MOLLUSCAN SURVEYS OF OFFSHORE CORAL REEFS IN NORTHWESTERN AUSTRALIA AND ADJACENT BIOGEOGRAPHICAL AREAS

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ABSTRACT

The Western Australian Museum undertook three major expeditions to the offshore atolls on the North West Shelf of Western Australia in the 1980s: Rowley Shoals (1982); Scoff and Seringapatam Reefs (1984); and Ashmore Reef and Cartier Island (1986). This was the first scientific work on the molluscs of the reefs. Survey reports on the fauna collected were subsequently published by the Museum. Work undertaken in the last 13 years, both on the offshore atolls and in biogeographically related areas, allows us to reevaluate biogeographical relationships of the molluscs of the oceanic atolls on the North West Shelf. The molluscan fauna of the offshore atolls of the North West Shelf is restricted: 260 species were collected during the original expedition to Rowley Shoals, 279 at Scoff Reef, and 433 at Ashmore Reef. This is substantially fewer than were collected in similar trips to the Philippines (651), Papua New Guinea (638) and Indonesia (541), and is also substantially lower than the 633 species collected at the Montebello Islands and 655 recorded from the Muiron Islands and Exmouth Gulf, both of these locations are along the inner continental shelf of Western Australia. With further collecting since 1986 a total of between 800 and 850 species of molluscs have now been collected on the North West Shelf atolls. The fauna of the oceanic atolls is very different from that recorded along the continental coastline of northern Western Australia, with only 33% of the species being recorded in both areas. In contrast to Christmas Island and the Cocos (Keeling) Islands, none of the molluscs collected on the North West Shelf atolls are Indian Ocean species; all are of Pacific origin. While *Drupella* were consistently collected in small numbers on the shelf atolls, no outbreaks were recorded. The offshore atolls in Western Australia have populations of a number of molluscs that have been, or could be, used as aquaculture species, including genera such as *Lambis, Strombus, Tridacna,* and *Trochus.*

INTRODUCTION

Compared to the Great Barrier Reef, off the coast of Queensland in eastern Australia, coral reefs in Western Australia are poorly known among the general public and have received little scientific attention. This lack of visibility does not mean there are no significant reefs in Western Australia. In fact, the Ningaloo Reef Tract on the western side of North West Cape, with a north to south length of approximately 250 km, is the largest fringing reef in Australia. The coral reefs of the Houtman Abrolhos Islands, on the west coast of the State, are home to one of the major fishing areas of Australia, with an annual catch worth approximately $ 50 million. The catch is dominated by the western rock lobster, *Panulirus cygnus,* which constitutes Australia's largest single species fishery. Major reef systems occur among the inshore islands and along the northern continental coastline of the State. Further

offshore there are major open ocean atolls. These are classic oceanic environments that are unusual in being located in an area of high tidal range. However, until very recently there had been no scientific examination of the reefs and their biota.

To rectify the situation, the Western Australian Museum undertook three major expeditions to the offshore atolls in the 1980s: Rowley Shoals (1982); Scoff Reef and the smaller nearby Seringapatam Reef (1984); and Ashmore Reef and Cartier Island (1986). Survey reports on the fauna collected were subsequently published by the Museum (Berry, 1986; Berry, 1993) and included details of the molluscs collected (Wells and Slack-Smith, 1986; Wells, 1993). A separate paper was prepared which compared the fauna of the offshore atolls with that of the continental shoreline (Wells, 1986). Data from the offshore atolls were also used in a comparison of distributions of marine fauna in Indonesia, Papua New Guinea and northern Australia (Wells, 1990).

More recently, the Museum surveyed the marine fauna of Christmas Island and the oceanic atoll of Cocos (Keeling) Islands; both are in the Indian Ocean. Additional surveys have been conducted along the mainland coast of Western Australia and the islands of many parts of the inner continental shelf from the Houtman Abrolhos Islands at latitude 29°S to the northern areas of the Kimberley at latitude 14°S. Details of the surveys are provided in Table 1. In addition, there have been three trips to offshore atolls made by shell collectors during the 1 990s. The junior author collected a large number of new molluscan records on these trips.

