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Role of the coralline alga *Halimeda gracilis* Harvey ex. J. Agardh in sediment development at Minicoy Island (Lakshadweep) during monsoon months

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ABSTRACT

The green alga *Halimeda* is a producer not only of carbon but also of loose carbonate sediment that is important for the building of a reef. Borings through the lagoon floor carried out at Bikini, Enewetak and other atolls of the Marshall Islands indicated that *Halimeda* segments are a major constituent of many lagoon deposits. The aged, white segments are shed from the *Halimeda* thallus by a natural separation from the node. Eventually, by process of disintegration, cementation and recrystallization, they are bound with other reef organisms into carbonate rock. *Halimeda gracilis* is the abundant species found at Minicoy. It performs two important sedimentary functions. The first one is the trapping of sediments, which are leached out from the beaches during monsoon. Secondly, it contributes to atoll mass by shedding the carbonate segments. The present study was carried out during the monsoon months at the southern reef flat, eastern shore reef and on the seagrass beds. In July, maximum sediment entrapment was noticed at reef flat with a value of 534 ± 315 g/sq.m, whereas in August it was maximum at shore reef (922 ± 520 g/sq.m). The contribution by the dead portion of *H. gracilis* plants was the highest at reef flat during July and August followed by shore reef and seagrass beds.

Introduction

The major objective of this study was to quantify the amount of calcium carbonate contributed by *Halimeda gracilis* to the reef and lagoon of the Minicoy Island. All species of *Halimeda* deposit calcium carbonate in the form of aragonite. Core samples through the lagoon floor obtained from Bikini, Enewetak and other atolls of the Marshall Islands indicated that *Halimeda* segments are a major constituent of lagoon deposits (Hillis-Colinvaux, 1980). The green alga *Halimeda* and other calcareous algae are not only producers of carbon but also loose carbonate sediment that is important for the building of a reef (Morrissey, 1980; Freile *et al.,* 1995). The aged white segments shed from the *Halimeda* thallus by a natural separation from the node. Eventually, by a process of disintegration,

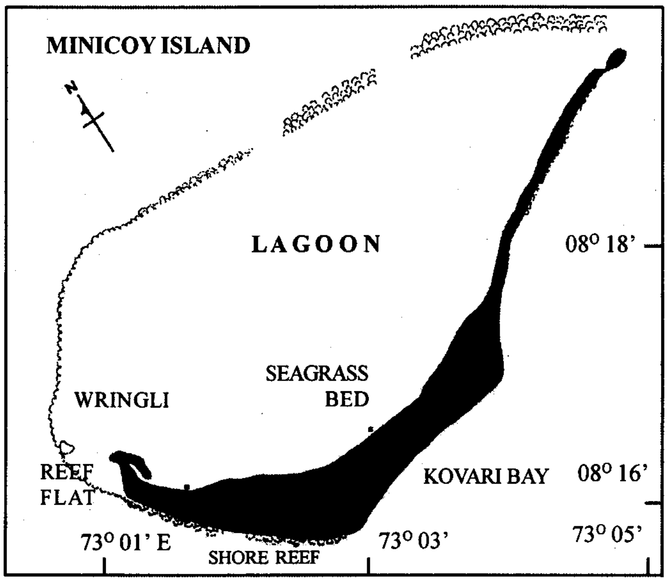

Fig. 1. *Map of Minicoy Island and the sampling sites*

cementation and recrystallization, sediments are bound with other reef organisms into carbonate rock (Hillis-Colinvaux, 1980). At Minicoy, the calcareous alga *Halimeda gracilis* contains the highest concentration of calcium (Jagtap and Untawale, 1984).

During a preliminary survey at Minicoy Island, *H. gracilis* was found covered by sand especially in the monsoon months. Although sediment control functions of seagrasses and mangroves in coral reefs are documented (Ogden and Gladfelter, 1983), there is very little information on the role of macroalgae in controlling sedimentation. Increase in suspended particulates nutrient loading and water turbidity are deleterious to coral growth (Kobulk and Lysenko, 1992; Hands *et al.,* 1993). In addition to their direct contribution of the carbonate materials, benthic plants assist reef construction in a mechanical way by consolidating or anchoring loose material or by covering surfaces and thus protecting them from erosion (Dahl, 1974). Drew (1995) observed the diversity of *Halimeda* in the Chagos Archipelago to be considerably greater than that reported for other Indian Ocean localities. The marine macrophytes including *H. gracilis* in Lakshadweep (Jagtap, 1987; Kaliaperumal *et al.,* 1989) and in Minicoy (Untawale and Jagtap, 1984) have been reported. Kaladharan and Kandan (1997) classified *H. gracilis* as a low primary producer. In the present study, the carbonate production by *H. gracilis* in three sites of Minicoy Island and its contribution to sediment entrapment are presented.

