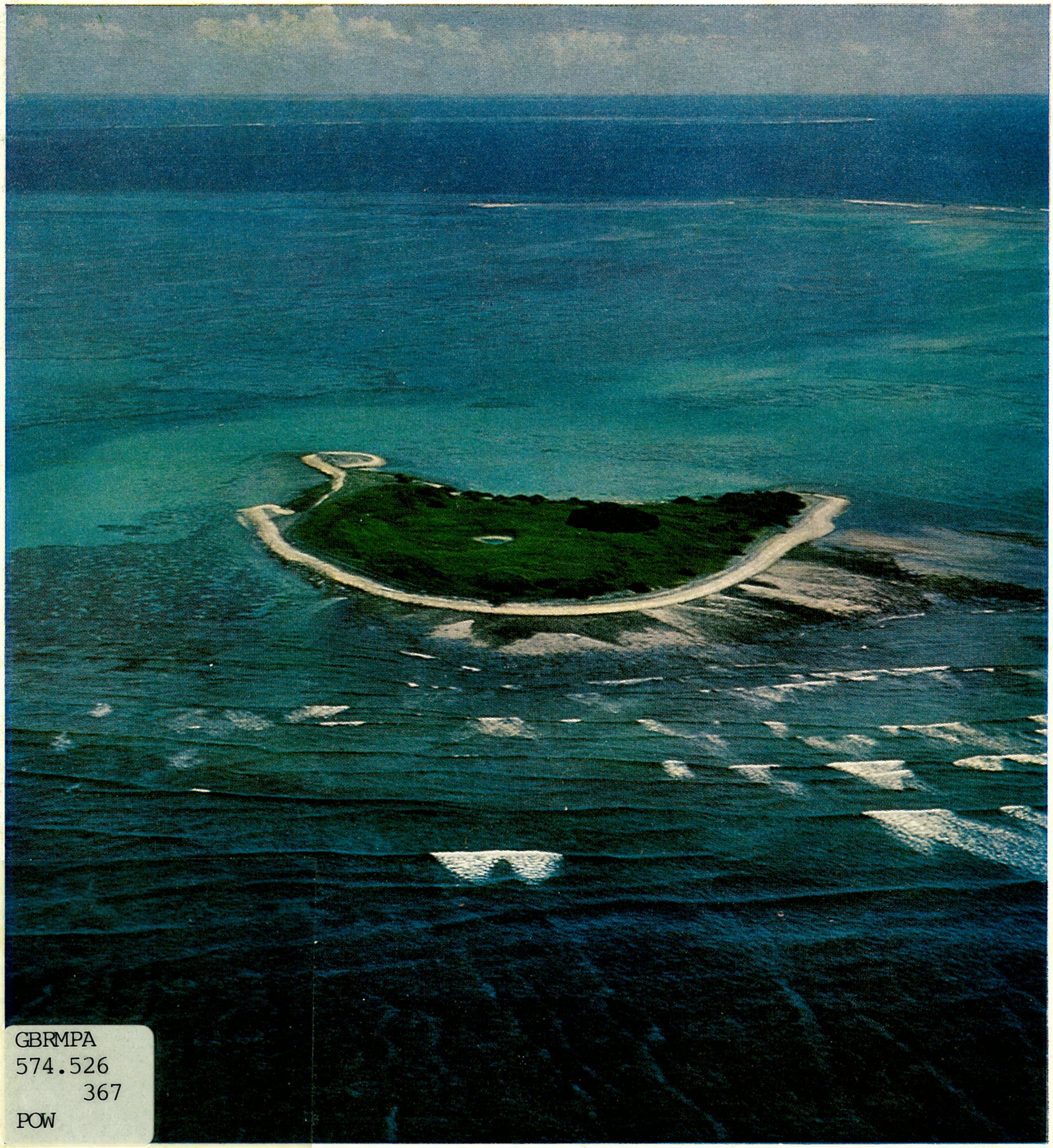
The Great Barrier Reef



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The Great Barrier Reef

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Editor: P. C. Pownall

Natural wonder of the world

The Great Barrier Reef is a natural wonder of the world, yet many Australians are just becoming aware of its beauty, potential and exotic marine life.

This publication brings together information about the origin of the Reef, its resources and the need to protect it.

Front cover — One Tree Island and reef, Capricorn Group, southern Great Barrier Reef. This small island of some 15 hectares is the breeding ground of thousands of sea birds and lies on the windward rim of a pseudo-atoll reef formation. The reef crest has no break, and protects a lagoon that is up to 6 metres in depth and has an intricate tracery of coral with a rich fish fauna. This island is leased to the Australian Museum, Sydney, for its coral reef ecology project.

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The present Great Barrier Reef structure is of recent origin — it started to form less than 15 000 years ago. However further east in the Pacific reef growth has been occurring for more than 70 million years.

By W. G. H. Maxwell
Technical Manager
Australian Petroleum Exploration Association

The Great Barrier Reef I: Origin

REEFS of organic origin appeared on the earth more than 600 million years ago and are preserved today as massive limestone bodies in the ancient sedimentary rock formations of most continents.

In Australia the spectacular limestone structures of Paradise Creek in the Mt Isa district probably represent the remnants of a major reef complex formed largely from marine algae in the early phases of earth history.

Coral first became a dominant component in reefs approximately 500 million years ago and has been strongly represented in most reef systems since that time.

In eastern Australia major coral-algal reef provinces existed in Devonian and Carboniferous times (400 million to 270 million years ago). Their remnants are preserved today in the belt from Monto to Chillagoe in Queensland, parallel with the present Great Barrier Reef and 95 to 160 km to the west of it.

After this early phase of reef-building the eastern Australian region was devoid of reefs for almost 200 million years and then (approximately 70 million years ago) reefs began to develop in the New Guinea seas.

However the Queensland shelf did not support reefs until more recently, the first extensive system forming less than 15 000 years ago, after the main Ice Age had passed. This comparatively late beginning was related to the lower sea-level of the Ice Age, which resulted in the greater part of the Queensland shelf being exposed as land for most of that period.

Further east in the Pacific reef systems that had been established during the preceding 70 million years survived the rigours of the Ice Age and continued to grow. It was probably these reefs that provided the first organisms which invaded the Queensland shelf as the sea began its advance 15 000 years ago.

Structure of the Queensland shelf

Eastern Queensland and its adjacent marine region forms part of a complex crustal belt extending from Victoria to New Guinea known as the Tasman Geosynclinal Belt. Major geosynclines have been recognised on every continent (e.g. Alpine, Appalachian, Andean, Ural) and all have become the sites of high mountain ranges. The Tasman Geosyncline is older than the examples cited above. Its mountainous core has been reduced during its long history, so that today it is neither as large nor as conspicuous as the mountain systems of the younger geosynclinal belts. Nevertheless this segment of the earth's crust experienced similar disruption, upheaval and deformation before becoming a stable part of the Australian continent.

The Tasman Geosynclinal began its history more than 500 million years ago, probably at the time when coral reefs were first appearing in other parts of the earth's seas. The crust of eastern Australia fractured into long north-south segments, some of which subsided to form basins that were invaded by the sea. The other segments remained as high stable blocks that shed their weathered surface material into the basins.

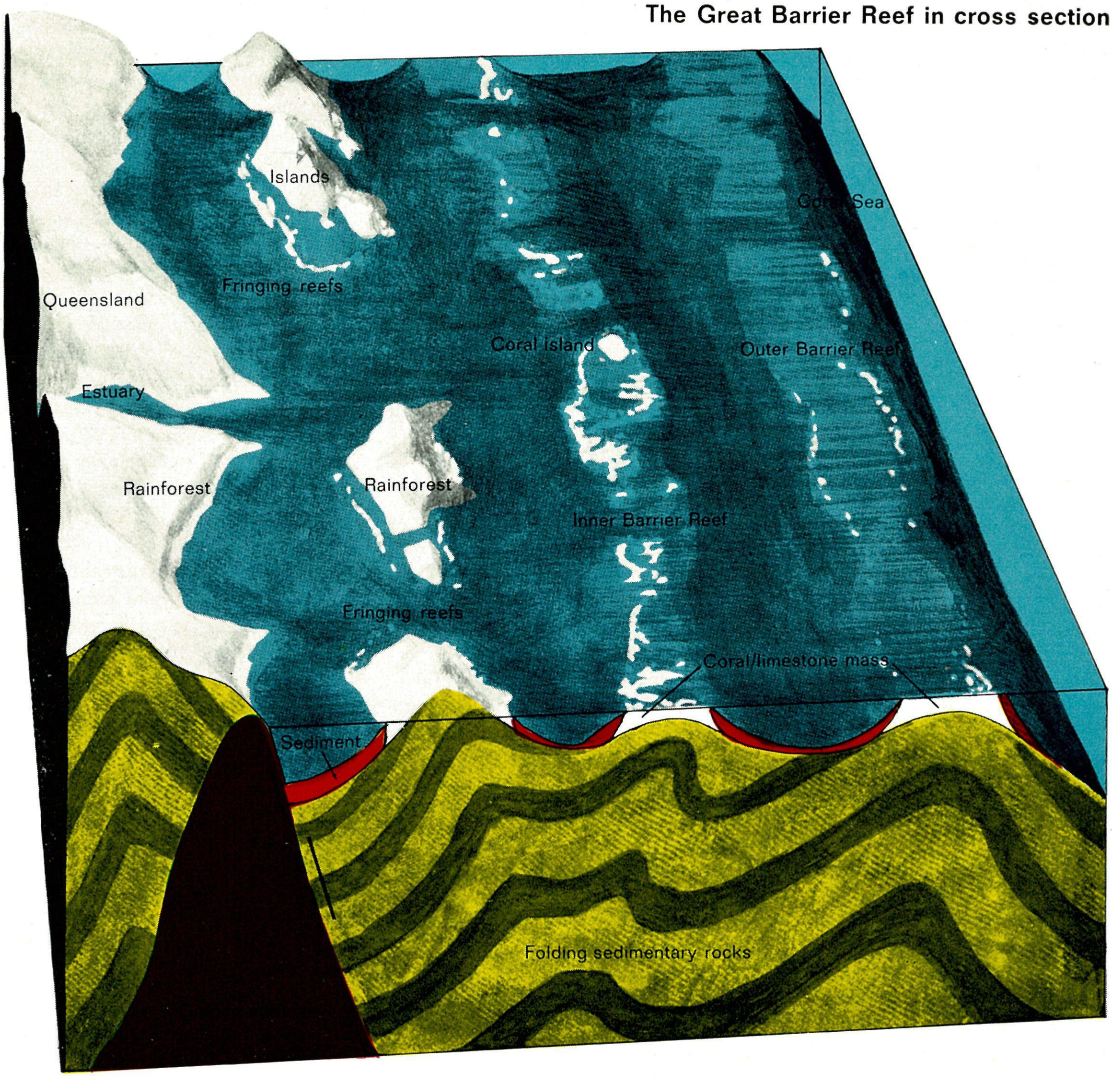
Volcanic eruptions along the fracture zones resulted in the out-pouring of lava and ash which were inter-layered with the sediment being deposited in the basins. Subsequent crustal movement deformed the basins and their contained sediment, granitic masses were intruded into the axial zones of the crustal segments, and general uplift of the geosynclinal belt occurred to form a major mountain system along eastern Australia.

