

## Research Article

# New Records of Atypical Coral Reef Habitat in the Kimberley, Australia

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New surveys of the Kimberley Nearshore Bioregion are beginning to fill knowledge gaps about the region's marine biodiversity and the national and international conservation significance of this little-known tropical reef system. Here we report the recent finding of two unique coral habitats documented at Adele Island and Long Reef during the *Woodside 2009/2010 Collection Project* surveys. Firstly, we report the finding of a subtidal zone of mixed corallith and rhodolith habitat which appears on current records, to be unprecedented in Australia. Secondly, we report the discovery of an atypical Organ Pipe Coral habitat zone and provide empirical evidence that this commercially valuable species reaches an unparalleled level of benthic cover. We provide additional details about the wider hard and soft coral assemblages associated with these unique habitats; discuss the potential biological causes and consequences of them, and make recommendations to benefit their conservation.

## 1. Introduction

Around the globe, most tropical reef locations have been the focus of at least some scientific studies. One of the last regions of shallow-water reef remaining to be explored is the Kimberley (north-west Australia). Renowned for huge tidal exchanges up to 11 m, frequent cyclones and crocodiles, this region has experienced little reef-based research apart from a series of biodiversity surveys conducted by the Western Australian Museum in the 1990s. Despite the growing public and industrial interest in this frontier region, the diversity of the tropical Kimberley reefs remains largely unknown, even at the coarse habitat level.

Geomorphological surveys of reef development in Western Australia suggest that reefs in the Kimberley coastal bioregion are uniquely characterized by the development of Holocene accretionary veneers of coral-algal limestone (>12,000 years old) on a Proterozoic basement (2,500–543 million years old) [1]. Neighbouring reefs on the north-west shelf (i.e., within the Western Pilbara and West Coast Bioregions) have origins in the Pleistocene (25 million–12,000 years ago). Thus, contemporary reefs in the Kimberley

appear to have more recent origins than others in Western Australia; however, the extent to which the difference in age translates to compositional differences between reefs remains to be resolved.

Along the Kimberley continental edge, there is extensive development of oceanic reefs. The offshore reefs (such as Ashmore, Cartier, and Scott Reefs) have been extensively surveyed as part of National and Regional management plans [2–9] and contain a surprising diversity of marine life given their isolation, including a high diversity of hard and soft corals. Despite forming a separate and distinct bioregion to the Oceanic Shoals [10, 11], only occasional coral collecting has been conducted within the nearshore Kimberley bioregion [12].

To address this information gap, a new project began in 2008 intended to quantify the diversity, distribution, and abundance of hard and soft corals along the Kimberley coast with that of other marine fauna and flora. The Woodside Collection Project (Kimberley): 2008–2011 (henceforth, the Woodside Project) (<http://www.museum.wa.gov.au/kimberley/marine-life-kimberley-region>) will combine inshore and offshore data to fill various important biogeographic and

taxonomic knowledge gaps. This will help define the current knowledge concerning the region's biodiversity to aid conservation managers, industry, and government in establishing the national and international conservation significance of the region.

Here we describe two unusual benthic habitats discovered during the Woodside 4 Project surveys in 2009 at Adele Island and in 2010 at Long Reef. We will also discuss their potential biological causes, consequences, and significance and make recommendations to benefit their conservation.

## 2. Methods

**2.1. Site Description.** Adele Island ( $15^{\circ}31.3'S$ ,  $123^{\circ}9.5.0'E$ ) is situated approximately 90 kms from the coastline on the inner section of the north-west shelf. Approximately 17 km long and 9 km wide, Adele is a true reef platform with a vegetated centre. The reef is considered one of the largest and mature of the Sahul Shelf [13]. Wilson [14] describes the reef platform as, "a bioherm ... [whose] top is a cap of Quaternary reefal limestone, built on an inundated rocky hill of the dissected Kimberley Basin margin over a Proterozoic basement." Prevailing westerly wind, swell, and diurnal tides, with up to 11 m range on high-water springs, have shaped the intertidal reef platform (rampart) that is heavily etched with small drainage channels and low, widely spaced ridges running parallel to the reef edge that resemble a series of long low and wide corrugations. Beyond the rampart, the reef slopes into sublittoral fore-reef and back-reef zones featuring hard corals, soft corals, hydroids, bryozoans and macroalgae, such as *Sargassum*.