Materials and Methods

Minicoy Island (8° 17'N; 73° 04'E) a coral reef island in the Arabian Sea is approximately 11.7 km long with a land area of 4.4 sq.km (Fig.1). The Minicoy Atoll has developed on the Chagos-Lakshadweep ridge during several sea-level changes that caused colonization of various coral communities. Minicoy lies in a NE-SW axis, elevated only a few meters above sea level. The lagoon with an area of about 25 sq.km has two ecologically distinct habitats - the coral shoals that occupy 75% of the area and the sand flats in the southern area of the lagoon. The average depth of the lagoon is 4 m with a tidal amplitude of 1.57 m and an exposed reef area of about 4 km. The hydro meteorological characteristics of the area, mainly the monsoon currents, the equatorial current and the equatorial counter current play an important role in the formation and ecology of the Minicoy Island. Air temperatures do not show any significant seasonal changes with mean daily air temperature ranging from 24.5 ° C in January to 33.5 ° C in April. The monsoon months are from May to September contributing 65% rainfall. Humidity vary between 80.5% (April) to 88.2% (October). Monthly surface seawater temperatures at Minicoy vary from 28.5 ° C to 33.0 ° C resulting in an annual range of 4.5 ° C. Annual variation in salinity is from 33.4 ppt to 34.3 ppt. Salinity changes do not correlate with the period of rainfall. Maximum and minimum dissolved oxygen values recorded in the monsoon months vary from 5.73 ml / *l* in September to 4.06 ml/l in June. The winds are southwesterly during southwest monsoon and northeasterly during northeast monsoon. In general, the winds are stronger and steadier during the southwest monsoon with speeds reaching 45-55 knots. The southwest monsoon prevails during June-September and northeast monsoon during November-February. The predominant wave periods and wave heights are 5-6 sec and 0.5 to 1.5 m respectively during fair weather season and 5-9 sec and 1-3 m respectively during the rough weather season (Kesava Das *et al.*, 1979).

Three sampling sites were selected one each on the reef flat, shore reef and seagrass bed for the collection of *Halimeda gracilis*. The reef between the main island and the islet of Wringili 30 m away from shore was selected as a representative of the reef flat site (Fig. 1). The total width of the reef is 110 m at the sampling site and the width of the reef flat is 25 m. Reef extends seawards to a length of 35 m and slopes down to 20 m depth contour. The reef is directly exposed to the action of incoming waves. Dominant corals are *Pocillopora damicornis* and *Porites spp.* (Pillai, 1972). Major algae noticed on the reef flat are *Turbinaria ornata* and *Gelidiella acerosa* during monsoon months. Shore reef extends along the entire length of the island on the eastern side with a maximum width of 30 m. The site selected for the study is located on the southeastern part of the shore reef with a width of 20 m. Shore elevation is about 2 m with coral rubble and coral boulders at the shore. Prominent algae are *Turbinaria ornata, Gelidiella acerosa* and *Sargassum duplicatum*. Seagrass vegetation in Minicoy Lagoon extends to an area of 2.2 sq. km along the intertidal zone of the lagoon (Kaladharan *et al.*, 1998). *Thalassia hemprichii* bed on the southern side of Fisheries Jetty was selected as the third site (seagrass bed). Bottom is sandy with thick vegetation of *Thalassia hemprichii* near the shore and with *Syringodium isoetifolium* in deeper waters. Predominant algae noticed are *Gracilaria edulis, G. crassa, Caulerpa racemosa* and *Chaetomorpha linoides*.

Due to the easy accessibility of all sites during the ebb tide, sampling was carried out during the morning hours when the average tide height was only 0.49 metre. Twenty temporary random quadrats of 0.25m sides were employed each month at the three sites to collect data on the biomass and the amount of sediment entrapped. *H. gracilis* was carefully removed without disturbing the sediment and stored in plastic bags for further analysis. The percentage cover was estimated visually with the aid of a square frame with 0.5 m sides subdivided equally into a grid consisting of four squares. Sediment traps were constructed using 5 cm internal diameter and

12.5 cm long PVC pipe sealed at one end (English *et al.,* 1994). In the laboratory, *H.gracilis* collected from each quadrat was washed and the entrapped sediment was removed into petridishes. Sediments were sun dried to constant weight, debris removed and weighed. The thallus was separated into green fleshy living part and white hard dead calcareous part, and their wet and dry weights estimated. Twenty-five sediment samples from the upper portion at each site were collected. Individual segments from 100 *H. gracilis* dead thalli at each site were cut dried and weighed for estimation of calcium carbonate (Hillis-Colinvaux, 1980). One-factor analysis of variance (ANOVA) was carried out to determine the statistical significance of any differences in the *H. gracilis* biomass and amount of sediment entrapped.