The main crustal upheaval ceased approximately 200 million years ago and reduction of the new landscape began. However in subsequent times less violent disruption of this eastern region occurred, and long segments again subsided and became the sites of substantial deposition of sediment.

Today the main crustal elements of the belt can still be recognised. They consist of basins now filled with sedimentary rock, separated by long segments of older, strongly altered rock called 'highs'. The basins contain the main coal formations and potential oil reservoirs while the highs are the mineralised areas where metallic ores are found.

The main basins, progressing from west to east, are Laura-Drummond, Bowen-Surat-Sydney, Yarrol, Maryborough-Moreton-Clarence and Capricorn-Herbert. In the far north the Papuan Basin lies to the north-east of Cape York. The Papuan, Capricorn-Herbert and part of

The Great Barrier Reef in cross section



the Laura and Maryborough Basins are situated on the Queensland shelf. They are separated by 'highs', the most important being the Swains and Bunkers Highs in the south and the North Coastal High in the north.

These crustal elements of the shelf were the most recently formed and were active long after the main geosynclinal belt on land had achieved stability. During the later stages of their history both basins and highs remained above sea-level for long periods so that a large proportion of the sediment deposited in the basins is non-marine in character.

After the Ice Age, as temperatures increased and sea-level rose, basins and highs were invaded by the warming sea and the faunas and floras of the south-west Pacific. Reef colonisation appears to have favoured the higher parts of the shelf and these corresponded in most cases with the crustal 'highs' that had formed during the evolution of the shelf.

Today the main reef development is found on the Swains High, Bunker High and North Coastal High. Reefs are sparse on the Laura, Herbert and Capricorn Basins and non-existent on the Maryborough Basin. In the Papuan Basin reefs are widespread but are most abundant near its margins with the highs.

Unlike the open ocean, where crustal subsidence has been a major factor in the localisation and extent of reef growth, the continental shelf supports its best reef development on those segments which have experienced greatest stability and its poorest reefs in areas where most subsidence has occurred.

Submergence of the Queensland shelf and reef growth

Evidence of the comparatively recent rise of sea-level has been obtained from the shelves of most continents, and this evidence is generally in the form of sub-marine terraces which were cut by shore-line processes of the past. The deepest of these features is found at approximately 128 metres. Shell material of inter-tidal origin, recently formed rock and encrusting coral from this terrace have been analysed by radio carbon methods and an age of 17 900 years determined, indicating that the eastern shore-line at this time was just below the present shelf-edge. It also indicates that the part of the reefs rising above the shelf floor today is younger than 17 900 years and in all probability younger than 13 000 years.

The post-glacial rise of sea-level appears to have been a spasmodic process which involved prolonged phases of still-stand or static sea-level during which were formed strand-line features such as beaches, off-shore bars and coastal dunes. As the sea renewed its advance these features were preserved on the shelf-floor. In the Great Barrier Reef province marked terraces and ridges are found at depths of 58, 36, 29 and 18 metres. All appear to be old strand-line features. There is also some evidence to suggest that sea-level oscillated from 29 to 26 metres as well as standing at these levels for some time.

The main significance of the ancient strand-line features is that they generally rise above the level of the surrounding shelf floor and that they are favoured zones for reef growth.

In the Swains complex the main inter-reef floor is at 58 metres, while the Bunker Group of reefs and the reef shoals north of the Capricorn Group lie just inside the 58 metre contour. In the Townsville-Mackay region reefs on the outer shelf also rise from this 58 metre terrace. The 36 and 29 metre levels are more conspicuous in the areas north of Cairns and Cooktown respectively. In the southern region (Gladstone-Rockhampton) the 29 metre line also marks a sharp change in the character of shelf sediment from predominantly carbonate (reef-derived) on the east to predominantly quartzose (land-derived) on the west. It is probable that the 58 metre sea-level occurred at 13 000 years, the 29 metre sea-level at 11 000 years and the 18 metre sea-level at 7 200 years.

Information on the history of submergence of the Queensland shelf also comes from the six bores that have been drilled by the Great Barrier Reef Committee and oil exploration companies. These wells have revealed a maximum thickness of reef of 152 metres resting on non-reefal rock. They have also shown that the growth of reefs from the time of their first appearance on the shelf was not a continuous process but in fact one interrupted by temporary sea-level retreat and extensive reef-erosion. Land-derived sand occurs at two levels in the Heron, Wreck and Michaelmas Reef bores, thus reflecting two phases of temporary lowering of sea-level during the reef's history. The main reef development in the Heron Reef bore is less than 88 metres. It is also evident that the reefs near the shelf-edge, and particularly those growing on the 58 metre terrace, are probably older than the reefs nearer the coast-line, where the shelf floor has been submerged for a shorter period of time.

Effect of the reef on the continental shelf.

The shelf area which comes under the influence of reefs is approximately 267 000 sq km, and of the 2 500 reefs on the shelf more than 2 000 are concentrated in a band 50 to 60 km wide which extends along the shelf margin.

This band, known as the 'reef zone', occupies 106 190 sq km. North of Cooktown the reef zone extends over a length of 788 km and its outer margin is occupied by linear reefs which account for 71 per cent of its length. These reefs form an effective buttress along the shelf-edge. Between Cooktown and Bowen (644 km) a shelf-edge reef system is almost non-existent, and the province is open to the ocean (45 per cent reefs, 55 per cent passages). South of Bowen a strong shelf-edge system extends for 241 km and is followed by dispersed reefs for the remaining 580 km (36 per cent reefs, 64 per cent passages).

The effect of this varied concentration of reefs along the shelf-edge is clearly reflected in the distribution of sediment on the shelf floor. Where reefs form a strong system strong currents sweep through the narrow passages and scour the shelf floor so that most sediment is removed. Where reefs are more evenly dispersed currents are weaker and sediment is able to accumulate on the floor.

The rate of sedimentation on the shelf is extremely variable, but in most areas it is quite low. The main sources of sediment are the reefs themselves, which shed enormous quantities of debris around their margins, and the land, which supplies large quantities of mud to the numerous coastal streams, particularly in the high rainfall area of the north. This mud is deposited mainly in the near-shore zone in depths of 9 metres and less. Thus except for the near-shore zone and the marginal zones of reefs the greater part of the shelf is receiving little sediment at the present day. Dense reef growth tends to induce vigorous current activity, which leads to the removal of sediment from the shelf floor in the immediate vicinity of reefs.

Corals reefs are the most interesting of all marine living systems and support a greater number of species of animals and plants than any other marine habitat.

By P. C. Pownall
Editor
Australian Fisheries

The Great Barrier Reef II: Natural features

THE GREAT BARRIER REEF is the largest coral reef in the world, and about 10 per cent of fish species in the world's oceans live among the thousands of reefs in the system with a vast array of other animals and plants.

The Reef is of absorbing interest to biologists and geologists who are only just beginning to understand some of its origins and complexities. It also is a tremendous attraction to tourists and there is mounting interest in its mineral wealth.

The Barrier Reef is not a continuous reef but a collection of coral reefs and islands. North of Cairns, where there is a marked 'outer barrier', the reefs are from 183 metres to 1.6 km wide and are up to 24 km or more long. They are separated from each other by narrow, deep passages and form more or less a continuous rampart along the edge of the continental shelf, their outer edges marked by a foaming line of breakers from the Pacific Ocean.

The greater part of each reef is submerged at all times. Living coral grows along the outer edges of the reefs, which rise to a ridge or crest composed of cemented coral debris, shells and sand. This crest may be from 0.6 to 1.6 metres above low water spring tides and slopes gradually into shallow water at the back of each reef.

South of Cairns the submarine slope flattens considerably and the continuous line of the outer barrier is less definite. Here the reefs gradually become more scattered and less linear and regular in form. They tend to appear in more or less isolated groups, particularly in areas around the Bunker and Capricorn Groups and Swain Reefs, where the edge of the barrier is some 32 km inside the 180 metre line.

The area between the mainland and the outer barrier is as a rule less than 61 metres deep. Rising from it are myriads of small reefs, known collectively as inner reefs, many of them crescent or horseshoe-shaped. There are also numerous patch or platform reefs, broad and tabular, oval or irregular in shape, sloping back gently from the reef crest to a sand flat and awash except when the tide is out.

The reef is the work of the coral polyp, which forms an underlying skeleton of lime. Polyps live together in colonies, and it is this family activity that has built up the Reef into such a spectacular showcase of the sea in which can be seen more than 300 varieties of coral ranging in colour from the lightest blue to brilliant yellow, often with tinges of lavender, purple, crimson, pink, green and lemon.

