CORAL REEFS

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Introducing coral reefs

Coral reefs are geological structures, yet they are made by living organisms. As such, they are the biggest and most conspicuous of all non-anthropogenic structures made by living organisms and have been a major physiographic feature of the earth's surface for the past 150 million years.

The key to this phenomenon is symbiotic relationship between plant and animal which allows the practically unlimited resources of sunlight and inorganic carbon to be used for the building of structures so large that they are the creators and controllers of their own macro-environment. Both energy, in the form of organic nutrients, and building materials, in the form of calcium carbonate or limestone, are products of the same process which is the nutrient base of all major terrestrial ecosystems: photosynthesis. In this sense, corals reefs are the marine equivalents of terrestrial forests.

This often-made analogy between reefs and forests readily extends to the diversity of organisms they house, for reefs and forests each provide the food, and the environment, for the earth's greatest number and variety of species.

soft terrigenous substrates, and light availability. Nutrients, or rather lack of them, are critical to reef development: reefs obviously thrive around islands in the "nutrient deserts" of the remote oceans; they also thrive around the more nutrient-rich waters of continental margins, but they appear to do so only where natural ecological checks and balances between corals and other organisms (e.g. herbivores and macro-algae) are preserved.

Because they are constrained to shallow (<100 m depth) oceans, they are profoundly influenced by global climatic changes which affect not only ocean temperature and circulation patterns, but much more importantly, ocean depth. Sea-level change has caused reefs to be repeatedly emerged and submerged throughout most of their geological history and thus, for example, only 20,000 years ago, all reefs were completely emerged as the sea level dropped to approximately 120 m below present levels. The reefs of today are living veneers on older formations which are themselves based on successively older foundations back in geological time.

Approximately one-third of the world's coral reefs, covering an area of about 200,000 km^2, occur in the central Indo-Pacific. This region is the world's centre of reef coral diversity, and a similar pattern applies to most other major groups of reefal organisms. The reasons involve a complex mixture of geological history, oceanography and biology,

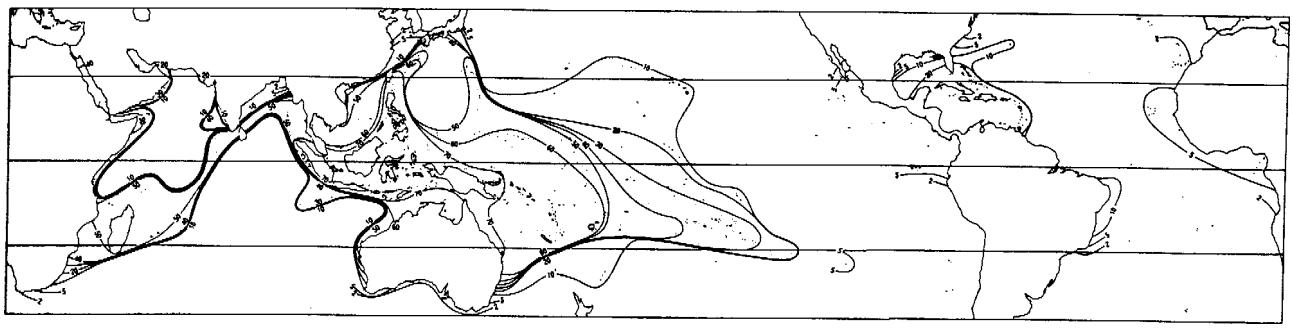

Figure 1. World wide distribution of coral reefs with contours of genetic diversity.

The world-wide distribution of coral reefs (and reef-building corals) is controlled primarily by bathymetry and temperature, for reefs can only develop in shallow, sun-lit waters where the temperature seldom falls below 18°C (Figure 1). Secondary constraints are related to Cenozoic geological history (e.g. the complete absence of reef building corals in the Mediterranean Ocean), surface circulation patterns (e.g. their paucity in the far eastern Pacific) and regional environments of which salinity (the absence of reefs in areas influenced by major rivers), substrate type (the paucity of reefs in extensive areas of soft terrigenous substrates) and nutrients are the most important. Clearly, surface circulation patterns and temperature are interlinked, as is bathymetry and the existence of extensive rive deltas,

but the principal reason concerns past and present sea surface circulation patterns for they provide the means of long-distance dispersal for all groups of organisms capable of maintaining a planktonic existence. Virtually all major groups of reef builders have that capability, usually in a larval phase of their life-cycle.