Long Reef ( $15^{\circ}56.5'S$ ,  $124^{\circ}12.5''E$ ) is situated approximately 28 kms from the coastline, also on the inner part of the NW Sahul Shelf. It is a north-south orientated elongated platform reef that is approximately 27 km long and 12 km wide, with a similar geological history to Adele Island. It was built on antecedent Proterozoic features that are remnants of topographic high points of the submerged Kimberley Basin margin [14]. Contemporary reef growth is controlled by wind, swell and extreme tidal exchanges. Long Reef features a large intertidal reef pavement zone resembling others in the inshore Kimberley such as Adele, but in contrast to Adele an island has not formed. There is, however, a central sandy spine running down the centre of the reef. The flat midlittoral reef pavement is covered with turf algae and tide pools which are fringed with small coral colonies. The reef pavement extends down to a narrow, honeycombed, and terraced fore-reef ramp that forms small drainage cascades resembling the low tide cascades of Montgomery Reef [15]. Subtidally, there is a steep fore-reef slope that descends beyond the 20 m contour and a fractured reef base with hard corals, sponges, hydroids, and other fauna and flora. The reef on the leeward side is gently sloping.

**2.2. Field Surveys.** Hard and soft coral biodiversity at Adele Island and Long Reef (Figure 1) were surveyed for the first time using standard benthic monitoring techniques. At Adele Island 13 stations were surveyed in October 2009



FIGURE 1: Map of the Kimberley coastline marking the location of Adele Island and Long Reef.

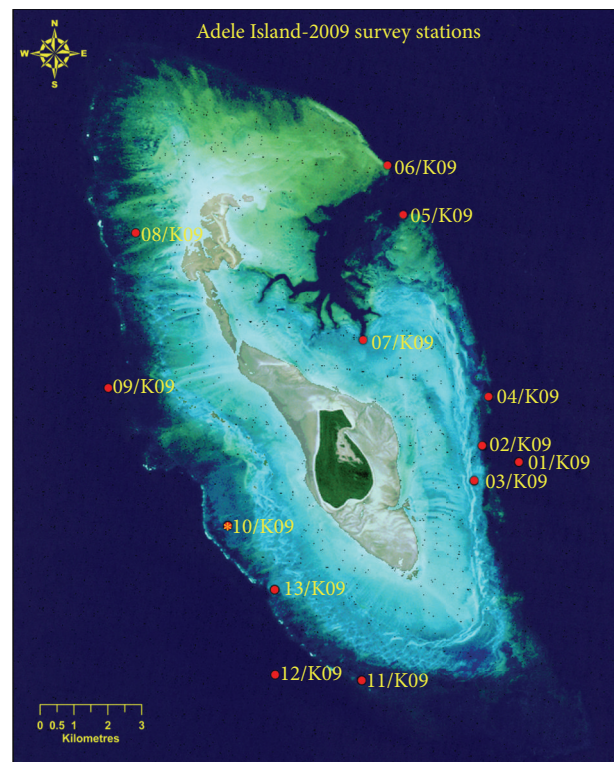


FIGURE 2: Satellite image of the extensive coral reef surrounding Adele Island with survey stations highlighted, the rollolith habitat zone is denoted by a star.

(Figure 2). Eleven stations were surveyed using SCUBA and two intertidal stations were surveyed. At Long Reef 15 stations were surveyed in October 2010 (Figure 3), nine stations using SCUBA and six stations were intertidal.

The mean species richness (+SE) of hard corals was calculated at each station from four replicated 15 m × 1 m wide



FIGURE 3: Satellite image of Long Reef with survey stations highlighted, the *Tubipora* habitat denoted by a star.

coral biodiversity belt transects. In addition, a 20-minute rapid visual search over the station (covering approximately 1000 m<sup>2</sup>) was conducted to detect rare and infrequent species. The total hard coral assemblage at each station was documented from pooled transect and rapid visual assessment records. For soft corals, a 60-minute rapid visual search was conducted over each station to obtain a thorough list of the soft coral assemblage.