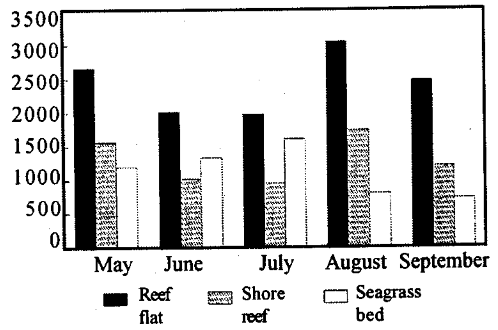

Fig. 2. *Mean monthly values (Wet. wt. kg/sq.m) of* H. gracilis *plants at the three sites*

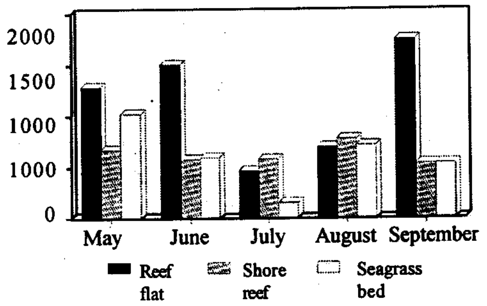

Fig. 3. *Variations in sedimentation rate (g/sq.m/day) at different sites*

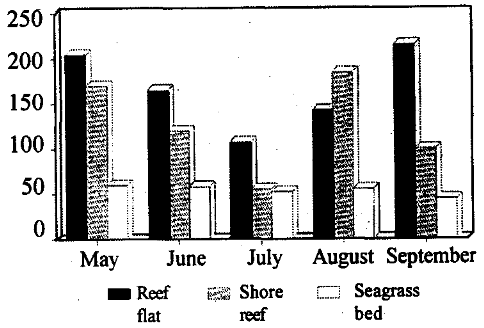

Fig.4. *Sediment entrapment (g/sq.m/day) by* H.gracilis *plants at the three sites.*

Results and Discussion

The mean monthly values of biomass of *H. gracilis* in the temporary quadrats of reef flat and shore reef were high in the month of August, while that in the seagrass bed in July (Fig. 2). A one-factor ANOVA showed that there were significant differences between sites in the biomass ($P < 0.01$). The period of maximum sedimentation varied between sites with the highest value of 1751.1 g/sq.m/day recorded at reef flat in the month of September (Fig. 3). Comparatively higher sedimentation was observed in the month of August at the shore reef, while at the seagrass bed in May. In general, sediment entrapment by *H. gracilis* showed a decreasing trend from May to July (Fig. 4). The values of other variables studied and their values are presented in Table 1. Percentage cover of *H.gracilis* was high at reef flat followed by seagrass bed and shore reef. Dead portion of *H. gracilis* was more than 50% at all sites. *Halimeda* fragments in sediment samples ranged from 25.0 (shore reef) to 31.9% (seagrass bed). Sediment entrapped to the total sedimentation rate was highest at the shore reef. Mean individual weights of segments were maximum at shore reef and hence the calcium carbonate also was the highest.

Table 1. *Values of selected parameters studied at the three sites of Minicoy Atoll*

Parameters	Reef flat	Shore reef	Seagrass bed
Percentage cover of *H. gracilis*	21.4	5.1	12.4
Percentage of dead *H. gracilis* in sample	63.6	74.0	56.6
Percentage of *Halimeda* fragments in sediment sample	29.8	25.0	31.9
Entrapment of sediment by *H. gracilis* / day (%)	16.41	36.15	12.64
Weight of one *H. gracilis* segment (mg)	8.65	12.17	5.83
Weight of Calcium Carbonate per segment (mg)	6.45	9.08	4.35

The aged white yellowish segments are shed commonly from the apical portions of a *Halimeda* thallus by a natural separation from the nodes, rather like tree leaves in the autumn (Hillis-Colinvaux, 1980). Segments are also lost basally and get deposited in situ, when lower portions of a thallus are buried. Mallik (1979) estimated that on an average *Halimeda* constituted 39% and 33% of sediments at Kavaratti and Kalpeni Islands respectively. A similar proportion of *Halimeda* in the sediments at Minicoy Island was observed with average value of 22% and maximum of 36%.