One of the most abundant types is the delicate branching staghorn coral (*Acropora*). Another common one is the brain coral (*Symphyllia*) which sometimes forms colonies up to 3 metres in diameter.

The *Porites*, a massive coral, builds up into formations as large as 6 metres across. The mushroom coral (*Fungia*) is a solid builder but seldom reaches more than 30 cm across, while the red organ pipe coral (*Tubipora*) lends an exotic touch to the marine underworld.

Coral can be killed by many agents — cyclones, flooding from adjacent mainland areas leading to dilution of reef waters, influxes of silt too heavy to be removed by the normal motion of the cilia of the corals, and changes in water temperature. But in recent years a new threat to the Great Barrier Reef has come from a predator — *Acanthaster planci,* the crown-of-thorns starfish.

Reports in 1966 of widespread coral destruction by the crown-of-thorns on the Great Barrier Reef, especially near the tourist resort of Green Island, off Cairns, led the Queensland Government to commission a three-year survey. It was undertaken by Dr R. Endean of the Department of Ecology, University of Queensland (project leader), and Mr R. Pearson, a research biologist with the Queensland Department of Harbours and Marine.

In his report presented in 1969 Dr Endean said that the survey had shown massive destruction of living corals by crown-of-thorns starfish in most of the inner patch reefs and fringing reefs of the section of the Great Barrier Reef from Cooktown to Townsville. Only outer reefs near the 180 metre line had escaped infestation. More than 90 per cent of corals on many of the infested reefs had been killed by the starfish and the destruction of corals on many other reefs in the area was continuing.

Infestation of coral reefs with crown-of-thorns starfish had also been reported outside Australian waters from Guam, Truk, Rota, Johnston Island, the Palaus, New Britain and Fiji.

Dr Endean recommended a number of steps to contain the plague. Among them were the appointment of collectors to gather crown-of-thorns starfish on reefs peripheral to the area of infestation, the importation of living specimens of giant tritons (which prey on crown-of-thorns) from areas outside Australia, and a ban on the taking of giant triton and giant helmet shells from the Great Barrier Reef.

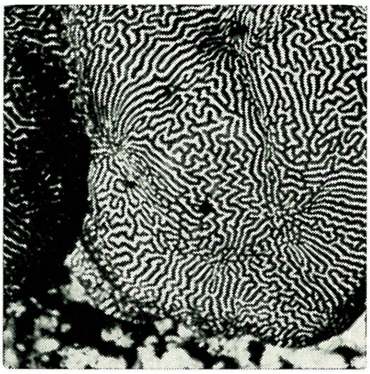
In 1970 the Australian and Queensland Governments established a joint committee to try to halt the starfish plague on the Great Barrier Reef. A Royal Commission to inquire into possible damage which might be caused by drilling for oil on the Great Barrier Reef also was established.

The tourist potential of the Great Barrier Reef is enormous and may perhaps become its most important resource in the future because the area is big enough to support an industry many times greater than that which exists at present. It is estimated that more than 300 000 persons, including day-trippers, visit the Great Barrier Reef each year. More than 60 000 of this number are resident guests and about 10 000 come from overseas. Tourism in the Great Barrier Reef in recent years has been growing at the rate of about 10 per cent annually.

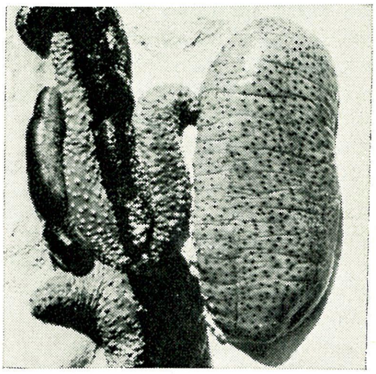
Tourist resorts have been established on many islands off the Queensland coast between Cairns and Gladstone. However only two of them — Heron and Green Islands — are actually on the reef. They are true coral islands or cays of which there are hundreds among the inner reefs of the Great Barrier. Some of these cays have become cemented and stabilised and are covered with vegetation derived from the mainland through the agency of the wind, waves, currents and sea birds. Many coastal plants produce floating seeds which are transported long distances by currents to the cays. They include goatsfoot convolvulus and creeping legumes which grow among the sandhills. The seed of the casuarina tree is equipped with a transparent wing which helps its distribution by the wind. The pisonia tree is abundant on the Great Barrier Reef cays as are the tournefortias, the fruits of which can survive in salt water for a year. Pandanus palms are also common and many types of mangrove grow on the flats.

The main tourist resort islands, situated between the reef and the coast, are rugged, picturesque and clothed in tropical forests.

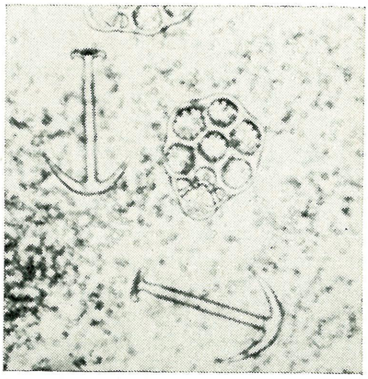
They are continental (mainland) islands and include Lindeman, about 80 km north of Mackay; Hayman, Daydream and South Molle in the Whitsunday group; Long Island adjacent to the Whitsunday Group; Dunk and



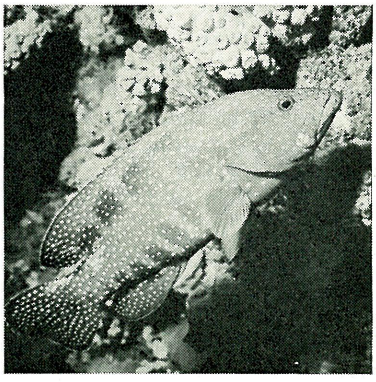
Brain coral



Beche-de-mer, once gathered in considerable numbers in northern Australia for export to Asia.



Glassy anchors and wheels in the skin of a species of beche-de-mer.



Spotted coral cod on the reef near Heron Island.

Bedarra, north of Hinchinbrook; Brampton, in the Cumberland group; and Orpheus, about 80 km north of Townsville.

If tourism on the Great Barrier Reef expands as dramatically in the next few years as predicted some control of human activity seems essential. Both the coral islands with their masses of breeding sea birds of various species and coral reefs with their rich variety and patterns of coral structures as well as a myriad of molluscs, other invertebrates and colourful fishes, are prone to damage if not protected.

At present tourists wander all over the reef, in many places trampling and breaking coral, collecting shells and coral specimens. Their activities have been described as like 'looking at a garden by walking through the flower beds' and would not be permitted in botanical parks on shore.

It has been suggested that it would not be difficult to restrict human movement in certain areas and have simple pathways from which the rich variety of the reefs could be viewed. This type of simple protection has not been attempted but will become imperative as large numbers of tourists visit the coral reef islands.

The Queensland Government some time ago recognised the value of the Great Barrier Reef as a natural phenomenon of great scientific and tourist interest when it declared a number of islands National Parks under the Forestry Act.

These parks are administered by the Conservator of Forests, whose powers extend to high tide mark. At Green and Heron Islands and the Wistari Reef area all marine organisms living on the reefs have been protected. These are popular tourist areas where living coral and marine organisms can be viewed. In effect they are marine national parks where the reef and the adjoining sea bed are protected.

Moves have been made to establish other marine national parks along the Great Barrier Reef on a much larger scale.

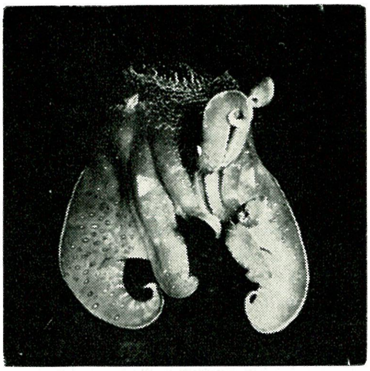
The marine national park concept is strongly backed by the noted Austrian scientist and underwater film-maker, Dr Hans Hass, who visited the Great Barrier Reef in 1970 to make a colour television documentary for European audiences.

Dr Hans Hass first visited the Reef in 1950 and was particularly impressed by reefs north of Cairns, notably Pixie Reef. On his recent visit he spent two days filming this reef, which he considered the most beautiful in the world.

'It is even more attractive today than it was then,' he said.

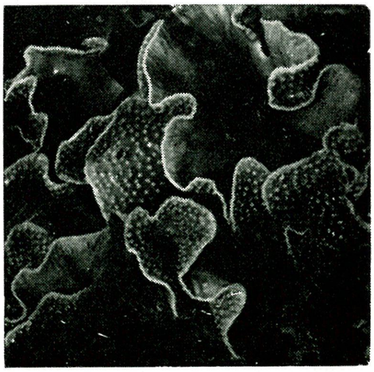
'With the introduction of jumbo jet airliners on air routes to Australia more and more Europeans will wish to visit the Great Barrier Reef,' Dr Hass predicted. 'Some will want to view the reef from the surface, others from underwater, while a number may wish simply to fish.

'These wants could be catered for in marine national parks. The underwater camera enthusiast could be allocated one area, the spearfisherman another and so on,' he said.



Cuttlefish, a close relative to the squid, have an eye system credited with being superior to that of a human being. Their inquisitiveness is often mistaken for aggression by divers on the Reef.

Reef heron, one of the many species of birds that frequent the Great Barrier Reef.



Frilly coral.

An astonishing number and variety of food fish inhabit Great Barrier Reef tropical waters but the annual commercial fish catch is relatively low compared with temperate regions of Australia.

By P. C. Pownall
Editor
Australian Fisheries

The Great Barrier Reef III: Fisheries resources

THE TOTAL value of fish, prawns, crabs, lobsters and oysters taken in the Great Barrier Reef each year is about $1 million.

One reason why tropical reef waters do not generally yield big quantities of food fish is believed to be that there is no rapid replenishment of nutrients.

In the Great Barrier Reef one of the biggest problems facing commercial fishermen catching coral-haunting fish is that nets cannot be set near coral.

