Marine Biodiversity (2023) 53:39
https://doi.org/10.1007/s12526-023-01348-x

SENCKENBERG

SHORT COMMUNICATION

Discovery of the dendrophylliid scleractinian *Heteropsammia cochlea* (Spengler, 1781) in *Halimeda* bioherms of the Northern Great Barrier Reef

Stefano Borghi[1] · **Matthew Clements**[2] · **Monique Webb**[2] · **Helen Bostock**[3] · **Jody M. Webster**[4] · **Mardi McNeil**[5] · **Luke Nothdurft**[6] · **Maria Byrne**[2]

Received: 25 September 2022 / Revised: 9 March 2023 / Accepted: 10 March 2023 / Published online: 10 June 2023

Abstract

Halimeda bioherms on the Northern Great Barrier Reef (GBR) extend for over 6000 km^2. To explore the ecological and biogeographical importance of these bioherms was one of the aims of a recent voyage on the Research Vessel (RV) *Investigator*. Through the use of underwater images and habitat sampling, we found populations of *Heteropsammia cochlea* (Spengler, 1781) living in the bioherms. The scleractinian coral genus *Heteropsammia* (Dendrophylliidae) is a group of solitary, apozooxanthellate, single-polyp corals with a widespread distribution in tropical and sub-tropical regions. Populations of *H. cochlea* were observed with individuals dispersed on open-sand habitat and among patches of *Halimeda* at 30–40 m water depth in mean densities of 89 and 29 corals per m^2, respectively. Fluorescence microscopy was used to assess the presence of zooxanthellae, indicating that they are actively photosynthesising at these depths. These are the first observations of *H. cochlea* in association with the *Halimeda* bioherms on the Northern GBR.

Keywords Biogeography · Distribution · *Halimeda* habitat · Zooxanthellae

Introduction

The scleractinian coral genus *Heteropsammia* (Dendrophylliidae) is a group of solitary, apozooxanthellate, single-polyp corals with a widespread distribution in tropical and sub-tropical regions (Schuhmacher and Zibrowius 1985; Hoeksema and Best 1991; Hoeksema and Matthews 2015; Igawa and Kato 2017). These free-living corals have a facultative association with zooxanthellae and occur on open sand near reefs at depths ranging from ~8 to 40 m (Fisk 1983; Hoeksema and Matthews 2015). On mesophotic reefs, they can occur to 100 m, supposedly as azooxanthellate corals (Hoeksema and Best 1991), but specimens have also been collected from 762 m (Kitahara and Cairns 2021).

The genus *Heteropsammia* is in need of taxonomic revision (Hoeksema and Best 1991). Of the three species currently accepted, *Heteropsammia cochlea* is currently considered the most widespread (Goreau and Yonge 1968; Fisk 1983). Originally described from the Bay of Bengal, the geography of the species changed after numerous *Heteropsammia* species across the Indo-Pacific were synonymised under the taxon *H. cochlea* based on morphological and ecological similarities (Yabe and Eguchi 1942; Hoeksema and Best 1991). These corals have an unusual symbiotic relationship with a range of invertebrates. The best studied of these associations is with the sipunculan worm, *Aspidosiphon muelleri muelleri* (Hoeksema and Best 1991; Schulze and Kawauchi 2021; Herrán et al. 2022). A similar association was recently observed

Communicated by B.W. Hoeksema

✉ Stefano Borghi
stefano.borghi@my.jcu.edu.au

1 ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, Australia

2 School of Life and Environmental Sciences, The University of Sydney, Sydney, NSW 2006, Australia

3 School of Earth and Environmental Sciences, University of Queensland, Brisbane, Australia

4 Geocoastal Research Group, School of Geosciences, The University of Sydney, Sydney, NSW 2006, Australia

5 Geoscience Australia, Canberra, ACT 2601, Australia

6 School of Earth and Atmospheric Sciences, Queensland University of Technology, Brisbane, QLD 4001, Australia

with the hermit crab *Diogenes heteropsammicola* (Igawa and Kato 2017). These symbionts benefit the host coral by actively stabilising the free-living corallum and preventing prolonged smothering by sediment deposition (Hoeksema and Best 1991; Igawa and Kato 2017), which free-living mushroom corals would need to do by themselves (Bongaerts et al. 2012). In turn, the associate benefits from the physical protection provided by the coral if threatened while feeding on the surface sediment (Yonge 1975; Igawa and Kato 2017).