Jagtap and Untawale (1984) observed highest concentration of Calcium in *H.gracilis* collected from Minicoy. But there is no report of the amount of calcium carbonate in segments of *H. gracilis*. By employing the values of Bohm (1973), it has been possible to estimate calcium carbonate from the weight of individual segments. The mean carbonate content of mature segments of *H. gracilis* from reef flat is 6.45 mg. Total numbers of segments in mature plants assuming one crop a year was found to be 1632. The flux of carbonate to reef sediments from a *H. gracilis* population in the reef flat therefore is calculated as 1632 x 6.45 = 10.53 g calcium carbonate per thallus per year. Similar concentration from the other two sites yielded values of 12.53 for shore reef and 5.99 g calcium carbonate per thallus per year for seagrass bed.

The estimated reef populations of 321000 *H. gracilis* plants then contribute 3380 kg of carbonate per year or approximately 316 g/sq.m/yr (area of reef flat 10 700 sq.m for 21.4% of plant cover). Similar values calculated for shore reef and seagrass beds are 1329 and 594 kg of carbonate per year. The total contribution of carbonate to sediments by *H. gracilis* works out to 5 tones in a year. This estimate refers only to shallow water plants. But extensive populations of deep-water species are known to exist (Jensen *et al.,* 1985). The reef flat carbonate production of 3380 kg is higher than the values reported by Hillis-Colinvaux (1980) for Glory Be reef, Jamaica. Carbonate flux produced by calcareous green algae is a function of population density, turnover times and the species involved in a particular reef.

Smith and Kinsey (1976) divided reef systems into two components: the reef ridges and the lagoon areas. In the reef very active growth of the coral assemblage and encrusting algae and in the lagoon a large contribution of *Halimeda* and other green macrophytes are seen. In atolls and barrier reefs with larger and shallow lagoons, the lagoon environments probably contribute most of the mass of the reef (Hillis-Colinvaux, 1980). At Minicoy, the contribution from *H. gracilis* of seagrass beds is lower than that of reef flat and shore reef. This is probably because only *Halimeda* of the seagrass beds have been considered and not the algae present in the deeper and sandy areas of the lagoon. Although algal resources of Minicoy have been surveyed (Kaliaperumal *et al.,* 1989; Chennubhotla, 1992), there is no information on the distribution and abundance of calcareous algae from different parts of the lagoon. In the present study also the algae of deep fore-reef, which may be swept up in the vigorous currents of Minicoy atoll and later deposited in the still waters of lagoons. The sand and reef dwelling *Halimeda* therefore forms a significant contributor of carbonate accumulation along with the deep-water plants.

Dredging, oil pollution, sedimentation, prolonged exposure, El-Ninos and over exploitation for industrial purposes are some of the factors that hasten the destruction of reef corals (Pillai, 1975). At Lakshadweep, the major factors of coral death are the dredging carried out in the lagoons and siltation from construction activities. Dredging has also a long-term consequence on coral growth. The silt and sediments generated by dredging and their excessive transportation over the reefs and lagoon coupled with sea erosion kill the coral (James *et al.,* 1989). Sedimentation can kill major reef-building corals, leading to eventual collapse of the reef framework (Rogers, 1990).

Sedimentation rate at Minicoy is much greater than the threshold level of normal sedimentation rates for coral reefs. The average sedimentation for all sites combined is 795 g/sq.m/day whereas the threshold is only 100 g/sq.m/day or less (Rogers, 1990). Present values compare well with those reported for Kavaratti (Suresh and Mathew, 1993) but are higher than those of Mathew and Navas (1995) for Minicoy lagoon. This is because of the higher values observed at reef flat during the monsoon in the present study while the figures reported by Mathew and Navas (1995) are from the lagoon area. Secondly, the exposure time of sediment traps in the study by Mathew and Navas (1995) is for a brief period, while in the present study traps emptied only after 30 days. High sedimentation rate in the reef flat is to be expected as opined by James *et al.,* (1989). The sediment brought by the water current from the north of lagoon has no escape into open ocean since the reef flat is elevated and remains exposed for most of the time and acts as an effective barrier. *H.gracilis* and other turf forming algae are often overlooked in reef ecological studies because of its short tufted growth form that act as an effective sediment trap. At Minicoy, *H. gracilis* on an average entraps 21.7% of the total sedimentation in a day with maximum values of 36.2% in shore reef. Therefore, in addition to carbonate production, *H. gracilis* acts as an effective binder of sediments in highly sediment areas such as the reef flat.

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