Prawning is Queensland's most valuable fishery, annual production being more than 4 540 000 kg, worth nearly $4 million to fishermen. However most of the catch is taken outside the Great Barrier Reef area.

Spanish mackerel is the most important commercial fishery in the Great Barrier Reef area, annual production of this fine food fish being about 454 000 kg. This is not a reef fish in the true sense but most fishing activities are carried out near emergent reefs or above submerged reefs, both close to the mainland or out near the main barrier. Spanish mackerel and less commonly Queensland school mackerel, wahoo, marlin, dogtooth tuna and yellow-fin tuna are taken. Other tuna and tuna-like fish are quite common but are not caught because of lack of satisfactory markets.

Reef fish include cod, coral trout, emperor, parrot fiish and sweetlip. These are found in close association with live coral reefs and also in the deeper areas from 18 to 36 metres, where living corals are associated with extensive stretches of coral clinker. The main commercial areas are the reefs within a 160 to 240 km radius of the northern Queensland ports from Gladstone to Cairns, but exceptionally they are fished as far afield as Princess Charlotte Bay and Torres Strait in the north and the Swain Reefs in the south. Registered charter boats also operate in much the same areas as the commercial boats and fish in the same fashion. There is no foreign participation in the fishery.

Another commercial fishing operation associated with the Great Barrier Reef is the taking of small exotic tropical fish for the aquarium trade. The number of fish caught is not great in relation to the total reef fish population, but as catching tends to be concentrated on rarer species it can cause problems.

Heron Reef was almost denuded of rare and attractive fire-fish until it was closed. The area is now slowly recolonising.

Most of the commercial and amateur fishing for food fish on the Reef is by hand-line. Other methods include trolling, trawling, beach seining, gill netting, potting, diving and spearing. Minimum size limits covering more than 60 food fish have been imposed by the Queensland Government.

Live pearl oysters gathered by divers in the far north of Queensland, the Torres Strait and Papua are used in the pearl farms. Trochus shell was also gathered in big quantities until several years ago. It was used in button manufacture but like

(Continued page 9)

Methods employed and varieties of fish caught are:

Fishing Method	Type of Fish
Trolling	Mackerel Kingfish Trevally Marlin Sailfish Tuna
Hand-lining	Coral trout Emperor Bream Cod Dart Flathead Jewfish Pike Ray Snapper Sweetlip Whiting
Trawling	Prawns Scallops
Onshore beach	Mullet
Seining	Garfish
Gill netting	Giant perch Threadfin
Fixed traps	Leatherskins Mackerel Mullet Threadfins
Baited pots	Mud crab Sand crab (Bodies)
Diving	Painted rock lobster Pea shell
Farming	Oysters
Hand collecting	Coral Shells Aquarium fish
Aboriginal spearing	Turtle Dugong

mother-of-pearl shell was supplanted by plastics. Beche-de-mer were once gathered extensively and dried for markets in Asia, and there is some revival of interest in this fishery at present. However operations are on a small scale.

Shell collecting is an increasing but localised occupation in many areas of the Reef. Shells are gathered mostly by fossicking on the reef platform, by dredging and occasionally by diving. 'Shelling' is prohibited in some areas and further control measures may be necessary in the future. There is a complete ban on the taking of giant triton and helmet shells.

The fishery for live coral for tourist requirements is restricted to holders of special licences. Operations are so regulated that regeneration keeps pace with exploitation.

Indications are that present fishing activities on the Great Barrier Reef are not endangering the survival of stocks, and it is probable that catches can be increased considerably in some areas.

They include oyster farming, diving for the tropical rock lobster and beche-de-mer, prawn and mud crab culture, the extraction of pharmaceuticals from certain reef animals, tuna long-lining, and the farming of milk fish, mullet and barramundi.

The Great Barrier Reef IV: Mineral resources

By J. L. Maclean
Fisheries Division
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The setting up in 1970 of the Royal Commission on Great Barrier Reef Petroleum Drilling highlights the conflict between conservation of the reef and utilisation of mineral resources.

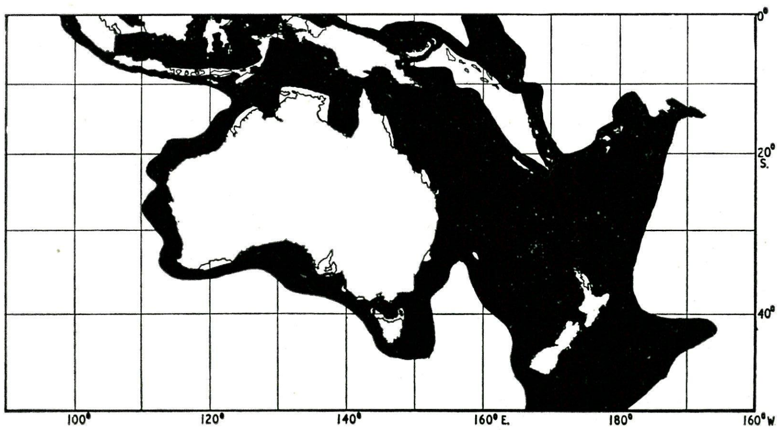
THE Commission's terms of reference were to inquire into and report on the effects of an oil drilling or gas leak resulting from exploratory or production drilling and the probable benefits to the State of Queensland and other parts of the Commonwealth of finding exploitable quantities of oil on the Reef.

Its establishment followed the decision by a joint Australian-Japanese company to exercise its oil exploratory rights to test drill waters inside the Great Barrier Reef. This has been halted pending the outcome of the Royal Commission.

Recent sedimentary basins favourable to petroleum formation occur around Australia. Seven are known to be wholly or partly within the Great Barrier Reef area. They cover approximately 40 per cent of the reef area, but as yet no basin has been explored sufficiently for its potential to be assessed accurately.

'Young' (Mesozoic-Tertiary) sedimentary basins contain almost all the world's accumulations of oil and gas. They develop around the coasts of continents, and usually the best part of them lies offshore. Offshore discoveries have in consequence had a record of higher yields per well and higher success ratio of drillings than onshore activities, even in the same basin. The Great Barrier Reef area is particularly attractive for oil drilling because it is shallow and protected from oceanic upheaval.

The mineral potential of the Reef is not well known. The Reef itself consists of a vast concentration of limestone (calcium carbonate), the skeletal material not only of coral but also of molluscan and foraminiferan shells which appear in bottom sediments



Offshore areas surrounding Australia believed favourable for petroleum. Because of the paucity of geological data their delineation is highly speculative.

Map gives only a rough indication of areas that seem most likely to contain petroleum accumulations. Source: World Subsea Mineral Resources, US Geological Survey.

of reef areas. Limestone is used primarily in cement and fertiliser manufacture.

Monazite, a component of certain sands, occurs in the Reef area to an unknown extent. It is a source of thorium and other rare earth elements. The value of thorium is such that in Brazil beach sands containing more than 1.3 per cent monazite can no longer legally be used as a source of titanium (i.e. in rutile and ilmenite) because of their potential as a thorium source.

The occupation of many islands in the Reef by large populations of birds has led to the formation of phosphate deposits (guano) and some of these have been worked for short periods.

Great quantities of nearly pure silica sands occur in many beaches as well as offshore in the Reef area. Offshore submerged beaches are also potential sources of a tremendous variety of heavy metals including columbium, chromium, platinum, tantalum, tin, gold, iron, silver, zirconium and several rare earths.

Quantities of minerals containing some of these metals were carried to coastal areas by rivers and stratified into workable deposits by wave action. As the water level rose (see Origins chapter) new beaches were formed and the old ones submerged, still bearing their valuable resources and still awaiting exploitation.

Australian beaches produce 95 per cent of the world's rutile, and it is most likely that offshore or 'placer' deposits of this mineral will be found in submerged beaches.

In the United Kingdom even offshore gravel beds are worked to provide material for heavy construction as onshore deposits become exhausted. The offshore gravel beds of South Africa are a rich source of diamonds; they are 20 times as productive as similar gravel beds on land. Mining is by suction dredge in waters averaging 24 metres in depth.

Oil drilling techniques are well known. Exploratory work involves examination of the magnetic properties or density of rocks. This is followed in promising areas by seismic surveys which in the case of offshore exploration involve bouncing shock waves off the deep rock strata from an energy source on board a vessel where the echoes are recorded. In the past dynamite was the principal energy source but is now largely replaced by low energy sources such as Aquapulse (a small explosion in a rubber sleeve) and the use of air guns which suddenly release compressed air. Both are harmless to fish.

The drilling rigs are either floating ship types, semi-submersible, or 'jack-up' rigs which stand on the sea bed. The well is encased to prevent the drill hole from collapsing and there are blowout preventers consisting of a number of devices to close off the flow at the sea floor.

The method of offshore mineral mining varies in different situations but is mostly by dredging. Exploratory surveys are similar to those used for petroleum but drill holes do not penetrate as far into the bedrock as do oil drills. Dead coral limestone is dredged in Moreton Bay, Queensland. A rotating cutter breaks up the material, which is sucked up a pipeline and discharged into waiting barges. Other dredge types include the ladder bucket, grab, and floating mechanical shovel. Looser deposits such as monazite sand can be won by suction dredging.

The danger to the Barrier Reef from oil drilling is of course not directly by any activity associated with drilling itself but from the spillage of oil from the well or from tankers. But the danger is by no means clear.

The nearest approach to a Reef 'disaster' to date was the grounding of the oil tanker *Oceanic Grandeur* in Torres Strait, in which about 1 100 tonnes of crude oil were spilt and more than 18 000 litres of detergent poured over the spillage as well as about 8 000 litres of dispersant (Corexit). There was however no record of any coral reef being touched by the resulting slicks. No damage to marine or other wildlife was observed as a result of the grounding but incidents such as the *Torrey Canyon* disaster off England and the blowouts at Santa Barbara, California, which occurred in more populated areas, serve as a warning.

Wherever oil comes ashore sand colonising plants and intertidal marine organisms appear to be surprisingly tolerant to it. Even when destroyed there is ample opportunity for them to re-colonise; however there has been a number of reports of sea birds and fish dying from oil pollution and subsequent cleaning up.