In addition, during the spring low tide of the 24th October 2010, six 10 m long point intercept transects were conducted in the exposed fore-reef ramp to quantify the benthic coverage of *Tubipora* sp. Our intention here is to describe two unusual benthic habitats that were encountered on these expeditions in an ecological context and articulate the extent of surveying we have conducted at these inshore Kimberley locations in order to establish the prevalence and significance of the new habitats.

### 3. Results

**3.1. Coralliths and Rhodoliths.** Intertidal and subtidal surveys of Adele Island revealed extensive development of hard and soft coral communities. Seventy-eight species of scleractinian coral were recorded in intertidal and shallow water stations (<6 m depth). The level of hard coral diversity increased to 176 species with additional surveying at subtidal sites (>14 m depth). These records indicate that approximately half of all the hard coral species currently known to occur in the offshore and inshore Kimberley bioregions are present at Adele Island [16].

Octocoral biodiversity in intertidal and shallow water stations under 6 m depth was species poor, increasing considerably with greater depth. Only four species of octocoral were recorded in habitats under 6 m depth (*Heliopora coerulea*, *Lobophytum* sp., and *Anthelia* sp., *Sansibia* sp.), whereas 28 species were recorded at a depth of 6 m to 14 m.

At station 10/K9, on the south west side of Adele Island a curious zone of benthic fauna was observed at the southern edge. This station was in <4 m depth on the midlittoral back reef. It was a high energy, current swept consolidated reef platform with many depressions leading to a labyrinth of underplatform tunnels. The depressions contained coarse sand and coral rubble. Fifty-five species of hermatypic coral were recorded at this station with the five most commonly encountered species on transects being *Goniastrea retiformis*, *Acropora papillare*, *Favites halicora*, *Goniastrea pectinata*, and *Porites annae*. Within the Alcyonaria only the blue coral, *Heliopora coerulea*, and one species of *Anthelia* sp. were recorded.

At the southern edge of station 10/K9, the consolidated habitat gave way to a rubble bed. This was dominated by a mixed assemblage of coralliths (free-living live coral nodules) and rhodoliths (free-living balls of coralline algae) (herein called the rollolith zone, *sensu* Baarli, 2010—where rollolith refers to motile balls of mixed origin, i.e., coral, algae, polychaete or bryozoan). Among the coralliths, four different species of coral were identified (*Pavona venosa*, *Psammocora profundacella*, *Cyphastrea chalcidicum*, and *Millepora* sp.) (Figures 4(a), 4(b), and 4(d)). Milleporinid coralliths were the most abundant and between 3 and 5 coralliths of the other genera were observed within the section of the rollolith zone that was examined. The maximum size of the coralliths was 12 cm (greater diameter).

Rhodoliths (Figure 4(c)) dominated the assemblage in the rollolith zone and covered the substrate. The largest rhodolith recorded was 8 cm (greater diameter). Generally the rhodoliths formed as a cluster of short (>1 cm) dense branches, some of which appeared to be formed around coral rubble or shells, others appeared to be entirely of algal origin.

**3.2. Long Reef: *Tubipora*.** Intertidal and subtidal surveys at Long Reef revealed extensive development of hard coral and soft coral communities. Preliminary systematic studies indicate 200 species of scleractinian corals occur at Long Reef, 68 of which occur in the intertidal zone. Octocoral biodiversity followed the same trend as Adele Island with low biodiversity in intertidal and shallow water stations under 6 m depth, and increasing to 29 species between 6 m and 14 m.

During a spring low tide surveys of Long Reef we encountered an atypical habitat zone dominated by the Organ Pipe Coral, *Tubipora* sp. on the reef platform bordering station 56/K10 (Figures 5(a) and 5(b)). The platform was on the south west side of Long Reef and featured many tide pools and a covering of algal turf. The platform extended down to a narrow, honeycombed fore-reef ramp that was terraced forming small drainage waterfalls. Numerous blow-holes occurred along the edge of the reef; however, these were only evident for a short duration over the lowest point of the tide.