The vast *Halimeda* bioherms of the northern Great Barrier Reef (GBR) are biogeographically important inter-reef habitats that host high invertebrate biodiversity (McNeil et al. 2021). We encountered populations of *H. cochlea* in association with this unique algal habitat. Here we report our observations on the presence of *H. cochlea* in the *Halimeda* bioherms and used fluorescence microscopy to assess the presence of zooxanthellae.

Material and methods

A 28-day research voyage was undertaken on the CSIRO Marine National Facility RV *Investigator* (IN2022_V07) during August–September 2022, to characterise the geomorphology and biota associated with *Halimeda* bioherms in the northern Great Barrier Reef (GBR).

Visual surveys of the habitat and biodiversity were undertaken by deploying drop cameras on 21 sites over a 6-km-long transect on the outer-shelf offshore from Lizard Island (14°39′26.9″S 145°32′09.1″E) (Fig. 1). The Deep Towed Camera Mark II was deployed with a GP Winch (HOTS) supported by a Triplex A-Frame. A HDSD Video Camera (Sony Alpha 9 Mark I, Zeiss Milvus Lens) provided a live video stream to the camera operator. The camera unit was lowered downward facing to approximately 2–4 m above the seafloor (dependent on rocky outcrops), where images were captured of the seabed environment with the starboard and port stereographic cameras