The effects of mineral exploitation on the Great Barrier Reef are unknown, and there are no precedents on which to base assumptions as to its possible effects. However it is clear that any process involving a large amount of sediment disturbance would kill by suffocation a large part of the fauna of any coral reefs in the vicinity. This is not to say that such destruction will occur. The mining of dead coral takes place within a few miles of an actively growing coral reef in Moreton Bay. This reef is surrounded by mud and muddy waters.

It has been suggested that controlled mining take place to a limited extent in a 'non-key' area of the Reef and the effects be carefully examined to determine a rational policy for future operations.

The question of oil drilling cannot be considered in the same category, since its effects are potentially much more widespread. Oil spills and blowouts are still regular features of overseas offshore wells and it is difficult to envisage 'controlled' or 'limited' drilling. The investigations of the Royal Commission are comprehensive, and its findings should be an authoritative guide to future action on this issue.

Australian Fisheries

Pictorial Atlas of The Great Barrier Reef

This supplement of four pictorial maps covers the entire Great Barrier Reef. It shows centres of commercial fishing, tourist development and general resource use, and illustrates a range of plants and animals associated with the area.

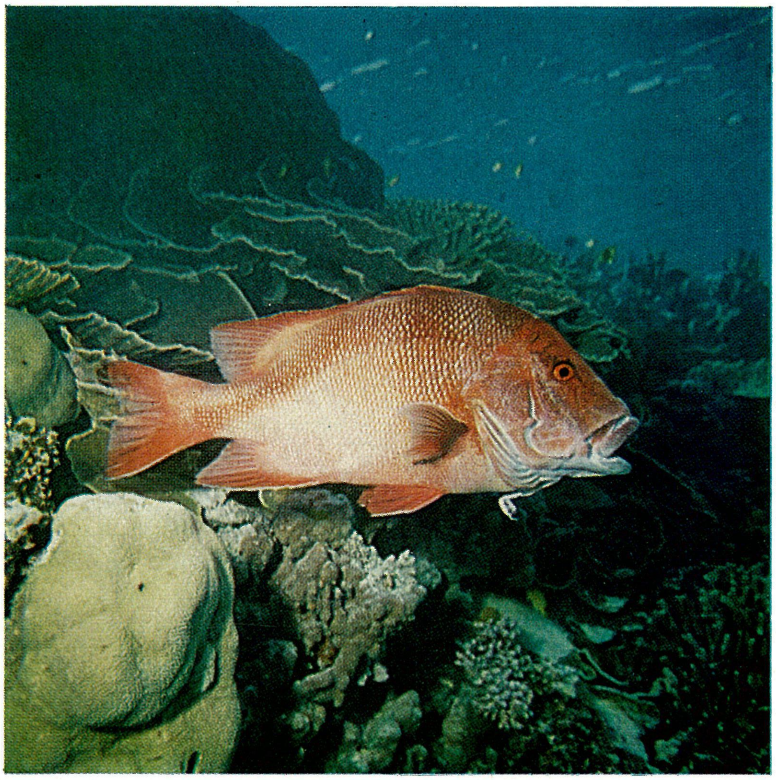
Interpretation and design by Robert Ingpen

Tropic of Capricorn reefs and islands

Stretching along the Queensland coastline, roughly from Lady Elliot Island in the south to Cape York in the north, a distance of about 2 000 km, the Great Barrier Reef is one of the natural wonders of the world. Actually it is a series of individual coral reefs that enclose an area of some 200 000 square km of ocean studded with islands.

Between Fraser Island and Broad Sound (see map opposite) there are some striking examples of true coral islands, formed by the heaping up of coral debris, sand and other marine materials. Among them is Heron Island, highest island in the Capicornia group and centre for a marine research station. Tropical waters in the area support commercial fisheries based on reef fish and crustaceans that inhabit the inner and outer systems and coastal waters.

1

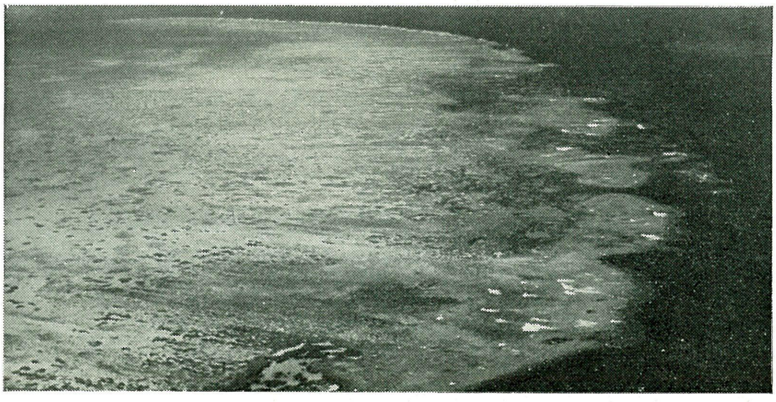


1. Red Emperor (*Lutjanus sebae*) an excellent food fish which is found over a wide area in the Great Barrier Reef and in deeper outside waters. It grows to at least 1.2 metres and can weigh up to 22 kg.

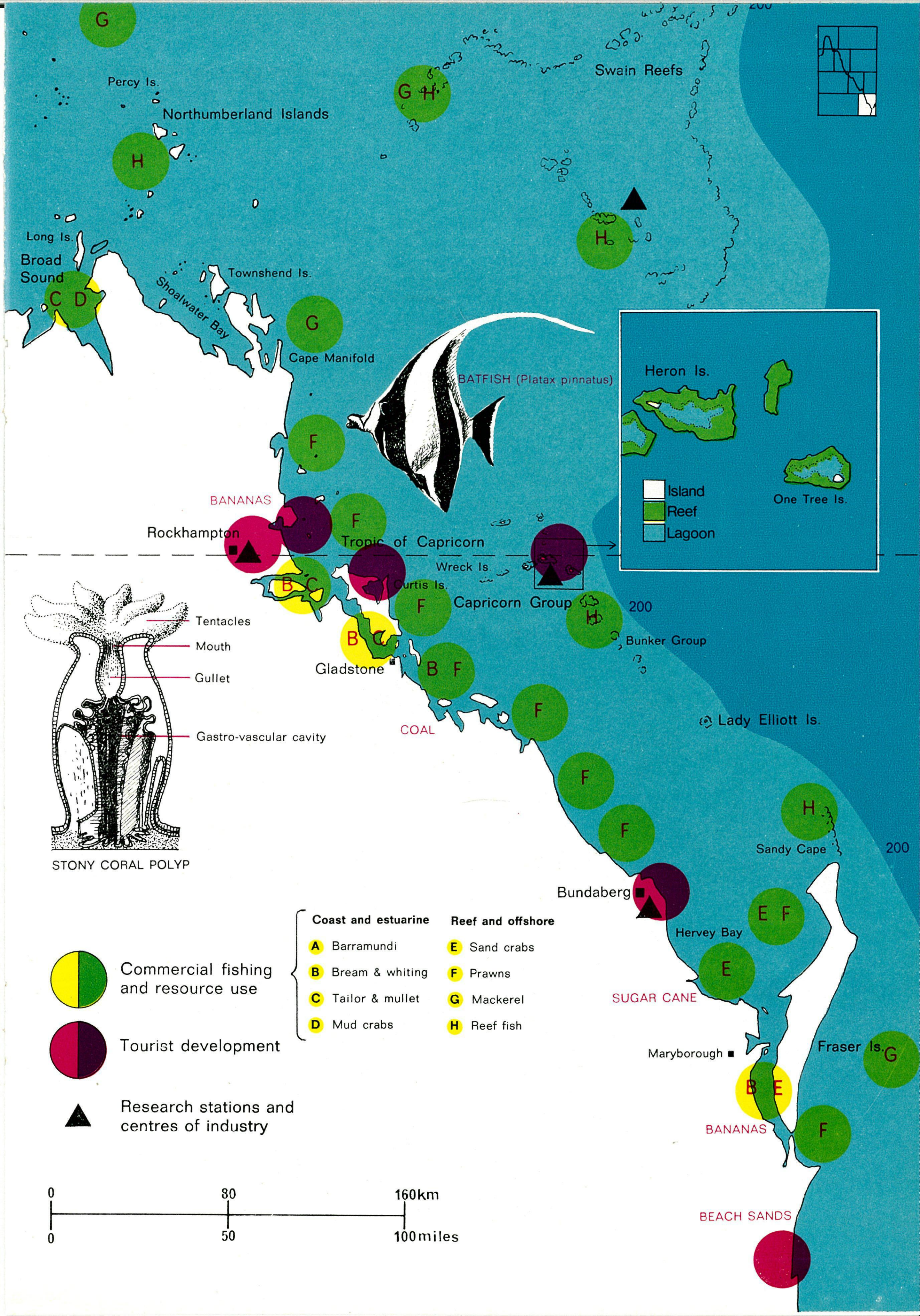
2

2. Orange coral (*Dendrophyllia)* found in rock pools around Heron Island.

3



3. Swain Reefs, which are generally regarded as marking the southern outer extremity of the Great Barrier Reef. South of here reefs are scattered and irregular. Northwards there are some reefs which stretch end on end for miles. These reefs rise steeply from the ocean depths of 1 800 metres or more on the outside.



