First field observations of *Halimeda* beds at depths of 37-62 m at Saya de Malha and Nazareth banks, Mascarene Plateau

Ranjeet Bhagooli[1,2,3]*, Sundy Ramah[1,4], Deepeeka Kaullysing[1,2], Arvind Gopeechund[1,2], Odd A. Bergstad[5]

[1] Department of Biosciences and Ocean Studies, Faculty of Science & Pole of Research Excellence in Sustainable Marine Biodiversity, University of Mauritius, Réduit 80837, Republic of Mauritius

[2] The Biodiversity and Environment Institute, Reduit, Republic of Mauritius

[3] The Society of Biology, Reduit, Republic of Mauritius

[4] Albion Fisheries Research Centre, Ministry of Blue Economy, Marine Resources, Fisheries and Shipping, Albion, Petite Rivière, 91001, Republic of Mauritius

[5] Institute of Marine Research (IMR), PO Box 1870 Nordnes, N-5817 Bergen, Norway

* Corresponding author: r.bhagooli@uom.ac.mu

Halimeda spp. are cosmopolitan benthic marine green calcifying macroalgae occurring in shallow and deep waters. Their leaf-like segments are produced in a branched and segmented manner. Reproduction occurs by the edges of the segments turning into whitish reproductive cells that release the protoplasmic contents of spores, a process known as holocarpy, followed by the death and disintegration of the *Halimeda* segments (Drew and Abel, 1988). The segments grow continuously with a maximum of one segment per branch per day (Vroom *et al*., 2003). This rapid segmental growth may have a full turnover of about 30 days or less (van Tussenbroek and van Dijk, 2007). Walters *et al*. (2002) documented the vegetative reproduction of fragments of *Halimeda* on Conch Reef, Key Largo, Florida, which generated 4.7 – 9.4 fragments m^{-2} day^{-1}. *Halimeda* beds, or bioherms, are important in fixing and storing atmospheric carbon in the long-term in the tropics (Kinsey and Hopley, 1991) and result in the production of extensive sediment deposits due to the large biomass resulting from the thick mats. Therefore, sediments from *Halimeda* may be considered as carbon sinks and carbonate buffers (Rees *et al*., 2007). In the tropics *Halimeda*'s calcareous segments provide a major carbonate sediment (Freile *et al*., 1995), contributing to a reef development framework and a build-up of carbonate platforms (Pomar and Kendall, 2007). This allows *Halimeda* spp. to significantly contribute to the carbon budget estimated to be similar to or exceeding that of corals within the reef (Rees *et al*., 2007).

The occurrence and increase of *Halimeda opuntia* cover from 1997 to 2002 in the shallow areas (<20 m) of the Ritchie Bank in the north of Saya de Malha has been reported by Hilbertz and Goreau (2002). They suggested these changes may be attributed to the coral bleaching/mortality of 1998, when some 77% on the windward and 87% on the leeward coasts bleached or died around St. Pierre, Republic of Seychelles (Spencer *et al*., 2000). A review by Vortsepneva (2008) indicated that Karpitenko and Bidenko (1980) reported that *Halimeda* algae were more frequently found on the low terrace, with study stations not clearly defined by depths, but related to the landscape of the submerged circular reef areas between the upper terrace and the slopes and foot of the reef. However, these studies in the 1980s, late 1990s and early 2000s did not thoroughly document the green coralline algae, *Halimeda*, in the dynamic southern bank of Saya de Malha, a region which is well known to be data deficient.

The May 2018 EAF-Nansen Programme research cruise provided a unique opportunity to visually document the green coralline algae-dominated beds at the studied locations (Fig. 1A) 36, 37, 39 and 40 at