Australia's geographic position within the world's centre of marine diversity is critical to conservation. Coral reefs mostly occur around the developing, over-populated countries of the world's tropics. Within major regions of the central Indo-Pacific Centre of Diversity, only western Micronesia, northern Papua New Guinea, Australia and (perhaps) Japan, have a low population pressure and/or the

capacity to permanently regulate human impacts. These impacts are , as yet, poorly known: my own subjective estimate is that 70% of all central Indo-Pacific reefs have been significantly degraded. This is due primarily to over fishing (which has effectively removed the top of the food pyramid of most of south-east Asian and Japanese reefs), eutrophication and increased sedimentation (from urban outfall, deforestation, agricultural run-off and coastal zone development) and direct intrusive activities (principally through subsistence food gathering, particular mining practices, shell collecting and unregulated tourism).

The often-made distinction between acute and chronic impacts on reefs is intuitively useful. Acute impacts, whether anthropogenic or not, are generally limited in area (*Acanthaster* and, to a lesser extent, *Drupella* outbreaks being the dramatic exception) and are often associated with widespread local death. Chronic impacts are generally sub-lethal, long-term and environmental. It is the latter which are of principal importance to coral reefs and which present the main challenge for scientific study. Environmental deterioration of the type that has so widely affected European forests opens a Pandora's box of present and future possibilities for coral reefs, among which is their capacity to cope with the synergistic effects of multiple chronic influences (such as eutrophication together with over fishing) and their capacity to recover from acute impacts while under the influence of chronic ones.

The result of anthropogenic influences are perhaps best seen by international comparisons. Truly pristine reefs, such as those of the remote outer northern Great Barrier Reef (GBR), some parts of the Coral Sea, and the reefs of the North-west Shelf have sharks and other big predators, turtles, whale-sharks and marine mammals in numbers that are seldom seen in the central and southern GBR (some specifics excepted), and which are rare anywhere in south-east Asia. Similar comparisons are valid for most collectable objects of value or interest, notably the big and/or valuable molluscs. Putting Australian reefs in a broader context is a subjective undertaking, but it appears clear, that in the next few generations, they will play a critical role in the conservation of a significant proportion of the species of the world's centre of reef fauna diversity.

Australian coral reefs

HIGH-LATITUDE REEFS OF EASTERN AUSTRALIA

The Solitary Islands, adjacent to the central New South Wales coastline, are a group of rugged islands which do not have coral reefs as such, but do have a combination of reefal and non-reefal biota that is not found elsewhere in the world. This includes 52 species of reef corals and 280 species of fish of which 80% are tropical. North Solitary Island has very large populations of giant anemones and attendant clown fishes. The fauna of the Solitary Islands, has