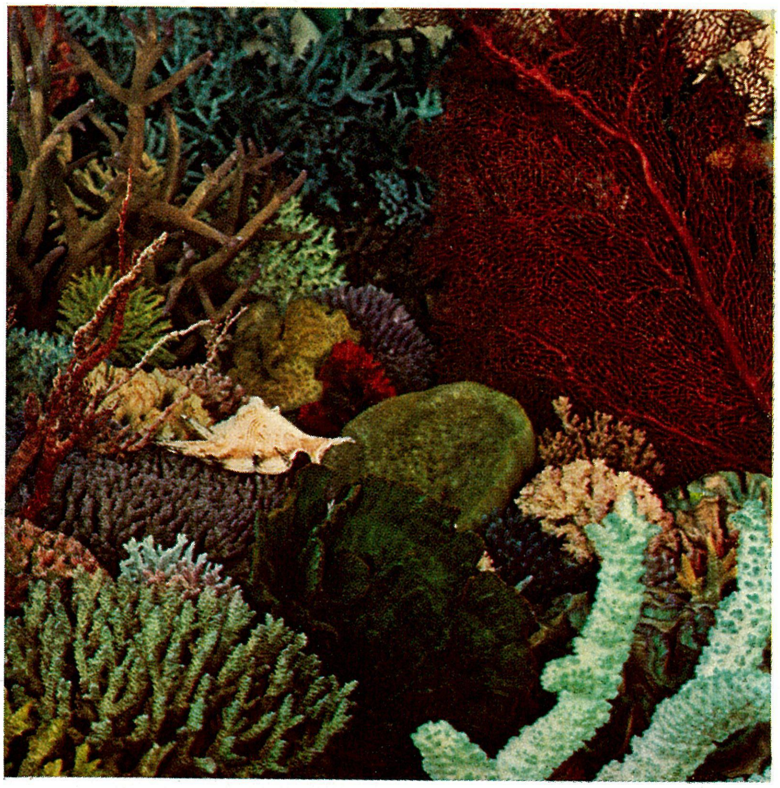
Percy Is.
Northumberland Islands
Swain Reefs
Long Is.
Broad Sound
Townshend Is.
Shoalwater Bay
Cape Manifold
BATFISH (Platax pinnatus)
Heron Is.
Island
Reef
Lagoon
One Tree Is.
BANANAS
Rockhampton
Tropic of Capricorn
Wreck Is.
Curtis Is.
Capricorn Group
200
Bunker Group
Gladstone
COAL
Lady Elliott Is.
Tentacles
Mouth
Gullet
Gastro-vascular cavity
STONY CORAL POLYP
Sandy Cape
200
Bundaberg
Hervey Bay
SUGAR CANE
Maryborough
Fraser Is.
BANANAS
BEACH SANDS
Coast and estuarine
A Barramundi
B Bream & whiting
C Tailor & mullet
D Mud crabs
Reef and offshore
E Sand crabs
F Prawns
G Mackerel
H Reef fish
Commercial fishing and resource use
Tourist development
Research stations and centres of industry
0 80 160km
0 50 100miles

Holiday isles north to Hinchinbrook

There are hundreds of islets in the channel that runs for hundreds of miles between the reefs of the outer Great Barrier Reef and the mainland. Some are true coral islands and others are offshots from the nearby mainland.

Coral islands are often called low islands, since in many cases they rise only slightly above sea level. Such islands as Lindeman, Whitsunday, Hinchinbrook and Magnetic are relics of high land which formerly was part of the Queensland mainland. They are continental islands, which often rise some hundreds of metres above sea level — the highest peak on Hinchinbrook is 1 067 metres. Such islands are most picturesque, are often clothed in tropical forest, and are popular tourist resorts. Some of northern Queensland's first prawn grounds were found in waters between Broad Sound and Hinchinbrook Island shown on map outside.

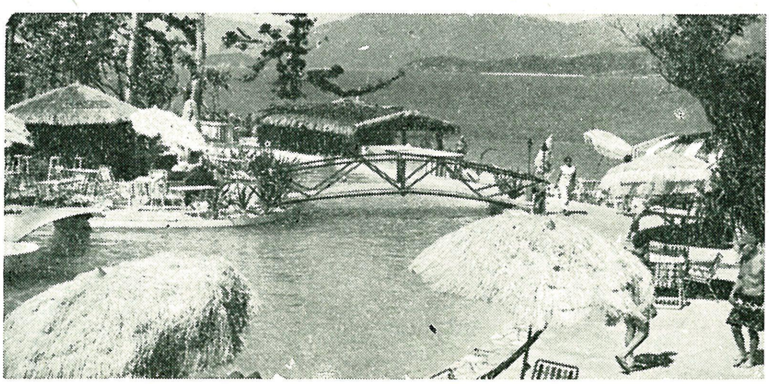
1



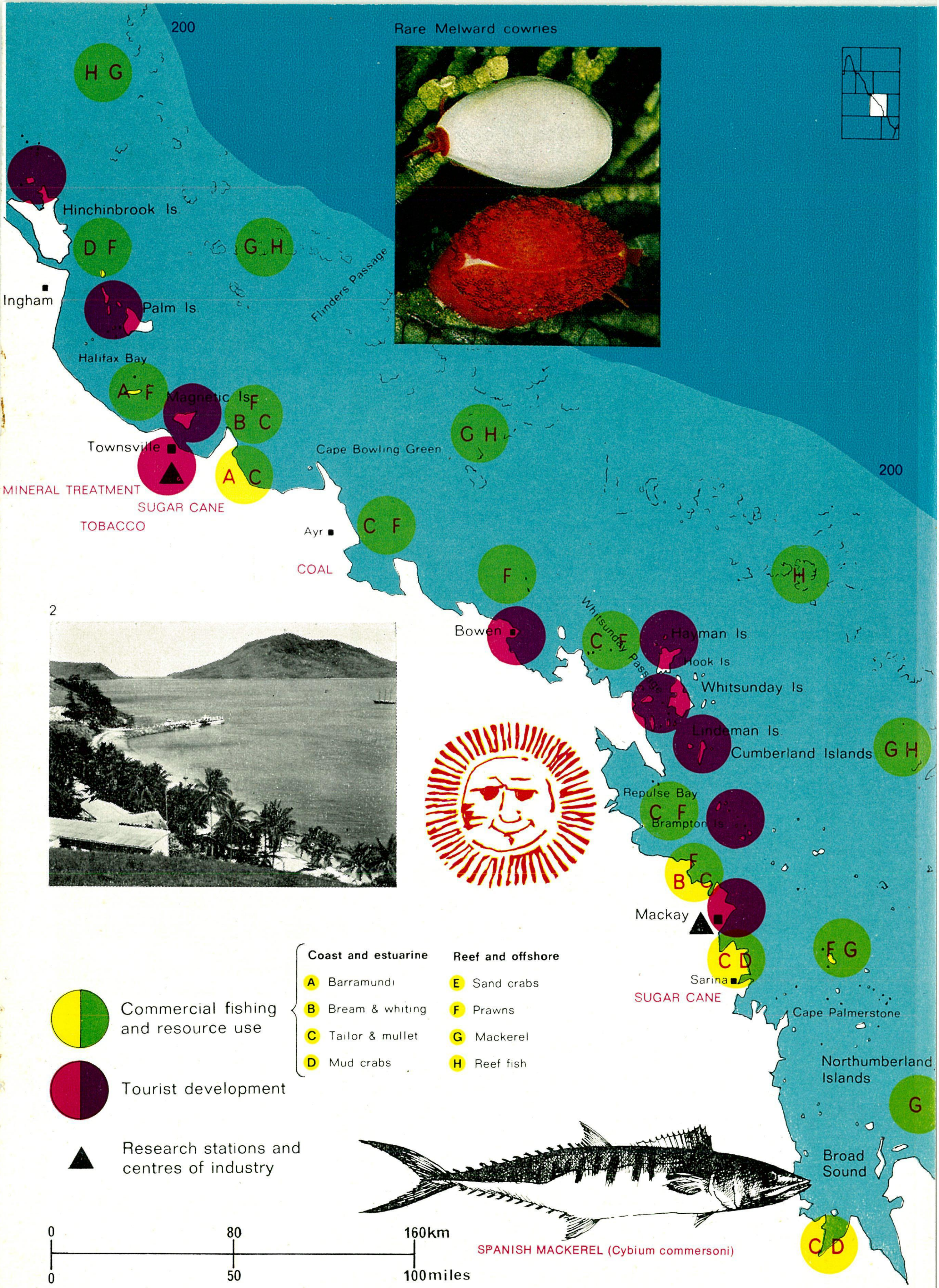
1. Living coral of the Great Barrier Reef is a riot of tropical colour. This collection was pictured at Mr Basil Keong's Mandalay Coral Gardens at Airlie Beach near Proserpine.

2. Lindeman, one of the Whitsunday Group, is part of an ancient coastal range. It is 70 km out from Mackay at the southern entrance of the famed Whitsunday Passage, named by Captain James Cook. The tourist resort at Lindeman is situated beneath a grassy bluff bordered by a wide sandy beach.

3



3. Visitors to the Barrier Reef can participate in every type of aquatic activity — swimming, skin-diving, water ski-ing and boating. This resort has all the atmosphere of a tropical South Seas coral isle.