http://dx.doi.org/10.4314/wiojms.si2021.2.14

Saya de Malha (Fig. 1B), and 44, 47 and 52 at Nazareth (Fig. 1C) Banks using the Video-Assisted Multi-Sampler (VAMS) for standard inspection of the seabed by video. The Van Veen grabs attached to the VAMS also collected some samples at the study locations. In this paper, the presence of quite large *Halimeda* beds is reported at depths ranging from about 37 to 43 m at locations 36 (Fig. 2 A, B, D, F), 37 (Fig. 2C), 39 (Fig. 2E) and 40 (Fig. 2G) at Saya de Malha, and locations 44 (Fig. 2H), 47 (Fig. 2I) and 52 (Fig. 2J, K) at Nazareth Bank, where such environments are considered as oligotrophic and receiving low irradiance. Ramah *et al.* (*in prep for submission in this Special Issue*) indicated that at locations 36, 37, 39, and 40, the general macroalgal cover was estimated at 23-72%, 52-71%, 21-71% and 48%, respectively. Based on the morpho-anatomy description in Oliveira *et al.* (2005), three species of *Halimeda* were observed, namely *H. opuntia*, *H. discoidea* and *H. tuna*, the latter being most dominant. *Halimeda* has been reported to live down to 130 m in clear tropical waters (Littler *et al.*, 1985). In Mediterranean waters, *H. tuna* stands have been documented at 35 m at Tossa de Mar (Ballesteros, 1991), while in Maltese waters the species grew at a depth of 75 m (Drew, 1969).

Halimeda beds not only provide an important substrate but also a diverse habitat for marine organisms (Multer and Clavijo, 2004). For instance, the ophistobranchian *Bosellia mimetica* feeds on the chloroplast and camouflages itself in a green colour similar to *H. tuna* (J Ellis and Solander) JV Lamouroux 1816, segments. The *Halimeda* beds of the southern Saya de Malha bank harboured fishes like the regionally endemic *Amphiprion* sp. (Fig. 2B), commercially important red emperor, *Lutjanus sebae* (Fig. 2D) and the emperor, *Lethrinus* sp. (Fig. 2F). The *Halimeda* fields of the Nazareth bank were inhabited by *Helipora coerulea* and *Porites* sp. (Fig. 2G), *Seriatopora* sp. (Fig. 2H), and the elephant trunk sea cucumber, *Holothuria fuscopuntata* (Fig. 2K); the first record of this species at a depth as great as 61.64 m. McGrouther (2018) mentioned the accidental discovery of a *Halimeda* bed or meadow at 30-40 m depth near Lizard Island on the Great Barrier Reef in 1982. Out of the 14 fish species they recorded, a new goby species, *Minysicya caudimaculata*, was described by Larson in 2002 (McGrouther, 2018). In 2001, Leis and colleagues collected fish samples at depths of 23-27 m at the same *Halimeda* bed and found 378 fishes (35 species in 18 families), at least 4 gobies of the genus *Heterelotris*, and 1 cardinal fish of the genus *Fowleria*

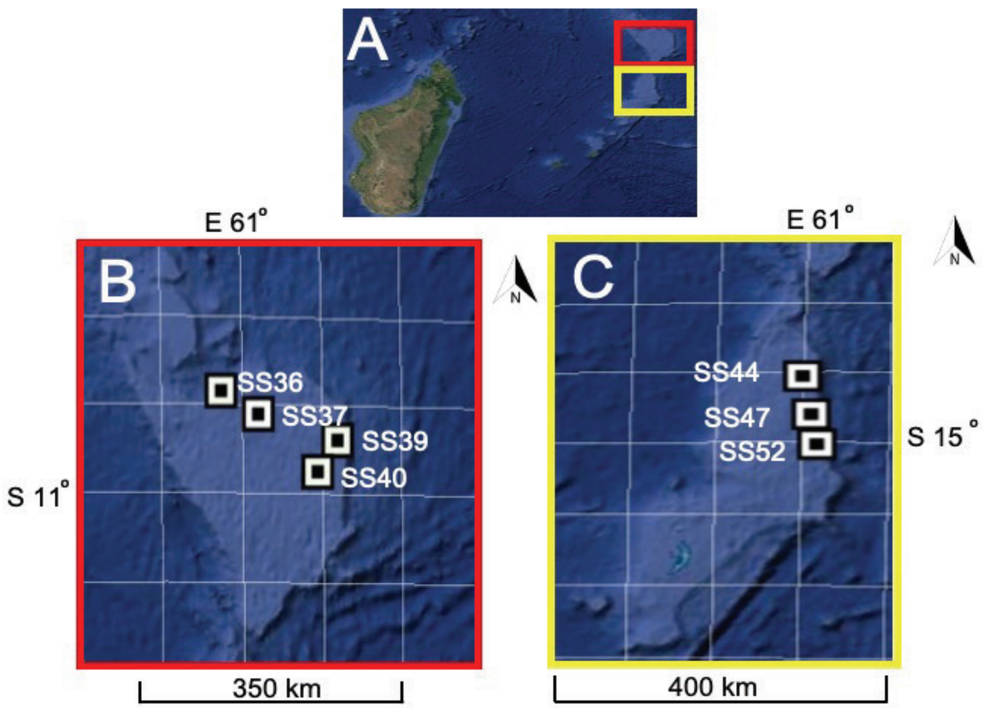

Figure 1 A. Map indicating the Saya de Malha and Nazareth banks studied during the EAF-Nansen 2018 research cruise on the Mascarene Plateau. B. Study locations 36, 37, 39 and 40 on the Southern Saya de Malha. C. Study locations 44, 47 and 52 on the Nazareth Bank.