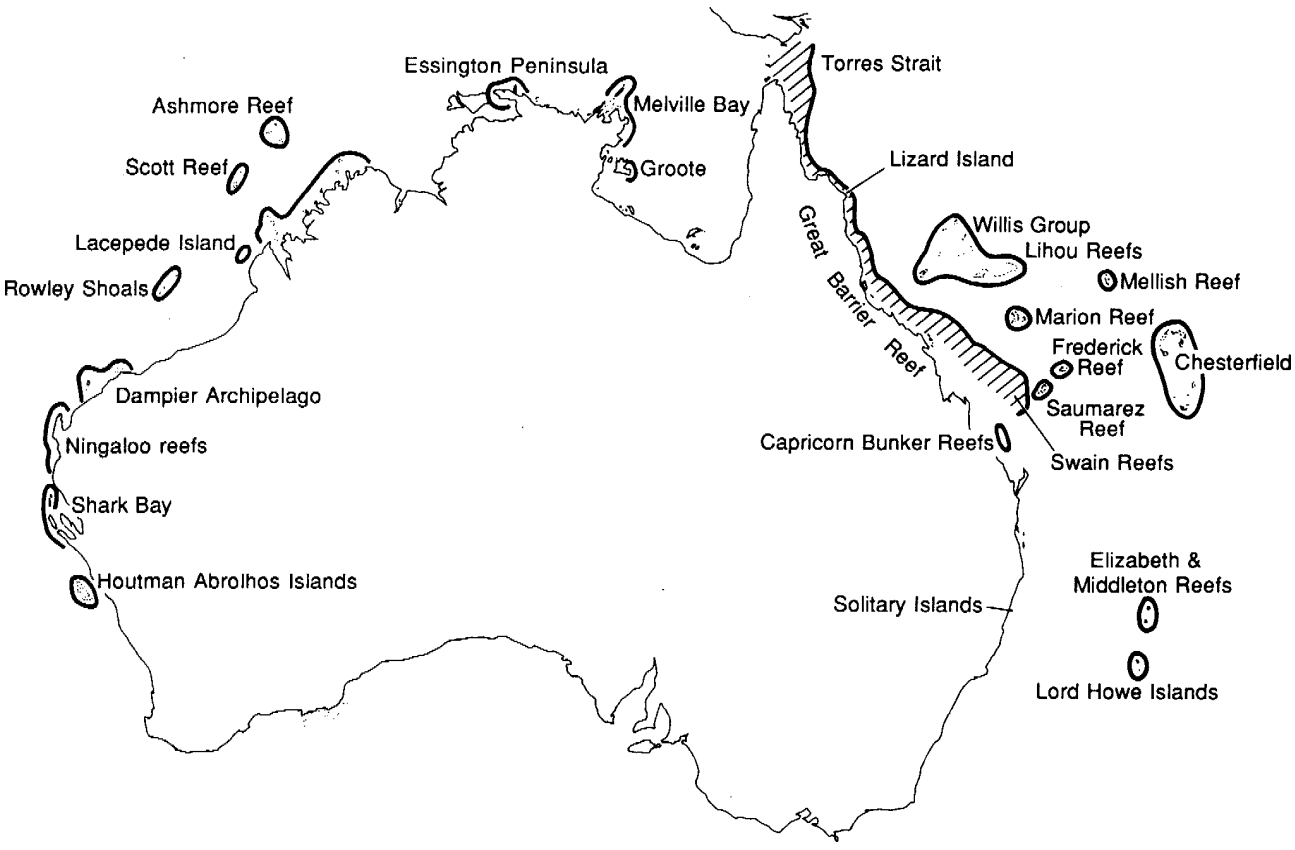

Figure 2. Distribution of Australian coral reefs.

long been largely unprotected but the area has recently been made a marine reserve.

Lord Howe Island, a spectacularly mountainous national park, is situated on a submerged volcanic seamount of the Lord Howe Island Rise. The reef which extends for approximately 6 km along the island's western side, is the world's southern-most coral reef. The outer slope, broken by three passages, rises from a sandy sea floor at 15-20 m depth. The reef is dominated by algae with tropical affinities. There are 65 species of coral, some in temporary populations, and 427 species of fish. The latter also have primarily tropical affinities.

Elizabeth and Middleton Reefs are large platform reefs, also on seamounts of the Lord Howe Island Rise, only 95 km north of Lord Howe Island. In all essential characters, these reefs closely resemble those of the tropics, yet they exist far to the south in very marginal conditions for reef development. They are much less accessible than Lord Howe Island and have not been as well studied. Their intrinsic interest is nevertheless enormous, because of their environment and isolation. One hundred and twenty-two species of reef coral, which includes most species found at Lord Howe Island have been recorded. Elizabeth Reef was one of the first east Australian reefs to have major Acanthaster outbreak in the 1980's, and since then both reefs have been extensively damaged, with the result that abundant coral is now restricted to the reef lagoons.