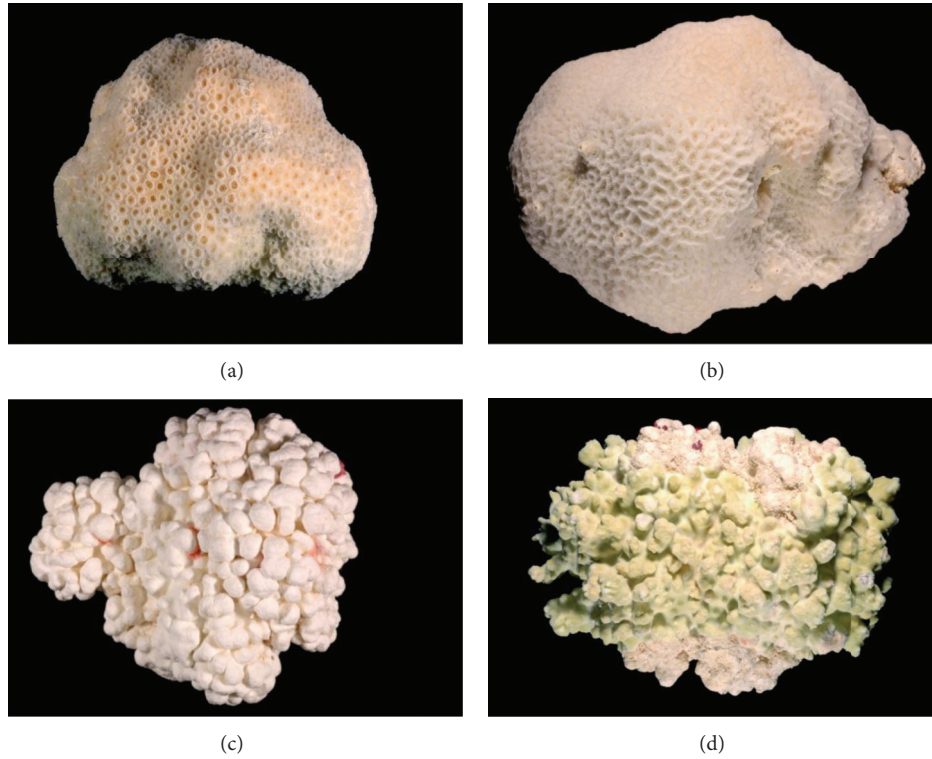


FIGURE 4: Rolloliths collected from Adele Island. (a) *Cyphastrea chalcidicum* corallolith. (b) *Pavona venosa* corallolith. (c) Red coralline algae rhodolith. (d) *Milleporina* corallolith. Skeletal photos Roger Springthorpe Australian Museum.



FIGURE 5: Organ Pipe Coral at Long Reef. (a) A single colony of Organ Pipe Coral (*Tubipora* sp.). (b) The narrow fore-reef habitat on the western side of Long Reef showing the prolific development of *Tubipora* as the tide advances.

Point-intercept transects conducted to quantify the percent cover of *Tubipora* in the zone verified that *Tubipora* was the dominant benthic organism with a mean of 27.67% ( $\pm 3.24$  SE) cover. Turf algae ( $22\% \pm 5.49$  SE); sand/rubble ( $18\% \pm 4.26$  SE); and coralline algae ( $9\% \pm 2.5$  SE) inhabited the majority of the remaining space. Ten other genera of scleractinian coral were recorded on benthic cover transects within this habitat (*Platygyra*, *Acropora*, *Goniastrea*, *Favia*, *Favites*, *Galaxea*, *Symphyllia*, *Goniopora*, *Seriatopora*, and *Porites*); however, their combined coverage was <20%. Six additional species of octocorallia were recorded within this *Tubipora* habitat zone (*Heliopora coerulea*, *Lobophytum* sp.,

*Cladiella* sp., *Capnella* sp., *Xenia* sp., and *Briareum* sp.), as well as a small number of sponges and hydroids.

#### 4. Discussion

**4.1. Rolloliths.** Free-living spheroidal corals (i.e., coralliths) were first noted from shallow tropical reef environments in Vanuatu and Indonesia in the late 1800s [17], and palaeontological studies have dated coralliths back to the Eocene (approx. 65 mya, [18]). Throughout the 70s, numerous papers arose concerning coralliths, conferring they occur right across the globe from Bermuda to Madagascar [19, 20]. More

recently, assemblages of coralliths have been recorded in the Cook Islands [21]; Barbados [22]; the North West Indian Ocean [23]; Galapagos [24]; Mexico; and the Red Sea [25]. In Australian waters, there are currently only isolated records of coralliths. For example, *Porites lutea* has been observed to form motile balls on the depositional reef flats at Heron Island [26] and *Cyphastrea micropthalma* forms motile balls at the Cocos Islands [27].