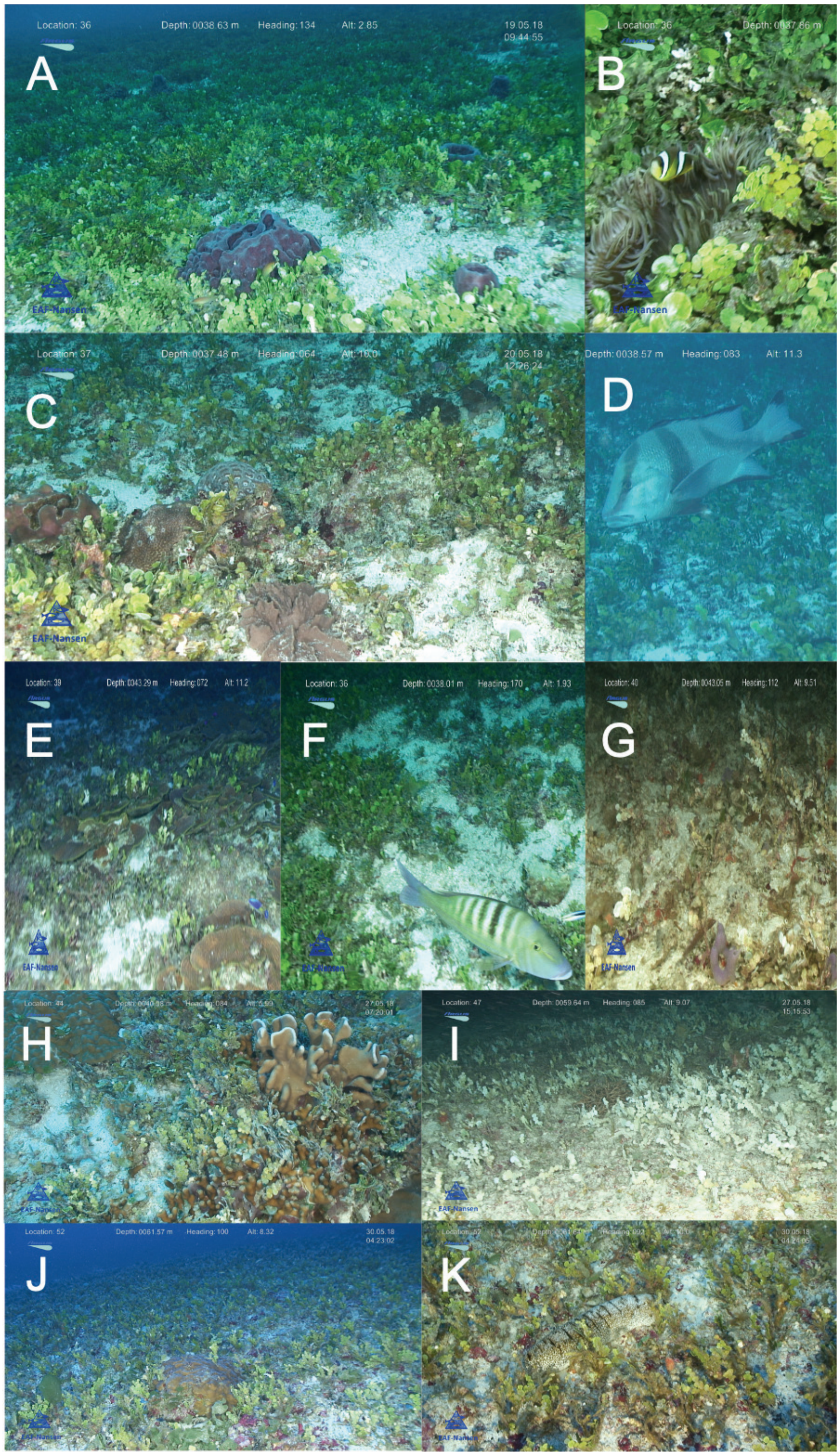

Figure 2. Fields of *Halimeda* at Saya de Malha Bank: A. Location 36 at a depth of 38.63 m – Sponges in the *Halimeda* bed; B. Location 36 at a depth of 37.86 m – Regionally endemic clownfish *Amphirion* sp.; C. Location 37 at a depth of 37.48 m – Corals in the *Halimeda* bed; D. Location 37 at a depth of 38.57 m – The emperor red snapper, *Lutjanus sebae*, native to the Indian Ocean and the Western Pacific region; E. Location 39 at a depth of 43.29 m – Plate corals in the *Halimeda* bed; F. Location 36 at a depth of 38.01 m – Commercially fished *Lethrinus* sp.; G. Location 40 at a depth of 43.05 m – *Halimeda* whitening. Fields of *Halimeda* at Nazareth Bank: H. Location 44 at depth 40.98 m - *Helipora coerulea* and *Porites* sp.; I. Location 47 at depth 59.64 m - *Seriatopora* sp.; J. Location 52 at depth 61.57 m - *Porites* sp.; K. Location 52 at depth 61.64 m - *Holothuria fuscopuntata* (elephant trunk sea cucumber, maximum depth previously reported is 30 m). Photos taken using the Argus Remote Operated Video (ROV). RV Dr Fridtjof Nansen, 2018.

(McGrouther, 2018). With only 3 collections, 8 fish species were recognised as new to Australia along with at least 5 undescribed ones, indicating that *Halimeda* beds are potential hotspots of biodiversity.

From a biotechnological perspective, in addition to antioxidant (De Oliveira e Silva *et al.*, 2012), antimicrobial properties (*Escherichia coli, Klebsiella oxytoca, K. pneumonia, Lactobacillus vulgaris, Proteus mirabillis, Pseudomonas* sp.*, Salmonella paratyphi, S. typhimurium, Staphylococcus aureus and Vibrio cholerae*), and antifungal (*Aspergillus flavus, A. niger, Alternaria alternaria, Candida albicans, Epidermophyton floccossum, Pencillium* sp.*, Rhizopus* sp., *Trichophyton mentagrophytes* and *T. rubrum*) (Indira *et al.*, 2013) properties, activity against the marine coronavirus A59 by Halitunal, an uncommon diterpene aldehyde isolated from *H. tuna*, has been documented (Koehn *et al.*, 1991).