In the last two years Conservation International (CI), a nongovernmental organisa-

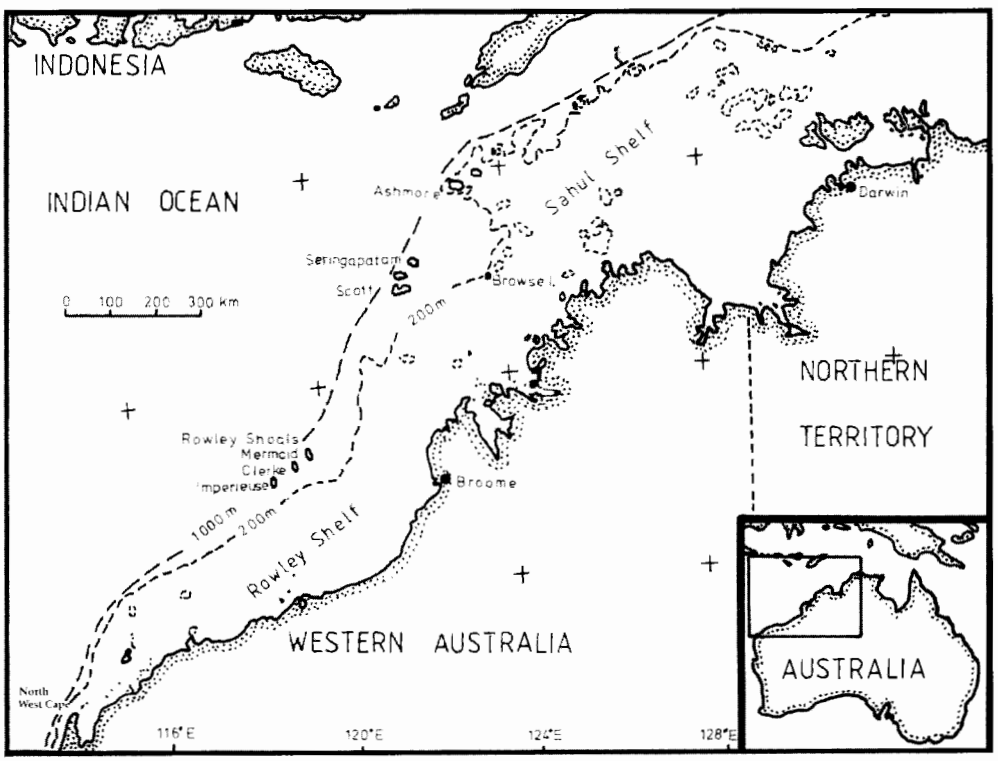

Figure 1. The study area, Western Australia

tion based in Washington, D.C. in the U.S.A., has started a marine rapid assessment program surveying reefs of the Indo-West Pacific coral triangle. The goal of the project is to survey a total of 10 reefs throughout the coral triangle to provide information on which to determine priorities for conservation of coral reefs. While fisheries information and data on the reef structures are also incorporated into the program, the core scientific work is an assessment of the biodiversity of each reef system, targeting corals, fish and molluscs. The scientists participating in the CI studies are the same individuals who worked in the Western Australian Museum studies, making the data directly comparable; the senior author undertakes the mollusc component of the Conservation International expeditions.

As indicated above, the work undertaken and published during the early to mid 1 980s provided considerable information on the molluscs of offshore coral reefs in northwestern Australia. Work undertaken since then on the atolls themselves and in biogeographically related areas allows an opportunity to reassess the Mollusca of the offshore atolls of Rowley Shoals, Scoff Reef and Ashmore Reef to determine whether conclusions made more than ten years ago are still valid in light of the additional information now available.

THE OFFSHORE ATOLLS

The continental shelf off northwestern Australia is one of the widest in the world, in some areas extending hundreds of kilometres out to sea. It is also relatively deep, with depths at the shelf break on the order of 500 m. There is a series of shelf edge atolls and reefs which lie on the seaward margin of the North West Shelf. There is a wide range in size of the structures: some of the atolls are large with extensive intertidal areas, others are small reefs that may break the surface or may be in shallow subtidal depths. The atolls are relatively undisturbed, though Indonesian fishermen heavily fish on some reefs. Although the atolls are in Australian waters, an agreement between the governments of Australia and Indonesia allows Indonesian fishermen to fish areas such as Ashinore Reef and Scoff Reef provided they use traditional means.