The largest corallith encountered at Adele Island was a colony of *Pavona venosa* which was 12 cm (greatest diameter). This is small in comparison to the normal size of this species which has the potential to grow to at least 1 m (greatest diameter) when attached to the substrate. Coralliths are likely to be size restricted because if they grow too large they would become partially or completely buried. It is also worthwhile noting that no attached forms of the four corallith species were recorded at station 10/K9; however, these four coral species were encountered in low abundance at other Adele Island stations.

Rhodolith beds, however, are very widespread. They are distributed from the poles to the tropics and can accumulate to form extensive communities on a wide variety of sediments in both deep and shallow water [28, 29]. The largest beds reported are on the Brazilian Shelf spanning 23 degrees of latitude [28, 30, 31]. In Brazil, rhodoliths are so abundant they are commercially mined [32]. Numerous studies have reported that rhodolith beds are important ecologically because they support a high diversity of associated flora and infauna [28, 33–35].

In Australia, rhodolith beds are also relatively widespread, occurring off Western Australia [36] in cold-temperate waters of southern Australia [37] and in southern Queensland where they cover up to 50% of the sea-floor from 50 to 110 m depth [38]. A study conducted at Montgomery Reef in the Kimberley describes rhodoliths as being important contemporary reef builders [15]. Rhodoliths are reportedly so abundant at Montgomery Reef that they form containment banks which impound a raised lagoonal habitat, the water from which feeds the unique system of low-tide cascades. Some of the Montgomery Reef rhodoliths have a core of coral fragment, but many are constructed entirely of algae. Similarly, on South Turtle Reef in Talbot Bay (inshore Kimberley), rhodolith banks form along the reef crest and enclose small pools that retain water over the low tide [39].

While there are records of rhodoliths from the Kimberley, there are, however, no current records of coralliths (at Montgomery Reef, Talbot Bay, or any other Kimberley locations). Moreover, there are no current records of Australian coral reef habitat featuring a mixed assemblage of living coralliths (from a variety of genera) and rhodoliths. Thus, the Adele Island fore-reef rollolith zone appears to be relatively rare. Therefore, our findings provide the first record of mixed corallith and rhodolith habitat for the Kimberley coastal bioregion and also for Australia.

Further taxonomic study is needed to confirm which species of algae form the rhodolith community at Adele Island. Nongeniculate coralline algae are considered to be challenging to identify, and at least eight genera belonging to three families of Corallinales (Hapalidiaceae, Corallinaceae,

and Sporolithaceae) contain species that commonly form rhodoliths. The rhodolith bed off Western Port, Victoria, for example, is composed of four species (*Hydrolithon rupestre* (Foslie) Penrose, *Lithothamnion superpositum* Foslie, *Mesophyllum engelhartii* (Foslie) Adey, and *Neogoniolithon brassica-florida* (Harvey) Setchell and Mason) [37] so it is likely that the Kimberley rhodolith beds also contains multiple species.

The rolloliths of Adele Island most likely form in the lee of prevailing wave action, as a cumulative response to unidirectional currents and the tidal pull on surface sediments. This maintains periodic yet constant movement enabling persistent growth on all sides of the colony [21]. The frequent disturbance of bottom sediments by browsing fishes and gastropods (bioturbation) has also been hypothesized to contribute towards the unique spherical form [19, 40, 41]. Holothurians and sea urchins have also been observed to aid in keeping coralliths and rhodoliths in motion [25].

**4.2. *Tubipora*.** *Tubipora* sp. is the only known hard, calcitic, reef-building alcyonarian (soft) coral. Its skeleton consists of calcite spicules fused into upright, parallel tubes connected by transverse platforms hence its common name of Organ Pipe Coral. Organ Pipe Coral is normally sporadic to rare throughout its range which spans the Indo-Pacific from the Red Sea and East Africa to Southeast Asia, Micronesia, Australia, and the Pacific [42]. *Tubipora* has, however, been observed in large quantities near Rat Island off Gladstone in Queensland, Australia (Philip Alderslade *pers. comm.*), and at an undisclosed location in Papua New Guinea [43]. The highest published benthic coverage estimate of *Tubipora* sp. is 11.9% from one location in the Red Sea [44]. Our quantitative data showing 27.67% (+3.24 SE) coverage of *Tubipora* at this one Long Reef location suggests this is an exceptionally rare, high density population.