This first observation of quite large *Halimeda* beds at 37-62 m depths at the Saya de Malha and Nazareth Banks suggests the possibility of such a habitat acting as an important carbon sink, requiring conservation and preservation of the regionally endemic and commercially important biodiversity, and warranting further exploration and sustainable use of the potential associated biotechnological resources of the Mascarene Plateau. Further in-depth ecological and biotechnological investigations are imperative to thoroughly understand the potential of such a biodiversity hotspot and its related marine resources, especially within the framework of Sustainable Development Goal 14, life under the sea.

Acknowledgements

The underlying work was made possible with the support of the EAF-Nansen Programme "Supporting the Application of the Ecosystem Approach to Fisheries Management considering Climate Change and Pollution Impacts" executed by Food and Agriculture Organization of the United Nations (FAO) and funded by the Norwegian Agency for Development Cooperation (Norad). The authors are thankful to FAO for funding and supporting the Indian Ocean research expedition 2018 on the Saya de Malha Bank and Nazareth Bank with the R/V Dr Fridtjof Nansen, the Department of Continental Shelf, Maritime Zones Administration & Exploration of Mauritius for co-leading and coordinating the scientific expedition, the Mauritius-Seychelles Joint Commission of the Extended Continental Shelf for their support and assistance and granting the necessary authorisations, the Ministry of Blue Economy, Marine Resources, Fisheries and Shipping for granting the permits for sampling, and the University of Mauritius for logistic support and laboratory facilities." The authors are indebted to the fellow participants on the expedition. The authors are thankful to the reviewer's comments that improved the paper.