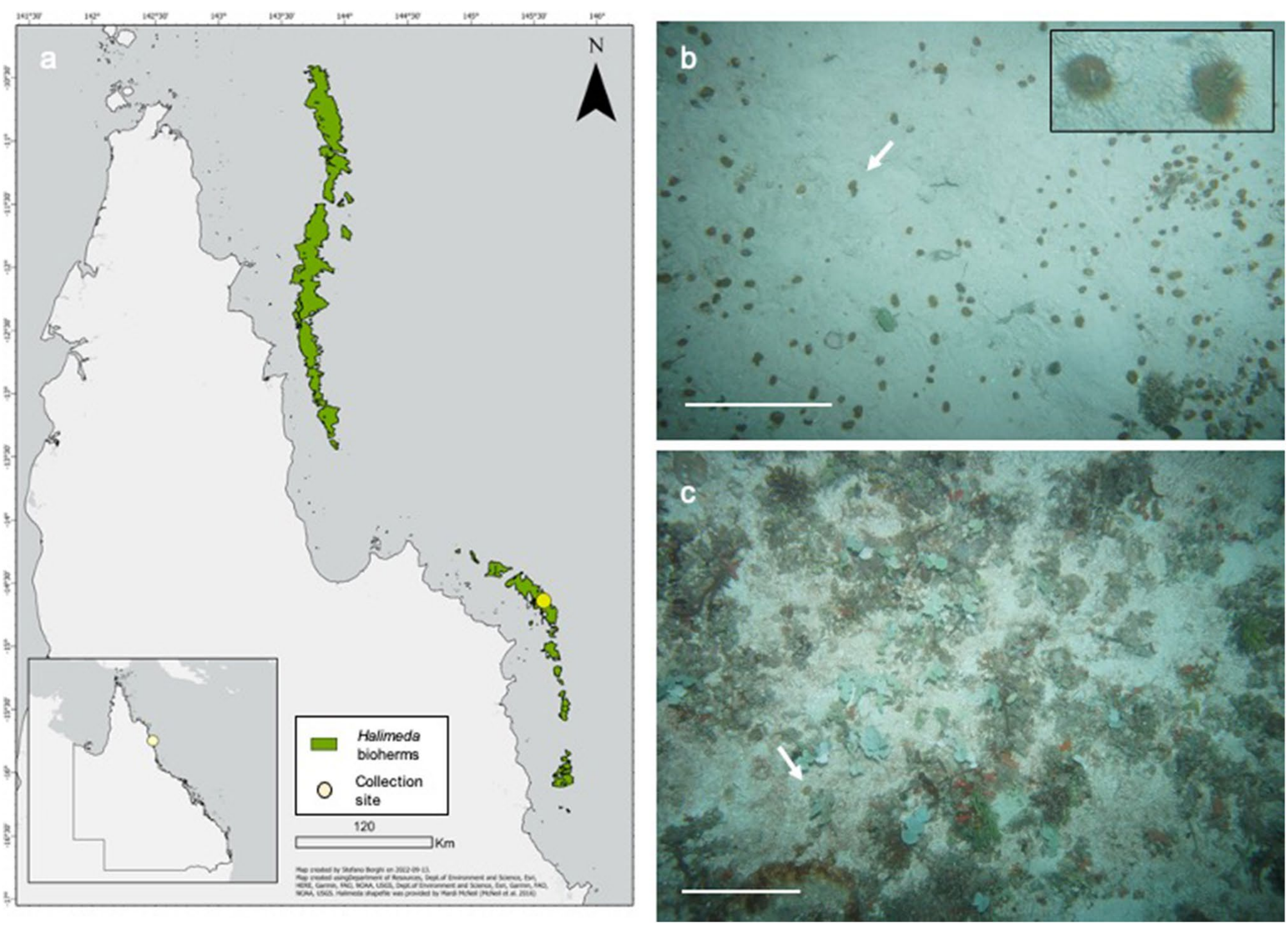

Fig. 1 **a** Distribution of the northern GBR *Halimeda* bioherm habitat (green) (McNeil et al. 2016) and the study area is indicated by the open circle (map created using ArcGIS Pro Intelligence 2.8); **b**, **c** Examples of *Heteropsammia cochlea* (insert and arrow) scattered in the sea floor on open *Halimeda* sand/gravel sediments and in areas with medium–high *Halimeda* cover (arrow; scale bar = 300 mm). The corals were observed and collected from four sites along the transect (Table S2)

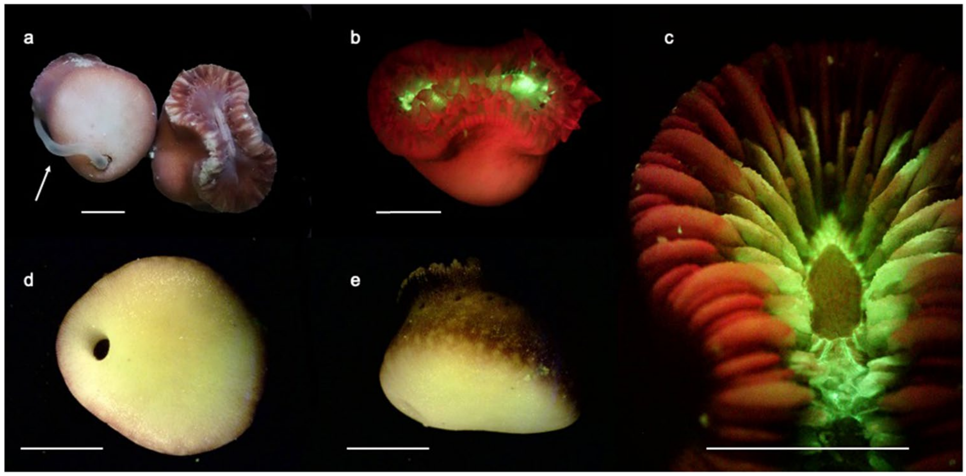

Fig. 2 *Heteropsammia cochlea* collected from *Halimeda* bioherms habitat (scale bars = 0.5 cm) ($n = 13$); **a** Oral (right) and aboral (left) view. Note the sipunculan worm emerging from the pore (arrow); **b**, **c** Fluorescence on adult colonies collected from ~28 to 34 m deep; **d** Base and **e** side views showing the pore that the worm uses to navigate in and out of the coral

(Sony Alpha 9 Mark II, Zeiss Lexia Lens) illuminated by strobe lights (DSP&L 2075 SeaStrobe LED Sealite). The photographs were used to estimate the density of *H. cochlea* and the size of their calicular view, which was measured on ImageJ using the known distance between camera lasers to set the scale. Sediments and samples of *Halimeda* and its associated biota were collected using a box corer and Smith-McIntyre grab along the same transect as the drop camera. We collected 13 living *H. cochlea* from the grabs. This confirmed the presence of the species as previously observed from the drop cameras.