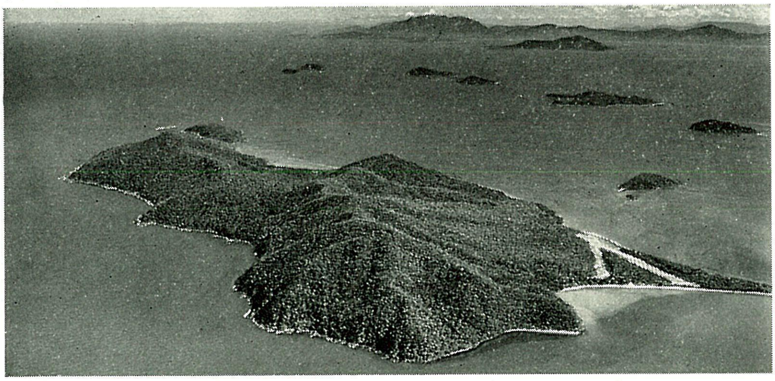
Rare Melward cowries
200
H G
Hinchinbrook Is
D F
G H
Ingham
Palm Is
Flinders Passage
Halifax Bay
A F
Magnetic Is
F
B C
G H
Townsville
A C
Cape Bowling Green
MINERAL TREATMENT
SUGAR CANE
TOBACCO
Ayr
C F
COAL
200
F
H
2
Bowen
C F
Whitsunday Passage
Hayman Is
Hook Is
Whitsunday Is
Lindeman Is
Cumberland Islands
G H
Repulse Bay
C F
Brampton Is
F
B C
Mackay
C D
Sarina
SUGAR CANE
F G
Cape Palmerstone
Northumberland Islands
G
Broad Sound
C D
Commercial fishing and resource use
Tourist development
Research stations and centres of industry
Coast and estuarine
A Barramundi
B Bream & whiting
C Tailor & mullet
D Mud crabs
Reef and offshore
E Sand crabs
F Prawns
G Mackerel
H Reef fish
SPANISH MACKEREL (Cybium commersoni)
0 80 160km
0 50 100miles

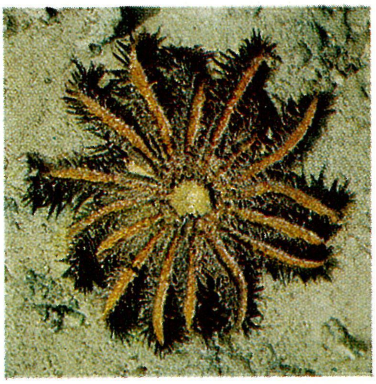
Where Cook sailed

Between Hinchinbrook Channel and Princess Charlotte Bay lies part of the famous shipping track inside the Great Barrier Reef. It is entered through a southward facing 'funnel' and it was not surprising that Cook, 200 years ago, found himself safely cruising northward without realising that to seaward there was a great barrier reef.

1

2

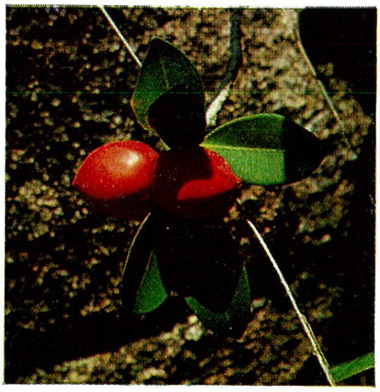




3

Approaching Cape Flattery the outer reef is only 40 km from the mainland, and it was near here that *Endeavour* ran up on a reef and was later refloated and sailed to Cooktown for repairs. This later led Cook to seek the outer ocean through a gap in the barrier at a place now known as Cook's Passage.

4



5

1. Hope Island, a true coral island, north of Cairns. Unlike many of the islands further south it is uninhabited, except for birds. In rough weather fishing vessels and small craft passing up the coast shelter here.

2. Dunk Island and islands of the Family Group between Ingham and Innisfail. Dunk Island, now a popular tourist centre, was made famous by E. J. Banfield in *My Tropic Isle* and other books.

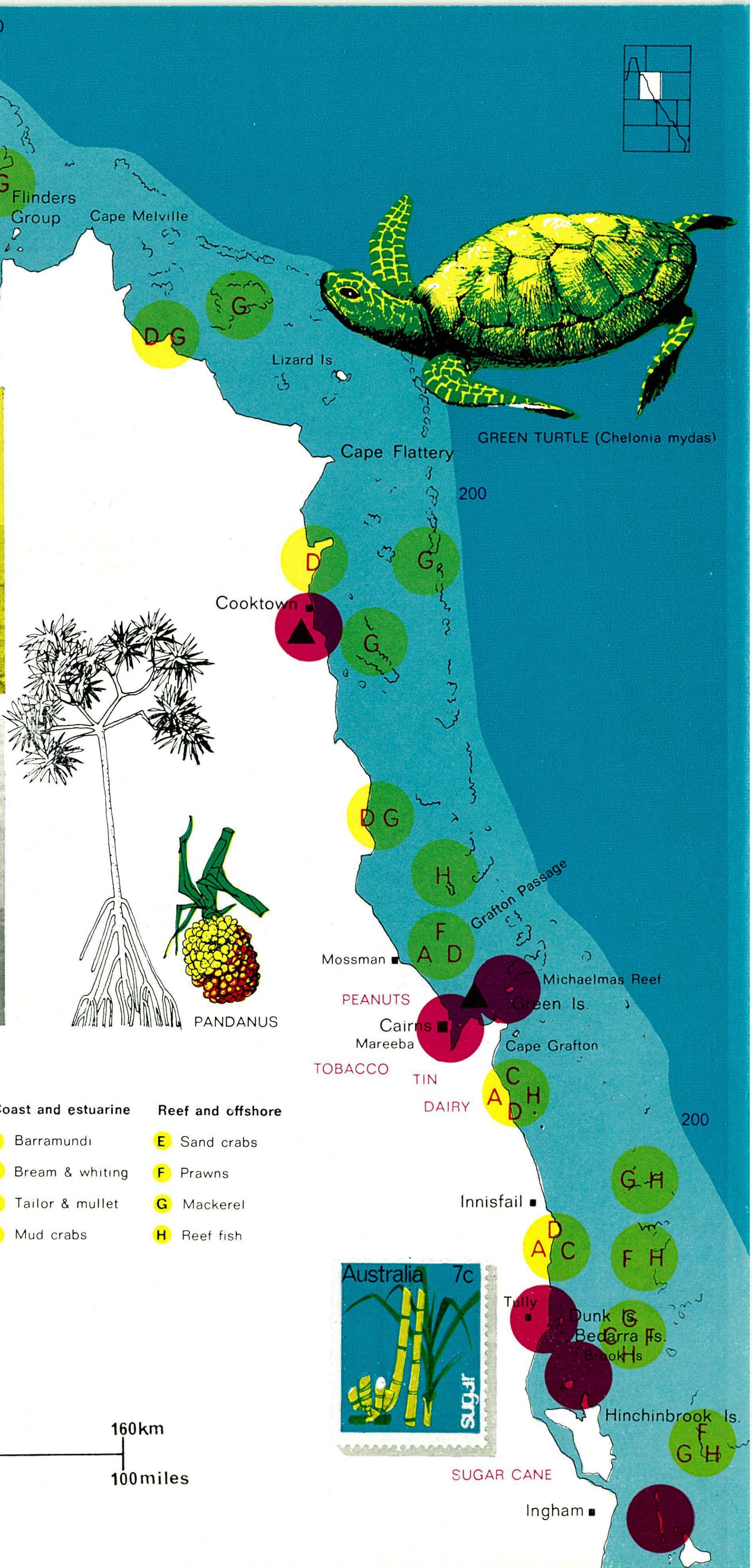
3. Sea-star (*Acanthaster planci*), commonly known as the 'crown-of-thorns', which has caused extensive damage to live coral in the central inner reefs off the Queensland coast.

4. Scarlet wedge-apple found on Bedarra, a heavily wooded island with dense tropical forest, off Tully.

5. Sooty or wide-awake tern, most active of the many species of sea birds that inhabit the Great Barrier Reef islands.

6. Reef fishing vessel *Trude B*, owned by Peter Behrens, rigged for mackerel fishing.

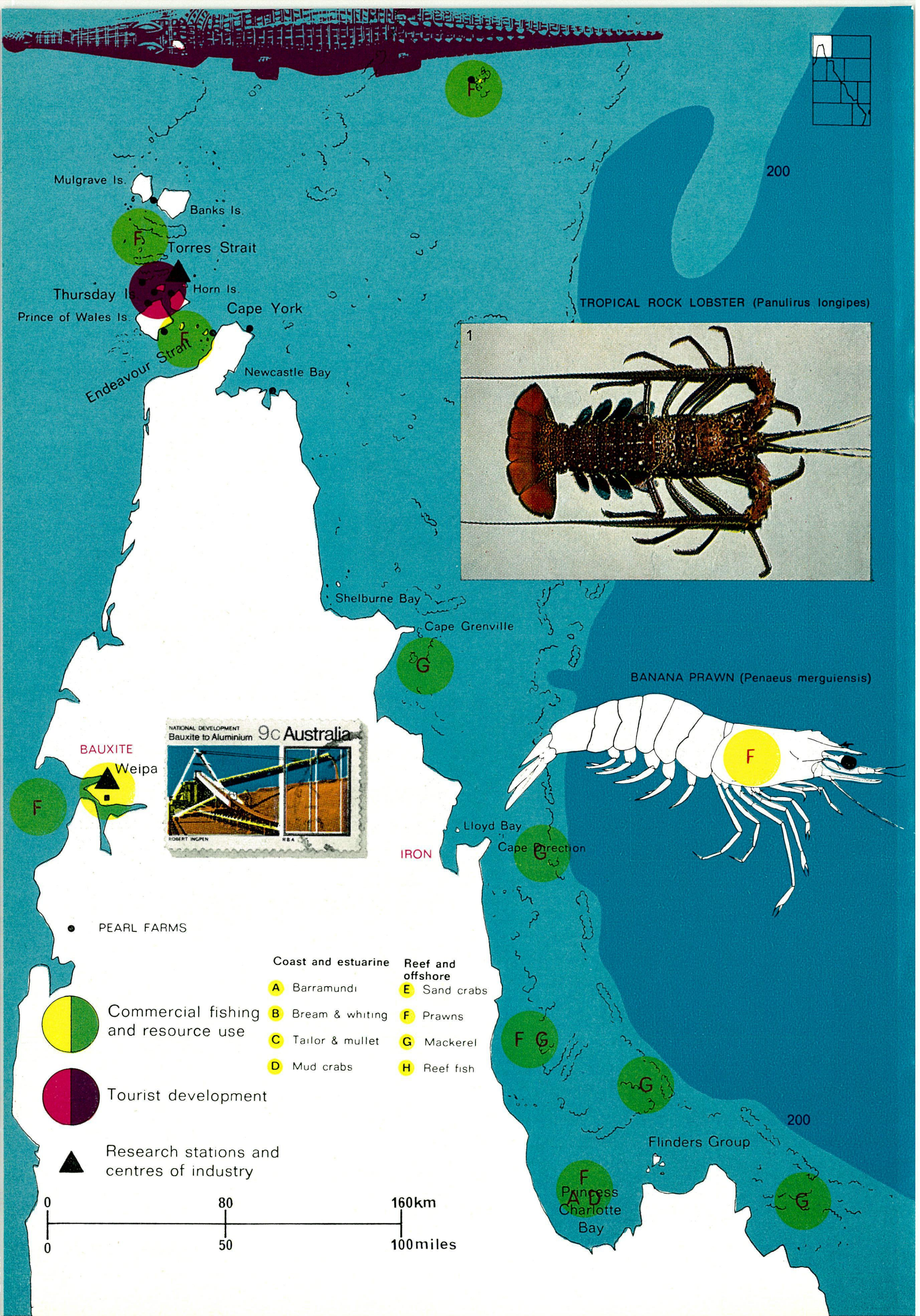
7. Deck-mounted reel to retrieve mackerel after they strike the troll line from the outrigger and become hooked.