References

Ballesteros E (1991) Structure of a deep-water community of *Halimeda tuna* (Chlorophyceae, Caulerpales) from the North-Western Mediterranean. Collectiona Botanica 20: 5-21

De Oliveira e Silva AM, Vidal-Novoa A, Batista-González AE, Pinto JR, Portari Mancini DA, Reina-Urquijo W, Mancini-Filho J (2012) *In vivo* and *in vitro* antioxidant activity and hepatoprotective properties of polyphenols from *Halimeda opuntia* (Linnaeus) Lamouroux. Redox Report 17 (2): 47-53

Drew EA (1969) Photosynthesis and growth of attached marine algae down to 130 meters in the Mediterranean. Proceedings of the VI International Seaweed Symposium 6: 151-159

Drew EA, Abel KM (1988) Studies on *Halimeda* II. Reproduction, particularly the seasonality of gametangia formation, in a number of species from the Great Barrier Reef Province. Coral Reefs 6: 207-218

Freile D, Milliman J, Hillis L (1995) Leeward bank margin *Halimeda* meadows and draperies and their sedimentary importance on the western Great Bahama Bank slope. Coral Reefs 14: 27-33

Hilbertz W, Goreau T (2002) Saya de Malha Expedition, March, 2002. 101 pp

Indira K, Balakrishnan S, Srinivasan M, Bragadeeswaran S, Balasubramanian T (2013) Evaluation of *in vitro* antimicrobial property of seaweed (*Halimeda tuna*) from Tuticorin coast, Tamil Nadu, Southeast coast of India. African Journal of Biotechnology 12 (3): 284-289

Karpitenko EA, Bidenko VG (1980) Trade investigations in the Indian Ocean. In: Fish economic investigations in north-east part of Indian Ocean, M. VNIRO. pp 53-65 (in Russian)

Kinsey D, Hopley D (1991) The significance of coral reefs as global carbon sinks–response to greenhouse. Palaeogsography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section) 89: 363-377

Koehn RE, Gunasekera SF, Niel DN, Cross SS (1991) Halitunal, an unusual diterpene aldehyde from the marine alga *Halmeda tuna*. Temhadron Letters 32 (2) 169-172

Littler MM, Littler DS, Blair SM, Norris JN (1985) Deepest known plant life discovered on an unchartered seamount. Science 227: 57-59

McGrouther M (2018) Halimeda, hot beds of biodiversity! [https://australian.museum/learn/animals/fishes/halimeda-hot-beds-of-biodiversity/]

Multer HG, Clavijo I (2004) *Halimeda* investigations: progress and problems. NOAA/RSMAS. pp 117-127

Oliveira EC, Osterlund K, Mtolera MS (2005) Marine plants of Tanzania – A field guide to the seaweeds and seagrasses. Botany Department, Stockholm University, Sweden. 267 pp

Pomar L, Kendall CGSC (2007) Architecture of carbonate platforms: a response to hydrodynamics and evolving ecology. In: Lukasik J, Simo JA (eds) Controls on carbonate platform and reef development. SEPM 89: 187-216

Rees SA, Opdyke BN, Wilson PA, Henstock TJ (2007) Significance of *Halimeda* bioherms to the global carbonate budget based on a geological sediment budget for the Northern Great Barrier Reef, Australia. Coral Reefs 26: 177-188

Spencer T, Teleki KA, Bradshaw C, Spalding MD (2000) Coral bleaching in the southern Seychelles during the 1997–1998 Indian Ocean warm event. Marine Pollution Bulletin 40 (7): 569-586

Van Tussenbroek BI, van Dijk JK (2007) Spatial and temporal variability in biomass and production of psammophytic *Halimeda incrassata* (Bryopsidales, Chlorophyta) in a Caribbean reef lagoon. Journal of Phycology 43: 69-77

Vortsepneva E (2008) Saya de Malha Bank – an invisible island in the Indian Ocean. Geomorfology, Oceanology, Biology. 44 pp

Vroom PS, Smith CM, Coyer JA, Walters LJ, Hunter CL, Beach KS, Smith JE (2003) Field biology of *Halimeda tuna* (Bryopsidales, Chlorophyta) across a depth gradient: comparative growth, survivorship, recruitment, and reproduction. Hydrobiologia 501: 149-166

Walters LJ, Smith CM, Coyer JA, Hunter, CL, Beach KS, Vroom PS (2002) Asexual propagation in the coral reef macroalga *Halimeda* (Chlorophyta, Bryopsidales): production, dispersal and attachment of small fragments. Journal of Experimental Marine Biology and Ecology 278: 47-65