Sea surface current flows in the area are poorly known. The Timor Current flows from the Banda Sea through the Timor Sea during the south-east monsoon, bringing water into the eastern Indian Ocean. Most recent estimates are of a flow from the Pacific Ocean on the order of 5 x 10 m sec^{-1}. The current is strongest in February to June (Godfrey and Ridgway, 1984; Fine, 1985; Holloway, 1988; Cresswell *et. al.* 1993). The current provides ready transport mechanism for larvae from Pacific Ocean and Southeast Asian species to reach the offshore atolls, and even the Australian coastline. The water is tropical, with sea surface temperatures of 24°C in the winter months of July and August increasing to 30°C in the summer months of January to March (Holloway and Nye, 1985).

The region is in the monsoonal belt. Cyclones are relatively infrequent near Ashmore Reef and Scott Reef, but are more frequent at Rowley Shoals, which is farther south. From 1975 to 1992, 10 cyclones passed within one degree of Rowley Shoals, twice as many as at Ashmore and Scott Reefs (Berry, 1993).

The major atoll systems are, from south to north, Rowley Shoals, Scott and Seringapatam Reefs, and Ashmore Reef, with the nearby Cartier Island. Rowley Shoals (17°07'S; 119°36'E), which Fairbridge (1950) considered to be the most perfect open ocean atolls in Western Australia, Scott Reef (13°40'S; 122°'E) and the nearby Seringapatam Reef are all 250 km or more from nearest mainland coast. They are open ocean atolls which rise up to the ocean surface from depths of 500 m. The continental shelf is deep in this area, and there is evidence of recent subsidence (Carrigy and Fairbridge,

1954). The atolls were formed by rapidly growing columns of coral; there is no evidence of volcanic origin (Fairbridge, 1950).

Rowley Shoals is composed of three separate reefs: Mermaid Reef, Clerke Reef, and Imperieuse Reef, which are separated from each other by 30-40 km of open ocean. The reefs are 16-18 km long on the north south axis. All are pear shaped, with the southern end broader, having a maximum width of 8-10 km. In contrast to Rowley Shoals, Scott Reef is a double reef. There is a circular reef in the north with a diameter of 16 km, and a 27 km wide horseshoe reef in the south. The reefs are separated by a narrow channel which has depths to 600 m. Seringapatam Reef is a small reef 20 km north of Scott Reef with a maximum dimension of 10 km. None of the reefs have vegetated cays, but there may be one or two small intertidal sand cays on each reef.

The structure of all of these reefs (except the horseshoe reef at South Scott Reef) is similar. The intertidal reef flats, which are up to 2 km wide, enclose large lagoons. The reefs each have one or more channels through them, usually on the northeastern corner. Reef flats on western sides, in the path of the prevailing swell, are broader than on the east. The reef flats are low, and drop off quickly into the seaward slope. Little is known of tidal ranges in the area, but spring tides at Rowley Shoals are estimated to be 5 m, and tides are semidiurnal. As the tide falls, water is trapped in the lagoon at low tide. At low water the lagoon surface may be as much as 2 m higher than the open sea, with strong currents flowing seaward through the channels. The lagoons are shallow, with maximum depths of 50 m. The bottoms are generally sandy, but there are isolated bombies which may reach nearly to the sea surface.

Ashmore Reef (12°17'S; 123°02'E) is only 145 km south of the Indonesian island of Roti, and is 350 km from Kimberley coast of Western Australia. It is similar in shape and structure to the other atolls but is oriented east to west rather than north to south. A shallow platform with extensive shoals less than 50 m deep is located to the east of Ashmore Reef, but the 200 m contour line is near the southern and western sides. Ashmore Reef is the largest of the offshore atolls: it is 26 km long and 14 km wide. The southern reef is exposed to prevailing swell and has a width of up to 6 km. The protected northern reef flat is only 1.4 km wide. There are three low vegetated cays at Ashmore Reef. West Island is the largest and is 1.4 km long and 500 m wide. The cays have a total area of 62 ha. Unlike the other reefs, Ashmore Reef is not a continuous reef, the northern side is discontinuous.