There are no other limestone reefs south of the GBR, although reef fauna and flora may occur in great abundance at some coastal localities, notably the little-studied Flinders Reef off Brisbane. Flinders reef is actually a sandstone outcrop, but has a diversity of corals which rivals that of Elizabeth and Middleton reefs. The same is likely to be true of other benthic groups, although most await study.

THE GREAT BARRIER REEF

The GBR is the largest single reef system in the world. It is not the most diverse in terms of species (Indonesian and Philippine reefs have greater number of corals), but is extremely diverse in terms of reef types, habitats and environmental regimes. The reasons are that the GBR is large enough to extend from the low latitude tropics to temperate zones, to have regions with very different climates (wind patterns and rainfall), tidal regimes, water qualities, bathymetry, island types, substrata, and even geological histories. To some extent the GBR fauna have regional identities, but in general, there is more variation across the GBR, than there is down its length. This is because the western (inshore) edge is dominated by shallow seas with terrigenous substrates and is exposed to periodic river run-off and consequent low salinity and high turbidity. Also, high (continental) islands occur only in inshore regions, and it is these islands which provide much of the GBR's habitat diversity. The GBR is conveniently divided in to four sections.

The Capricorn and Bunker Reefs are the southernmost reefs of the GBR and are among the best known. The region as a whole is characterised by well-defined platform reefs with entire, steeply sloping sides. Inter-reefal water is relatively deep. Many have vegetated cays which are much sort after by visitors. Faunistically, the reefs are very uniform, the same zones or community types being repeated from one reef to the next. The overall diversity of corals, and probably most other faunal and floral groups, is low compared with other major regions of the GBR because of this uniformity.

The Swain Reefs and Pompey Complex extend further from the coast than any other part of the GBR and have, until recent times, been known only form a brief description in Maxwell's *Atlas of the Great Barrier Reef*. Seen from the air, the Pompey Complex forms a spectacular panorama of interlocking reefs, channels, sandbars and lagoons, all set in the highest tidal range of the GBR and forming a major barrier to tidal water movement. So-called "deltaic" reefs of the outer "hard line" of the Pompeys, resemble river deltas in reverse, the deltas being solid limestone and the tributaries being U-shaped channels carrying extremely strong, reversing, tidal currents. The reefs of the Swain complex form a southward pointing wedge, both sides having exposed outer faces and protected inner margins. The two sides are ecologically dissimilar; the eastern side has several sparsely vegetated cays. This increased habitat diversity is reflected in a higher diversity of corals in this region compared with the Capricorn/Bunker reefs.

The central GBR is a vast area, primarily characterised by the absence of both cays and well-defined outer barrier reefs. Perhaps the best-studied aspect of it is the change in fauna that takes place across the shelf from inshore to offshore, in response to major environmental gradients. The relatively shallow, turbid, terrigenous coastal waters which are protected from strong wave action and subject to seasonal river flooding (and attendant pulses of silt and organic nutrients), support a reefal and inter-reefal fauna and flora of a very different character to that found offshore. The complex of high islands of the Whitsunday and Lindeman Groups have a very high diversity of benthic fauna, perhaps the highest diversity of the GBR, and certainly one of the most varied.

The continental shelf is narrowest in the Northern Section of the Great Barrier Reef and it is here that the Queensland Trough forms, and deepens to the north. "Ribbon reefs" occur where the trough and Great Barrier Reef shelf meet. They follow the shelf-edge break all the way to to Torres Strait (720 km), forming the most conspicuous physiographic feature of the whole GBR. On the eastern side where they are very exposed to ocean swells, they plunge steeply into the abyssal depths of the Queensland Trench. Although the water is very clear, the lower slopes are too deep for scuba divers to explore and almost nothing is known about them.

Inside the ribbon reefs is a band of open water mostly devoid of reefs where the substrate, particularly in the vicinity of passes between the reefs, consists of enormous bioherms of *Halimeda*. The mid-shelf is occupied by extensive areas of reefs with roughly parallel east-west margins, cut by rivers at low sea levels. The inner shelf contains a wealth of reef types, high islands and coral cays, many of which are heavily vegetated.

