 72 ± 17.8% of its biomass (P < 0.03) was grazed from the initial biomass of 5 g fresh wt. The corresponding grazing value for G. dura was 57.4 ± 28% (P < 0.02), for G. corticata, 47.2 ± 27.2% (P < 0.02), for L. papillosa, 41 ± 21% (P < 0.01) and for K. alvarezhii, 34 ± 10.4% (P < 0.01) against their original

*For correspondence. (e-mail: ganesanr@yahoo.com)
biomass of 5 g fresh wt each. These observations apparently show that grazers prefer coarsely branched, filamentous algae or succulent algae because of the amenability for grazing. Rhodophycean (red) algae were preferred over Phaeophycean (brown) and chlorophycean (green) algae and this could be attributed to palatability of the grazers. Plants gained protection from herbivores, if neighbouring plants are less palatable.

Keywords: Alga, fishes, grazing, herbivores, seaweeds.

MARINE herbivores, particularly molluscs and sea urchins in rocky shore habitats and fishes and urchins on tropical reefs, play key roles in the organization and functioning of marine benthic communities. Herbivores occur chiefly in warmer waters (40°N to 40°S) and are especially significant in the tropics. Many marine herbivores are edible and have an aquaculture potential (e.g. abalone, rabbit fish).

Seaweeds are macroscopic, multicellular, marine red, green and brown algae. They live attached to the seafloor between the top of the intertidal zone and the maximum depth to which adequate light for growth can penetrate. In general, seaweeds can be found along the seashore in large amounts that cling to a solid substrate like corals, rocks or shells. Seaweeds harbour diverse assemblages of small, mobile herbivores dominated by crustaceans, gastropod molluscs, and polychaete worms. Because of their small size, abundance, short generation times and consequently higher rates of secondary production, herbivores are major conduits of primary production to higher trophic levels and are thus critical players in near-shore trophic transfer. The effects of grazers may be either detrimental or beneficial to the surrounding plants, depending on the species of herbivore and alga.

Several reports have been published on the cultivation of commercial seaweeds in the Gulf of Mannar, southeast coast of India. However, grazing of seaweeds by herbivores causes inconsistent crop yields that make commercial farming a less economically viable venture along this coast. The present study was undertaken with the aim to identify seaweeds that are prone to grazing by the common herbivores often associated with seaweed farming.

The grazing experiment was carried out in a lagoon near the experimental seaweed farming area at Kurasadai Island (9°14.823′N; 79°12.921′E), Gulf of Mannar, southeast coast of India. The lagoon is shallow with a sandy bottom and protected by the long extended coral reef located about 200 m from the shore. Both live and dead corals are seen scattered throughout the area. The lagoon provides an ideal environment for good growth of seaweeds. Experimental cultivation of agar-yielding seaweed, G. dura is being carried out by CSMCRI at this site. Herbivores like Siganus javus (Rabbit fish), Acanthurus sp. (Surgeon fish), Cetoscarus sp. (Parrot fish) and sea urchin Tripneutes sp. (Figure 1) were found to be abundant in the farming site.

Figure 1. Herbivorous fishes commonly found near the experimental site. a. Parrot fish (Cetoscarus sp.); b. Rabbit fish, (Siganus javus); c. Surgeon fish (Acanthurus sp.); d. Sea urchin, Tripneutes sp.
causing severe loss to the seaweed crop. Eighteen different seaweed species representing all the three major algal classes (Chlorophyceae, Phaeophyceae and Rhodophyceae) collected from the lagoon were C. racemosa, C. taxifolia, H. gracilis, H. macroloba (all Chlorophyceae), S. wightii, T. conoides, D. dichotoma, P. boergeseni, P. variegata (all Phaeophyceae), H. musciformis, H. valentiae, C. parvula, A. spicifera, G. acerosa, G. crassa, G. edulis, G. corticata and L. papillosa (all Rhodophyceae). The remaining two species G. dura and K. alvarezi were obtained from cultivation.

A hollow PVC tube (3 mm thickness) of 10 cm diameter and 1 m length was chosen as a substratum. Twenty small holes (4 mm diameter) were made on the tube. Seaweeds were blotted dry and 5 g of each seaweed was weighed, placed on the hole and tied tightly. The hollow portion of the tube was filled with sand and buried at the bottom of the sea, to mimic the natural habitat. Five replicates of PVC tubes were seeded with the above seaweeds. Among the five, one tube was covered with fish net bag (0.5 mm mesh) to avoid grazing and it served as control (Figure 2). The tubes were kept in the sea for ten days and observations on grazing were made daily. On the 11th day, the tubes were taken out, the seaweeds were removed, blotted dry and weighed. The difference in initial and final fresh wt of algae was calculated for ascertaining the percentage of biomass grazed. Grazing values were statistically analysed using t test (SYSTAT version 7).