MATERIALS AND METHODS

In order to obtain as many species of molluscs as possible of >5 mm in shell length, collecting was undertaken in a variety of ways on each expedition, including extensive SCUBA diving and reef walks at low tide, and less extensive dredging and sorting of drift algae. Expeditions were for varying lengths, but most were from two to three weeks; the amount of collecting time in each location is indicated on Table 1. All of the major marine habitats that occur in each area were collected. The offshore atolls are essentially open coral reef environments, but areas along the continental shoreline also had rocky shores and in some areas extensive mangroves.

RESULTS AND DISCUSSION

A number of major findings were made in the initial reports of the expeditions to the offshore atolls (Wells, 1986; 1990; 1993; Wells and Slack-Smith, 1986). The sections below discuss whether or not the points are still valid, or if conclusions should be modified because of the additional information collected in recent years.

Diversity of fauna on the offshore atolls

Essentially the same collecting techniques were used in all of the trips. In addition, the

senior author participated in all expeditions, so the data on relative diversity obtained in the Western Australian Museum and Conservation International expeditions are reasonably comparable. The expeditions to Rowley Shoals and Scott/Seringapatam Reefs were only a week long, which reduced the time available for obtaining molluscs. However, there was a subsequent expedition to Rowley Shoals by private collectors who generously made available the list of species they collected. Only a few additional records were obtained; these are incorporated into Table 1.

During expeditions such as these, clearly all species collected on the first day are new records for the trip. The proportion of new records rapidly decreases as the common species are found during the first few days; in the expedition to the Calamian Islands in the Philippines for example 147 records were collected on the first day, but a total of only 106 new records were obtained during the last week (seven days) of the expedition. In addition, two mollusc specialists were present on all of the expeditions to offshore atolls in northwestern Australia, but only one was present on some of the other expeditions, particularly those organised by Conservation International.

Table 1. Numbers of mollusc species collected during surveys of the faunas of coral reefs on the north coast of Western Australia and adjacent parts of the Indo-Pacific Ocean.

Location	Collecting days	Mollusc species	Reference
Togian-Banggai Islands, Indonesia	11	541	Wells, in press b
Calamian Group, Philippines	16	651	Wells, in press a
Milne Bay, Papua New Guinea	19	638	Wells, 1998
Cocos (Keeling) Islands	20	380 on survey; total known fauna of 610 spp.	Abbott, 1950; Maes, 1967; Wells, 1994
Chagos Islands	Accumulated data	384	Shepherd, 1984
Christmas Island	12 plus accumulated data	313 on survey; approx. 520 total spp.	Iredale, 1917; Wells & Slack-Smith, 1988; Wells *et al.*, 1990
Ashmore Reef	12	433	Wells, 1993; Willan, 1993
Cartier Island	7	381	Wells, 1993
Hibernia Reef	6	294	Willan, 1993
Scott/Seringapatam Reef	8	279	Wilson, 1985; Wells & Slack-Smith, 1986
Rowley Shoals	7	260	Wells & Slack-Smith, 1986
Kimberleys 1988	19	413	Wells, 1989
Kimberleys 1991	19	317	Wells, 1992
Montebello Islands	19	633	Preston, 1914; Wells et al., 1993
Muiron Islands and Exmouth Gulf	12	655	Slack-Smith & Bryce, 1995
Bernier and Dorre Islands, Shark Bay	12	425	Slack-Smith & Bryce, 1996
Abrolhos Islands	Accumulated data	492	Wells & Bryce, 1997

Even with these reservations, it is clear that the molluscan fauna of the offshore atolls of the North West Shelf is very restricted: 260 species were collected at Rowley Shoals, 279 at Scoff Reef, and 433 at Ashmore Reef. This is much fewer than in the Philippines (651), Papua New Guinea (638) and Indonesia (541), all areas in the coral triangle surveyed during the Conservation International expeditions.

Diversity on the northwestern Australian atolls was also substantially lower than the 633 species collected at the Montebello Islands and 655 recorded from the Muiron Islands and Exmouth Gulf, both of these locations are along the inner continental shelf of Western Australia.

The Cocos (Keeling) Islands in the eastern Indian Ocean are oceanic atolls, and are thus most similar to the shelf atolls on the North West Shelf. It is interesting that the 380 species recorded from Cocos (Keeling) is within the range of the North West Shelf atolls, being more diverse than was found at Rowley Shoals and Scott Reef, but less than at Ashmore Reef.