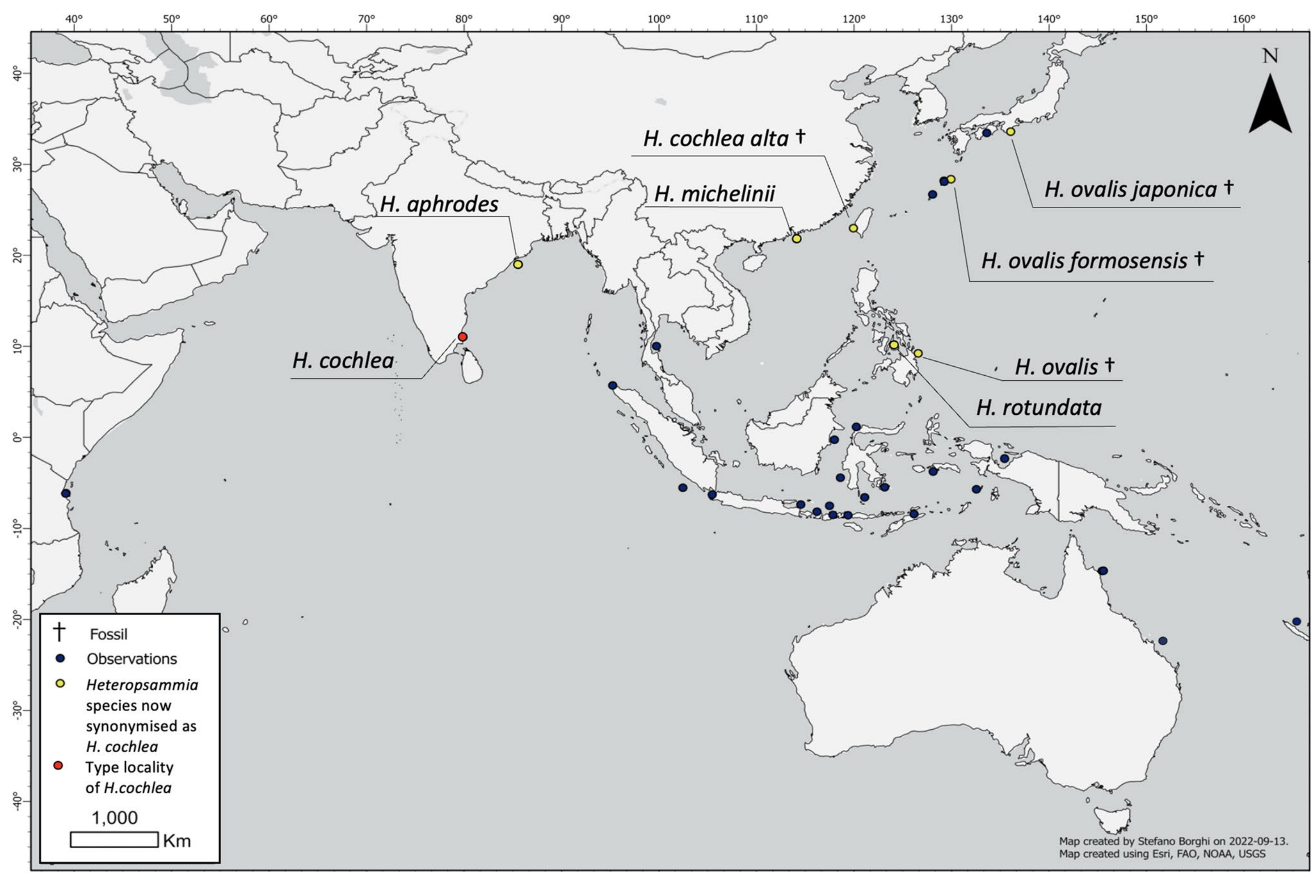

Fig. 3 Distribution of *Heteropsammia cochlea* based on observations and original descriptions from the literature (Table S3). Locations of the original descriptions of *Heteropsammia* species currently synonymised as *H. cochlea* are displayed in yellow. Descriptions based on fossil records for *Heteropsammia* species are shown with the † symbol. Type locality of the species is displayed in red. Map created using ArcGIS Pro Intelligence 2.8

The fluorescence of the corals collected was visualised using the Dino-Lite® 5MP Edge AM7915MZT microscope paired with NightSEA® lighting system (https://nightsea.com/) excited by royal blue wavelength (440–460 nm) together with the stereo-fluorescence long pass barrier filter. Fluorescence microscopy was undertaken to assess the presence of zooxanthellae.