A research station on Lizard Island, a high island on the mid-shelf, provides the only land-based access to the Northern and Far Northern GBR. Inaccessibility of this enormous region has truncated even the most basic faunistic and descriptive studies.

The continental shelf widens in the Far North, but the extensive shelf-edge reefs remain. Raine Island is a special place by any standards, having the largest green turtle rookery in the world and some of the largest sea bird rookeries as well. The outer barrier in the far northern abounds with life in dramatic abundance no longer seen in the south. Numerous large near shore reefs are found only in this region.

In Torres Strait, the outer barrier reefs become broken up into a series of "deltaic" formations (similar to reefs of the Pompey Complex, whence the name arose), then the almost impenetrable line of "dissected" reefs. Inside the barrier line is an aggregation of reef complexes, high islands and cays of great variety. The sea becomes progressively shallower and more turbid towards the west, finally forming the Warrior Reefs which are essentially vast mud flats fringed in the east by coral. In terms of interest and variety, both above and below water, Torres Strait and the far northern outer barrier has, in my view, no equal anywhere on the GBR.

REEFS OF THE CORAL SEA

The Western Coral Sea is essentially divisible latitudinally into three parts. To the north, and not far removed from the GBR, are Ashmore Reef, Portlock Reefs and Eastern Fields, each very different from the others, the first being atoll-like. South of these lies only very deep empty ocean. In the Central Coral Sea are the widely dispersed reefs of the Queensland Plateau, some with cays. Further to the south are even more isolated reefs including Marion, Kenn, Frederick, Cato and Wreck Reef. Of all of these reefs, Flinders Reefs nearest to Townsville is the best studied, but even these have only been the subject of expeditionary cruises.

REEFS OF NORTHERN AUSTRALIA

There are a scattering of little-known fringing reefs along most of the complex coastline of the Northern Territory. The shallow, turbid waters of the eastern Arafura Sea are not conducive to reef growth and what reefs there are are mostly shallow. Reef development increases to the west and reaches modest diversity in the vicinity of the Essington Peninsula. Strong tidal currents dominate the environment in this region and increase towards the west. The sponge-dominated soft bottom communities of the western Northern Territory have, in general, attracted more interest than sparsely developed reefs.

COCOS (KEELING) ATOLL AND CHRISTMAS ISLAND

Cocos (Keeling) Atoll in the eastern Indian Ocean, is Australia's only true atoll. Most scientific interest is in its geomorphology, especially as influenced by sea-level changes, and its isolation which is of particular interest in faunistic studies. Due to its long occupation and recent expeditions, the atoll's fauna is relatively well known. Christmas Island to the east, is a high mountainous island with a plunging shoreline. Its reefal fauna is similar to that of Cocos (Keeling) Atoll.

REEFS OF THE NORTH-WEST SHELF

Ashmore Reef, situated 350 km off the Kimberley Coast on the outer edge of the Sahul Shelf, is basically a large sedimentary accumulation with reef patches, but has the highest diversity of corals, sea snakes, and probably most other major reefal taxa of Western Australia. Scott Reef, Seringapatam Reef and Rowley Shoals, are all "shelf-edge atolls", a reef type not found in the east. They are visually spectacular, due to clear oceanic water with a high tidal range, and each has its own distinctive characteristics. Again, knowledge of them is mostly limited to faunistic studies.

REEFS OF COASTAL WESTERN AUSTRALIA

Compared with the reefs of the east coast, these have been much neglected scientifically and remain little-known. Western Australian reefs are interestingly distributed down the coast in a series of "stepping-stones", each connected to the other by the southward flowing Leeuwin Current. The result is a chain of geographically and environmentally discrete localities forming a natural setting for long-distance dispersion of reefal fauna from Indonesia.

The reefs of the Kimberley coast are still only superficially explored; they exist in turbid waters constantly mixed by large tidal fluctuations. Of all the coastal reefs of NW Australia, those of the Dampier Archipelago off the Pilbara coast are the best known and probably the most diverse. With an inshore muddy environment and offshore clear waters, all mixed by strong tidal currents, the archipelago has a range of marine environments probably unmatched by any other area of similar size anywhere around Australia.