*Tubipora* was once thought to be a single ubiquitous species: *Tubipora musica* Linnaeus 1758 (Family Tubiporidae, Order Stolonifera, Class Anthozoa, Phylum Cnidaria) however there are now several nominal species of *Tubipora*. Our preliminary systematic study has raised doubt about which species of *Tubipora* is present in the Kimberley. Hence, further investigations, based on gross morphology of its skeleton and molecular sequencing, are necessary to confirm or refute prior assumptions about the species identity. In addition to the required taxonomic research, further biological research is needed to understand the age, growth rate, reproductive biology, and molecular ecology of the Long Reef *Tubipora* in order to understand why they are so prevalent at this particular location.

Shared among the various nominal species of *Tubipora* is the distinctive bright red colour of the skeleton. The red colouration is a result of organic pigments, including carotenoids, which give the orange colour to carrots and the red colour to cooked lobsters. Carotenoids occur naturally in plants but are not manufactured by animals, so it is likely the Organ Pipe Coral assimilates the pigments via heterotrophic feeding on phytoplankton. Incorporating pigment into the skeleton is likely to serve the coral in two ways: firstly, it would assist light absorption and maximize the potential for

photosynthesis by symbiotic dinoflagellates; and secondly, carotenoids may help protect chlorophyll from photo damage [45].

**4.3. Conservation Implications.** Both hard coral and calcified macroalgae are vital components of nearshore ecosystems in tropical and temperate systems through their contributions to carbon cycling and productivity [46]; the provision of habitats and their associated biodiversity; their role as nursery areas [47, 48]; and their contribution to the development of reef structures [49]. Rhodoliths also offer the potential to serve as paleoclimate proxies [40, 50–52]. A recent study measuring carbonate deposition in two slow-growing rhodolith species ( $<200 \mu\text{m y}^{-1}$ ) permitted biweekly sampling resolution leading the authors to suggest rhodoliths are unique, globally distributed palaeothermometers, which may help refine regional climate histories during the Holocene [53].

The remote location and lack of conservation management of Adele Island and Long Reef combined with the high density of rhodoliths/coralliths and Organ Pipe Coral in the unusual habitat zones we describe here renders these marine resources highly susceptible to harvesting pressure in the future. Traditional fishers have utilized the marine resources of the Kimberley region since the early eighteenth century [54, 55], but there is currently no historical record of hard corals, soft corals, or calcifying macroalgae being targeted. There is, however, substantial and rapidly growing trade in corals [56] including Organ Pipe Coral, which is used in the curio, jewellery, and aquarium industries because of its attractive bright red skeleton [57]. In consideration of this, Organ Pipe Coral is currently listed as Near-Threatened on the IUCN red-list of threatened species [57].

Scleractinian and nonscleractinian corals are afforded some amount of protection from international trade as they are listed under Appendix I and II of CITES; however, calcifying macroalgae are not listed. At an international level, we advocate the inclusion of rhodoliths under CITES regulation and that special conditions be made to ensure the trade of coralliths is monitored. Further, more timely access to national-level CITES trade data is needed to monitor trends in the export of marine resources.

It is important that regional marine resource managers direct special attention towards these atypical Kimberley habitats because corals and calcifying macroalgae are vulnerable to changes in the environment. Specific recommendations for conserving these unique benthic habitats include the establishment of marine protected areas in the Kimberley encompassing Adele Island and Long Reef and the inclusion of these locations in the existing program of Customs surveillance. Further research into *Tubipora* and rhodolith taxonomy is also important to support conservation efforts. Ongoing adaptive management and long-term monitoring of wild coral harvest in Western Australia are needed to manage risks and to ensure Western Australia's unique natural resources are protected. The Kimberley is the new frontier for tropical reef research and given the industrial interest in the region, more information is needed to provide

the basis for sound decision-making and sustainable resource management.

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