Results and discussion

We observed conspicuous assemblages of *H. cochlea* in association with the sipunculan worm *A. muelleri muelleri* during the investigation of the *Halimeda* bioherms habitat. While *H. cochlea* has been reported from nearby Lizard Island (Fisk 1983), our report represents the first observations from the *Halimeda* bioherms (Fig. 1a), which are an expansive, but understudied habitat on the Great Barrier Reef that extend for over 6000 km^2 (McNeil et al. 2016). The taxonomic diversity of *Halimeda* in the bioherms remains to be determined, but previous surveys reported high frequency of occurrence of *H. bikensis*, *H. borneenses*, *H. gigas*, *H. opuntia*, *H. gracilis*, and *H. discoidea* (Pitcher et al. 2007; Hurray et al. 2013; Diaz-Pullido 2019). Based on the drop-camera underwater video and photographs, *H. cochlea* mostly occurred at depths between ~ 24 and 35 m on sand with scattered *Halimeda* (Fig. 1b, c; Table S1). Populations of *H. cochlea* were observed at four sites (Table S2) along the transect scattered across open sand and in association with *Halimeda* (Fig. 1b, c) at mean densities of 89 (SE = 45.12; range 12–195) and 29.25 (SE = 16.25; range 2–72) per m^2, respectively. Possibly, the corals were found within two species of *Halimeda*, including *H.* cf. *gracilis* and *H.* cf. *discoidea* (Diaz-Pullido 2019). The *H. cochlea* from the open sand and live *Halimeda* habitats had mean diameters of 16.92 mm (SE = 0.71, n = 40, range = 9.74–29.68 mm) and 16.13 mm (SE = 0.69, n = 35, range = 7.70–28.02 mm) respectively, with normal size frequency distributions (Fig. S1). *Heteropsammia cochlea* was conspicuous in association with *Halimeda* sediment (coarse sand to gravel) and also in association with live *Halimeda*, which occurred as patches over the substrate (Fig. 1c).

The corals showed fluorescence when excited by a 440- to 460-nm royal blue source (Fig. 2), confirming the presence of zooxanthellae. The presence of zooxanthellae in numerous mesophotic coral populations is known, but the presence and role of fluorescence in those assemblages have been largely overlooked (Eyal et al. 2015). *Heteropsammia cochlea* as deep as 40 m are known to have zooxanthellae (Hoeksema and Best 1991; Fine et al. 2013), but these are the first observations of fluorescence in this species. Since *H. cochlea* has zooxanthellae, the presence of the species on coarse sediments can be beneficial. The coarse sediments can reflect the light to the sides of the corals, so that the buried portion of the coral can receive a greater amount of light for photosynthesis (Fine et al. 2013). Despite their location in deeper water, *H. cochlea* individuals have also been observed to bleach during heatwaves (Hoeksema and Matthews 2015). This species may, therefore, be vulnerable to bleaching, similar to other stony corals in adjacent shallow waters of the northern GBR during recent heatwave events (Frade et al. 2018). However, as this species is heterotrophic and can ingest large preys (Mehrotra et al. 2016), it may be able to meet the metabolic requirements through heterotrophic feeding during bleaching (Mehrotra et al. 2019). Although fluorescence has been proposed to screen harmful radiation in shallow coral populations, its biological role in mesophotic corals and/or their symbionts remains uncertain (Eyal et al. 2015; Roth et al. 2015). *Heteropsammia cochlea* is also likely to be vulnerable to predation by the two species of the sea star genus *Acanthaster* that co-occur with this coral on the Great Barrier Reef (Byrne et al. 2023; Keesing et al. 2023). In a recent study, *A. brevispinus* was shown to prey on *H. cochlea* (Keesing et al. 2023).

As the *Halimeda* bioherms appear to be a suitable habitat for *H. cochlea* and cover an estimated area of ~ 6000 km^2 on the GBR, with patches extending as far south as the Swains Reefs (McNeil et al. 2016), this coral may be more abundant and widespread than previously reported. The global records of the distribution of *H. cochlea* are patchy, but indicate that this coral is potentially widespread across the entire Indo-Pacific (Fig. 3). The global distribution of *H. cochlea* was obtained from original descriptions (Gill and Coates 1977; Fisk 1983; Hoeksema and Best 1991; Igawa and Kato 2017) and from available literature including fossil records (Hoeksema and Best 1991). That said, as the taxonomy of these free-living corals is uncertain and primarily based on macro-morphological differences (Hoeksema and Best 1991), it is not possible to know if this species represents one or a suite of species. Recent phylogenies have highlighted incongruities between morphology-based taxonomies and molecular data (Arrigoni et al. 2014). However, research on the taxonomy of the genus *Heteropsammia* is lacking. A comprehensive systematic assessment of the genus is needed. This is especially important when these corals occur in specific habitats, such as the *Halimeda* bioherms.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12526-023-01348-x.