The 230 km long Ningaloo Reefs, by far Australia's biggest fringing reef, are situated at the barren far western

extremity of the country where the continental slope comes closest to the coast. They are readily accessible to visitors from Perth and until recently have been heavily fished.

The Houtman Abrolhos Islands, situated some 400 km north from Perth, are the most southerly reefs of the Indian Ocean and are one of the most interesting coral reefs of Australia. Although they form the southern distribution limit of most Western Australian coral species, the corals show few signs of environmental stress and in some areas they form the most luxuriant communities to be found on any Australian reef. Curiously, *Acanthaster* has never dispersed to these islands although it has reached the Solitary Islands and Lord Howe Island in the east. In other areas, corals grow with the kelp and *Sargassum* in an extraordinary mixture of the tropical and temperate. The islands themselves are covered with shacks used seasonally by rock lobster fishermen and have little natural scenic value.

The value of the Great Barrier Reef

The GBR is arguably the most valued part of Australia's natural inheritance. Its importance to life on this planet, and its intrinsic value to future Australians is beyond measure. Unlike most of the other great natural wonders of this earth, the GBR has nothing of the robustness we naturally associate with vast and apparently pristine regions. It is only a veneer of life on limestone foundations, and that veneer is fragile and as sensitive to environmental degradation as any other ecosystem. It is the challenge of the future to preserve that veneer for all time, and do so in the face of human usage that appears likely to undergo an exponential increase.

Some would place the value of the GBR to individual Australians second only to its value to world heritage. Most Australians, and indeed most educated people from any country who take an active interest in global issues, would place a high value on the conservation of the GBR. This value, I believe, is part of our national and international culture and is thus difficult to describe and impossible to define.

It is clear that Australian coral reefs in general are currently only at the dawn of international tourism. The GBR, as no other reef region in the world, offers true wilderness areas, still largely unexplored, of vast proportions. So far, the remoteness of these regions have preserved them almost completely from the tourist industry. How long this will last is guess-work, for future projections of tourist numbers and activities are inevitably prone to error because of the difficulty of predicting technological advances in transport and accommodation (such as high-speed aluminium catamarans and floating hotels) not to mention international economics.

At this time, most of the reef tourist industry is catering for a combination of speed and ease of access. In these respects there are many other places in the Indo-Pacific which effectively compete with the GBR. In perhaps a decade or less, this appears certain to change as better informed visitors demand more personal experience, more adventure and better access to remoteness and the unknown. In a decade or so beyond that, the place Australia will have in the global conservation of coral reefs will create management issues that can only be imagined at present.

In October, 1981, the Great Barrier Reef was inscribed of the World Heritage List having satisfied all criteria set out in Article 2 of the World Heritage Convention: an example of a major stage in the earth's evolutionary history; an outstanding example of geological processes, biological evolution and human-environment interactions, a place with unique, rare and superlative natural phenomena, a place which provides habitats for rare and endangered species of plants and animals.

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CREATING A CAPTIVE CORAL REEF ECOSYSTEM

Martin S Jones

Introduction

The Great Barrier Reef stretches over 2000 km along the north east coast of Australia covering an area of 350,000 km^2 (Figure 1). The Reef contains more than 2,900 individual reefs, 900 islands and has a great diversity of animals and plants. The Reef is managed by the Australian Government through the Great Barrier Reef Marine Park Authority (GBRMPA). To support the management and educational roles, the Authority operates a living coral reef aquarium and interpretive facility.

The Aquarium, which has been open since June 1987, is part of a complex on the bank of Ross Creek in Townsville, which contains shops, a branch of the Queensland Museum, the Magnetic Island Ferry Terminals and offices for the GBRMPA. The centre was built with Commonwealth Bicentennial funding and money from the Queensland Government, private enterprise and the Townsville community.

In addition to having plenty of sunshine (necessary to grow a coral reef) Townsville has the advantage of being a centre for tropical marine research. The Australian Insti-