Of the total 20 seaweeds studied, only five species were grazed by the herbivores. G. edulis was the preferred choice for herbivores and 72 ± 17.8% of its biomass ($P < 0.03$) was grazed from the initial biomass of 5 g fresh wt (Figure 3). The corresponding grazing value for G. dura was 57.4 ± 28% ($P < 0.02$), for G. corticata, 47.2 ± 27.2% ($P < 0.02$), for L. papillosa, 41 ± 21% ($P < 0.01$) and for K. alvarezi, 34 ± 10.4% ($P < 0.01$), against their initial biomass of 5 g fresh wt each. Daily observations showed that grazing started on the third day. Herbivores first nipped K. alvarezi (Figure 4) because of its bigger size and prominence in appearance. On the fourth day, all the three species of Gracilaria (G. edulis, G. dura and G. corticata) were grazed (Figure 5). L. papillosa was grazed from the seventh day. Interestingly, all the three species of Gracilaria grazed were less susceptible to grazers when they were placed near unpulatable seaweed species like Caulerpa spp. and Halimeda spp.

All the five seaweeds grazed were coarsely branched filamentous forms with higher calorific content than the sheet-like forms. All the five algae grazed belonged to the

![Figure 2. Experimental set-up. a. Initial day of experiment. Five replicates of PVC tubes with seaweeds. b. Tube covered with fish net served as control. c. Final day of experiment. Selective seaweeds were grazed.](image)

![Figure 3. Biomass loss due to grazing after ten days. Bars indicate standard deviation.](image)
red algae and none was green or brown algae. Algal digestion resides with the ability of hydrolysis of polysaccharides, which are greater energy reserves than proteins or lipids. Alpha-linked polysaccharides such as starch are more susceptible to amylases than beta-linked polymers like cellulose and their derivatives. Brown algae have beta-linked polymers as storage compounds and extracellular substances. Though green algae store starch, an alpha-linked polymer, cell walls are high in resistant beta-linked polymers. Red algae store starch and their extracellular compounds are dominated by alpha- and beta-linked polysaccharides. Therefore, red algae are more liable to digestion than the green and brown algae.

It was also observed that herbivores not only chose between different algal sources offered, but also exhibited their preference for grazing selective parts of the thallus. Grazers fed preferentially on growing apical tips of all the five red seaweed species due to which growth of these algae was affected.

Seaweeds have developed structural, morphological or chemical defences that significantly lessen their susceptibility to herbivores. *Sargassum* and *Turbinaria* have tough and spiny thalli and hence are not preferred by the grazers. Harder texture of the thallus of *G. acerosa* and *P. variegata* prevented their consumption by herbivores. Seaweeds produce a diverse range of secondary metabolites such as terpenoids and polyphenols that are defensive against a wide variety of herbivores. Species of *Dictyota* are known to produce diterpenes that are able to strongly
affect the behaviour and survival of herbivorous fishes and sea urchins. Caulerpa species produce compounds, like Caulerpin and Caulerpin that are toxic against many herbivore fishes. Halimeda is a highly calcified alga. It adopts an interesting strategy in defence against herbivores by producing new buds at night when herbivore fishes are inactive. The newly grown buds are non-pigmented and pigmentation of tissue takes place during early hours of sunlight. Calcification begins along with photosynthesis. After 48 h, calcification and morphological toughness together provide adequate protection from herbivores.

Besides morphological and chemical defence, proximity to unpalatable alga also provides protection from grazers. All the three species of Gracilaria suffered less grazing damage when they were tied nearer to the toxic alga, Caulerpa and unpalatable alga like Halimeda in the tube. Littler et al. also demonstrated that palatable alga A. spicifera suffers much less grazing damage when it is close to the toxic seaweed Stypodium zonale. Similarly, Gracilaria tikvahiae was also protected by Sargassum.

From the present study, it is evident that grazers prefer coarsely branched, filamentous algae or succulent algae because of their amenability for grazing. Red algae were preferred over brown and green algae and this could be attributed to the palatability of the grazers. Plants gained protection from herbivores if neighbouring plants were less palatable. Secondary metabolites of seaweeds like terpenoids and polyphenols are highly defensive against herbivores. One key question that remains to be answered is that if grazing pressure causes an increase in deterrent compounds, how much energy does that plant put into its enzymatic machinery and deterrent molecules, and how much benefit does it derive in terms of tissue saved from grazing?


ACKNOWLEDGEMENTS. We thank Dr Puhpito K. Ghosh, Director, Central Salt and Marine Chemicals Research Institute, Bhavnagar for encouragement.

Received 27 January 2000; revised accepted 20 June 2000