Acknowledgements The research was supported by a grant for sea time on the RV *Investigator* from the CSIRO Marine National, Facility, part of Australia's national science agency. We acknowledge the Master Andrew Roebuck, the crew and the technical support for facilitating the research undertaken on the voyage. The corals were observed and collected under permit G19/39364.1 granted by the Great Barrier Reef Marine Park Authority. The authors are grateful for help from reviewers.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions We also acknowledge funding support from The National Geographic Society (Grant # NGS-63813R-19) and the Ian Potter Foundation Science Grant (31110113) to QUT.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval All applicable international, national, and/or institutional guidelines for animal testing, animal care, and use of animals were followed by the author.

Sampling and field studies All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities and are mentioned in the acknowledgements.

Data availability The data on size and abundance of the corals generated or analysed during this study are included in the supplementary information files, including the codes used for the analysis. The datasets on depth and GPS coordinates are available from the corresponding author on reasonable request.

Author contribution SB: conceptualisation, data curation, formal analysis, validation, investigation, methodology, project administration, visualisation, writing, and editing. MC: conceptualisation, data curation, investigation, methodology, writing, and editing. MW: conceptualisation, data curation, investigation, methodology, writing, and editing. HB: validation, writing, and editing. JMW: funding acquisition, validation, writing, and editing. MM: funding acquisition, validation, visualisation, writing, and editing. LN: funding acquisition, validation, methodology, writing, and editing. MB: conceptualisation, data curation, validation, investigation, methodology, supervision, writing, and editing.

References

Arrigoni R, Kitano YF, Stolarski J, Hoeksema BW, Fukami H, Stefani F, Galli P, Montano S, Castoldi E, Benzoni F (2014) A phylogeny reconstruction of the Dendrophylliidae (Cnidaria, Scleractinia) based on molecular and micromorphological criteria, and its ecological implications. Zool Scr 43:661–688. https://doi.org/10.1111/zsc.12072

Bongaerts P, Hoeksema BW, Hay KB, Hoegh-Guldberg O (2012) Mushroom corals overcome live burial through pulsed inflation. Coral Reefs 31:399. https://doi.org/10.1007/s00338-011-0862-z

Byrne M, Foo SA, Vila-Concejo AV, Wolfe K (2023) Impacts of climate change stressors on the Great Barrier Reef. In: Wolanski E, Kingsford M (eds). Oceanographic processes of coral reefs: physical and biological links in the Great Barrier Reef. CRC Press, Taylor and Francis Group, Oxford UK

Dias-Pullido G (2019) Macroalgae. In: Hutchings P, Kingsford M, High-Guldberg O (eds) The Great Barrier Reef Biology. Environment and Management CSIRO Publishers, Clayton Victoria, pp 207–217

Eyal G, Wiedenmann J, Grinblat M, D'Angelo C, Kramarsky-Winter E, Treibitz T et al (2015) Spectral diversity and regulation of coral fluorescence in a mesophotic reef habitat in the Red Sea. PLoS ONE 10:e0128697. https://doi.org/10.1371/journal.pone.0128697

Fine M, Sabbah S, Shashar N, Hoegh-Guldberg O (2013) Light from down under. J Exp Biol 216:4341–4346. https://doi.org/10.1242/jeb.025106

Fisk DA (1983) Free-living corals: Distributions according to plant cover, sediments, hydrodynamics, depth and biological factors. Mar Biol 74:287–294. https://doi.org/10.1007/BF00403453

Frade PR, Bongaerts P, Englebert N, Rogers A, Gonzalez-Rivero M, Hoegh-Guldberg O (2018) Deep reefs of the Great Barrier Reef offer limited thermal refuge during mass coral bleaching. Nat Commun 9:3447. https://doi.org/10.1038/s41467-018-05741-0

Gill GA, Coates AG (1977) Mobility, growth patterns and substrate in some fossil and recent corals. Lethaia 10:119–134. https://doi.org/10.1111/j.1502-3931.1977.tb00601.x

Goreau TF, Yonge CM (1968) Coral community on muddy sand. Nature 217:421–423. https://doi.org/10.1038/217421a0