Subsequent to the offshore atoll expeditions there have been a total of six expeditions to the Kimberley region of the continental coastline of Western Australia. Only the two most pertinent expeditions are shown on Table 1. The 317 and 413 species recorded on these expeditions again fall within the range recorded on the oceanic atolls. These two expeditions included work on some of the coral reefs on the islands of the Kimberley coastline and recorded a higher diversity of fauna than the remaining trips, which concentrated on the inner shoreline which are muddy environments dominated by mangrove communities and subtidal sand and mud; diversity is low in these areas.

Differences between offshore and inshore molluscan fauna

Wells (1980) examined distributions of molluscs along the 12,000 km coastline of Western Australia. Because the phylum is so large and many of the identifications of species were doubtflul, 20 of the best known families of prosobranch gastropods were selected for analysis. When data from the three offshore reef trips subsequently became available, an analysis was made comparing distributions of species of the same families along the continental shoreline with the offshore atolls (Wells, 1986). A clear difference was demonstrated. Of the 394 species examined, only 115, or 29%, occurred on both the mainland and the offshore atolls. A total of 571 species of these 20 families are now known from northwestern Australia (Table 2), an increase of nearly half since the 1986 paper was published. Despite the increased available information, the strong difference between the inshore and offshore fauna has been retained, with only 33% of the species being recorded in both areas.

Table 2. Relationships of gastropod species from mainland localities and offshore reefs in northwestern Australia.

Faunal characteristics	Mainland		Offshore reefs	
	No.	%	No.	%
Restricted to area	280	60	103	35
Known from mainland and offshore	188	40	188	65
Total	468	100	291	100

As was previously described (Wells, 1986), not only is the presence/absence of species different on the open ocean atolls, but the community composition is different. Many species, such as *Conus miles,* which are rare along the continental shoreline are abundant on the offshore atolls.

Penetration of Indian Ocean species

Maes (1967) was intrigued by the faunal relationships of the marine molluscs she

found at Cocos (Keeling): 82% were widespread Indo-West Pacific forms; 15% were Pacific species; and only 3% were Indian Ocean species. The Western Australian Museum expeditions demonstrated that there is a close faunal similarity between the molluscs of Cocos (Keeling) and the atolls on the North West Shelf (Wells, 1994). However, Indian Ocean species, such as *Drupa lobata,* which were recorded at Cocos (Keeling) and Christmas Island, do not occur on the offshore atolls off northwestern Australia. This is not surprising given the movement of water from the Pacific Ocean into the Arafura Sea through the Indonesian Archipelago (Godfrey and Ridgway, 1984; Fine, 1985; Holloway, 1988; Cresswell *et al.* 1993).

Drupella infestations

During the late 1 980s and early 1990s population explosions of the neogastropod *Drupella cornus* occurred along the Ningaloo Reef Tract on the west side of North West Cape, in Western Australia. The outbreaks caused considerable damage to the reefs (summarised in Turner, 1992). Other reports of damage by three species of *Drupella* have been widespread throughout the Indo-West Pacific (Cumming, 1999).

Drupella rugosa and *D. cornus* have been recorded on many of the other expeditions in Western Australia, including those to the offshore atolls off northwestern Australia, but no outbreaks have been recorded except for that on the Ningaloo Reef Tract.

Genetic resource

One of the major thrusts of the Tropical Marine Mollusc Programme has been to develop the aquaculture of shallow water marine molluscs. It is evident from the results of previous workshops in this program that considerable progress has been made in this work.

The offshore atolls in Western Australia have thriving populations of a number of species that have been, or could be, used as aquaculture species, including genera such as *Lambis, Strombus, Pinctada, Tridacna,* and *Trochus.* Species of these and other genera have become rare in many parts of Asia because of over collecting for food and/or shells, pollution, habitat degradation, and a number of other causes. Mollusc populations on the North West Shelf of Australia are a potential genetic resource which could be used to provide broodstock for aquaculture. Production systems have been developed in Western Australia for *Trochus* at Broome and several companies operate commercial hatcheries for *Pinctada.* A facility for *Tridacna* is currently being developed at the Cocos (Keeling) Islands).

A number of recent studies have demonstrated that populations of a given species in different areas may be genetically different (Benzie and Williams, 1995; Borsa and Benzie, 1996; Johnson and Black, 1998). Any translocation of broodstock requires careful consideration of the risks.

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