Herrán N, Narayan GR, Doo SS, Klicpera A, Freiwald A, Westphal H (2022) High-resolution imaging sheds new light on a multi-tier symbiotic partnership between a "walking" solitary coral, a sipunculan, and a bivalve from East Africa. Ecol Evol 12:e8633. https://doi.org/10.1002/ece3.8633

Hoeksema BW, Best MB (1991) New observations on scleractinian corals from Indonesia: 2. Sipunculan-associated species belonging to the genera *Heterocyathus* and *Heteropsammia*. Zool Med 65:221–245

Hoeksema BW, Matthews JL (2015) Partial bleaching in an assemblage of small apozooxanthellate corals of the genera *Heteropsammia* and *Heterocyathus*. Coral Reefs 34:1227. https://doi.org/10.1007/s00338-015-1314-y

Hurrey LP, Pitcher CR, Lovelock CE, Schmidt S (2013) Macroalgal species richness and assemblage composition of the Great Barrier Reef seabed. Mar Ecol Prog Ser 492:69–83. https://doi.org/10.3354/meps10366

Igawa M, Kato M (2017) A new species of hermit crab, *Diogenes heteropsammicola* (Crustacea, Decapoda, Anomura, Diogenidae), replaces a mutualistic sipunculan in a walking coral symbiosis. PLOS ONE 12:e0184311. https://doi.org/10.1371/journal.pone.0184311

Keesing JK, Mortimer N, Hellmrich L, Godoy D, Babcock RC, Heyward A, Paton D, Harvey ES (2023) The short spined crown-of-thorns starfish Acanthaster brevispinus is a corallivore too. Coral Reefs 42:399–404. https://doi.org/10.1007/s00338-023-02351-1

Kitahara MV, Cairns SD (2021) Azooxanthellate Scleractinia (Cnidaria, Anthozoa) from New Caledonia. Mem Mus Natl Hist Nat 215:1–722

McNeil M, Webster JM, Beaman RJ, Graham TL (2016) New constraints on the spatial distribution and morphology of the Halimeda bioherms of the Great Barrier Reef, Australia. Coral Reefs 35:1343–1355. https://doi.org/10.1007/s00338-016-1492-2

McNeil M, Firn J, Nothdurft L, Pearse A, Webster J, Pitcher C (2021) Inter-reef *Halimeda* algal habitats within the Great Barrier Reef support a distinct biotic community and high biodiversity. Nat Ecol Evol 5:647–655. https://doi.org/10.1038/s41559-021-01400-8

Mehrotra R, Scott CM, Hoeksema BW (2016) A large gape facilitates predation on salps by *Heteropsammia* corals. Mar Biodivers 46:323–324. https://doi.org/10.1007/s12526-015-0379-8

Mehrotra R, Monchanin C, Scott CM, Phongsuwan N, Caballer Gutierrez M, Chavanich S, Hoeksema BW (2019) Selective consumption of sacoglossan sea slugs (Mollusca: Gastropoda) by scleractinian corals (Cnidaria: Anthozoa). PloS ONE 14:e0215063. https://doi.org/10.1371/journal.pone.0215063

Pitcher R, Doherty P, Arnold P, Hooper J, Gribble N (2007) Seabed biodiversity on the continental shelf of the Great Barrier Reef World Heritage Area AIMS/CSIRO/QM/QDPI. Final Report to CRC Reef Research (CSIRO Marine and Atmospheric Research, 2007)

Roth MS, Padilla-Gamiño JL, Pochon X, Bidigare RR, Gates RD, Smith CM, Spalding HL (2015) Fluorescent proteins in dominant mesophotic reef-building corals. Mar Ecol Prog Ser 521:63–79. https://doi.org/10.3354/meps11108

Schuhmacher H, Zibrowius H (1985) What is hermatypic? A redefinition of ecological groups in corals and other organisms. Coral Reefs 4:1–9. https://doi.org/10.1007/BF00302198

Schulze A, Kawauchi GY (2021) How many sipunculan species are hiding in our oceans? Diversity 13:43. https://doi.org/10.3390/d13020043

Yabe H, Eguchi M (1942) Fossil and recent simple corals from Japan. Sci Rep Tohoku Imp Univ 22:105–178 (pls 1–12)

Yonge CM (1975) A note on the mutualism between sipunculans and scleractinian corals. In Rice ME & Todorovic M (Eds.), Proceedings of the international symposium on the biology of Sipuncula and Echiura 1970, Kotor, Yugoslavia (Vol. 1, pp. 305–311). Naucno Delo

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.