200
G F
G
Flinders
Group
Cape Melville
F
A D
Princess
Charlotte
Bay
D G
G
Lizard Is
GREEN TURTLE (Chelonia mydas)
Cape Flattery
200
D
G
Cooktown
G
PANDANUS
D G
H
Grafton Passage
F
A D
Mossman
Michaelmas Reef
PEANUTS
Green Is.
Cairns
Mareeba
Cape Grafton
TOBACCO
TIN
DAIRY
C
A H
D
200
G H
Innisfail
D
A C
F H
Australia 7c
sugar
Tully
Dunk Is.
Bedarra Is.
Brook Is
Hinchinbrook Is.
F
G H
SUGAR CANE
Ingham
Commercial fishing and resource use
Tourist development
Research stations and centres of industry
Coast and estuarine
A Barramundi
B Bream & whiting
C Tailor & mullet
D Mud crabs
Reef and offshore
E Sand crabs
F Prawns
G Mackerel
H Reef fish
0 80 160km
0 50 100miles

6

7



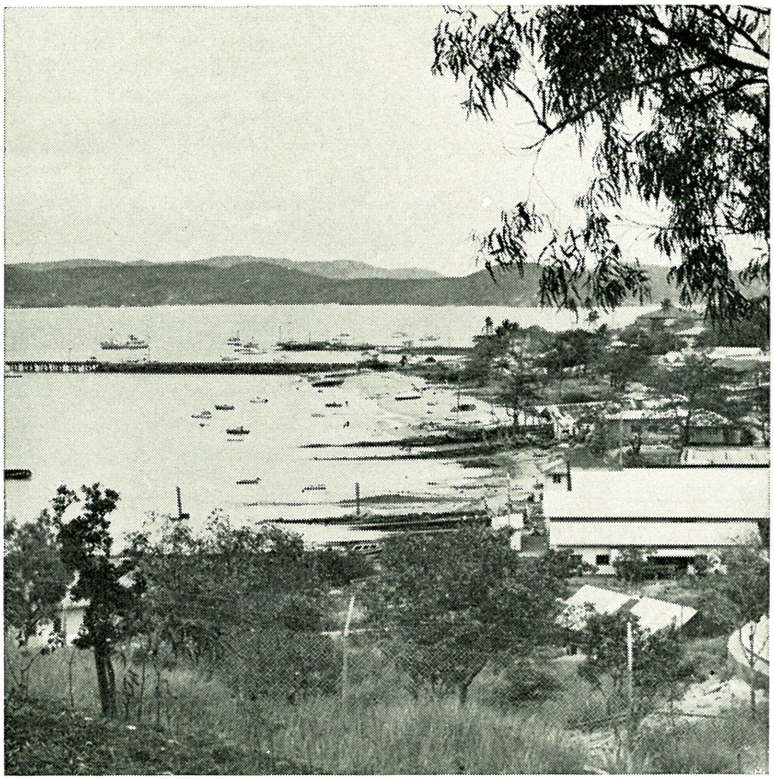
200
Mulgrave Is.
Banks Is.
Torres Strait
Thursday Is.
Horn Is.
Prince of Wales Is.
Cape York
Endeavour Strait
Newcastle Bay
TROPICAL ROCK LOBSTER (Panulirus longipes)
1
Shelburne Bay
Cape Grenville
BANANA PRAWN (Penaeus merguiensis)
BAUXITE
Weipa
NATIONAL DEVELOPMENT
Bauxite to Aluminium
9c Australia
ROBERT INGPEN
RBA
Lloyd Bay
Cape Direction
IRON
PEARL FARMS
Coast and estuarine
A Barramundi
B Bream & whiting
C Tailor & mullet
D Mud crabs
Reef and offshore
E Sand crabs
F Prawns
G Mackerel
H Reef fish
Commercial fishing and resource use
Tourist development
Research stations and centres of industry
200
Flinders Group
Princess Charlotte Bay
0 80 160km
0 50 100miles

Reef waters yield treasure

One of the least known and less frequently visited parts of the Great Barrier Reef lies between Princess Charlotte Bay and the tip of Cape York Peninsula. Yet this section of the reef once contained its richest treasure — pearl shell from the silver and black-lip pearl oysters which are the largest in the world. Today the shell is no longer of great value but the oysters are used to culture lustrous pearls.

Trochus shell (for buttons) and beche-de-mer were also once important fisheries. Today Princess Charlotte Bay and waters east and west of Cape York Peninsula are becoming increasingly important prawning grounds, while bauxite is mined at Weipa.

3



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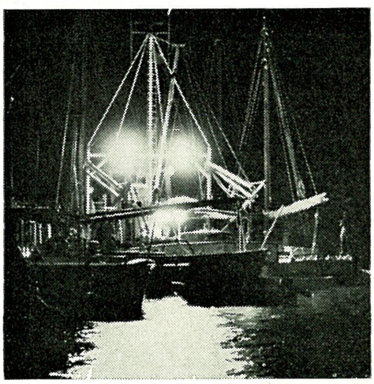

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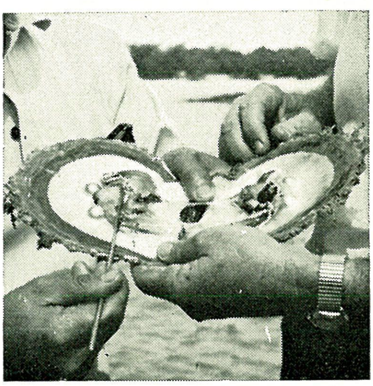

1. Tropical or painted rock lobster (*Panulirus longipes*), one of six species of lobster found in northern Australian waters. It does not enter baited pots like rock lobsters in western and southern Australian waters. A commercial fishery for tropical rock lobster has been started on Thursday Island in Torres Strait.

2. Prawn trawlers at Thursday Island. A processing plant has been established on the island to receive catches from trawlers operating in Torres Strait, the Gulf of Carpentaria and as far afield as the Arafura Sea.

3. Thursday Island, once centre of a prosperous pearl-shell industry. Today pearl culturing and prawn fishing are of prime importance. Photo shows slipways, main wharf and boat harbour.

4. Cultured blister or half pearls grown on a farm in Torres Strait.

Coloured illustration: A coral garden on Pixie Reef, north of Cairns. This reef in the outer barrier system is seldom visited by tourists and has remained untouched for the past 20 years. Reef right is at Heron Island, a popular tourist resort where visitors fossick on the reef crest at low tide.

First glimpse of tropical nature is an unforgettable experience. Much of the accounts of early travellers are full of 'purple passages' and superlatives to convey the feeling of immensity and complexity, variety and seemingly uncontrolled growth.

By L. J. Webb
Principal Research Scientist
CSIRO Tropical Rain Forest
Ecology Section, Brisbane

The Great Barrier Reef V: Tropical rain forests

IN the first book in English on the tropical rain forest, almost 70 years ago, Schimper remarked how, 'when the rain forest is viewed from outside, say from a ship sailing by a forest-clad coast, many distinctions between it and forest in temperate regions meet the eye. In side view the canopy is irregularly jagged and crested, and forms a richly varied mosaic, while the great diversity of tree-trunks, the irregular tangle of lianes, and the variety in the forms of the foliaged crowns forcibly strike the eye'.

Similarly man's early concern with tropical coral reefs off Australia sprang not only from their hazards to navigation but also, as Maxwell recently put it, because they are 'among the most spectacular and most awesome of nature's phenomena'.

Nowadays both tropical rain forests and coral reefs are recognised as the densest and most complex communities of living organisms on earth and provide one of the most provocative challenges to biological science, so different are they from animals and plants of the temperate world. Should the tropical zone be regarded as an evolutionary cradle of new forms, or as a sanctuary and museum for evolutionary old age? asks Dohzhansky.

Tropical islands fascinate students of evolution but unfortunately, as Stoddart points out, by the time some of the problems have become defined and hypotheses developed many of the more accessible and attractive areas have been settled by European man, resulting in the disruption of many unique assemblages of animals and plants. It is certain however that tropical nature holds the key to understanding many of the fundamental evolutionary and ecological processes upon which man himself depends, and that he will become increasingly aware of this dependence in the future. More than this, the land and sea of the tropical zone are a rich repository of genetic material and potential variability with an immense wealth of species and literally thousands of genera. To maintain this role of genetic recruitment key areas in the world's tropics must remain vast and little disturbed by man.

Typical dense tropical rain forest in North Queensland.

Perhaps the most telling argument in favour of conserving large chunks of tropical rain forest and coral reefs is the argument of ecological interdependence, of dynamic balance among the parts which form the whole. As Margalef points out, tropical forests and coral reefs are examples of mature ecosystems which are stable *but* drastic interference by man is liable to produce total collapse of such ecosystems, in which 'nature is not prepared for a step backwards'. It is the job of modern ecology to identify different types of ecosystems in terms of their stability and maturity, their inherent weaknesses and their reactions to particular forms of disturbance as the basis for scientific and wise management of resources.

between forest and swamp, between mangrove marsh and the sea.

Rain-water which leaches from undisturbed tropical rain forest on land and which passes through the soil and into streams is practically distilled water. It contains only traces of minerals because of the efficiency of the nutrient cycle in the intact rain forest, where leaf-litter is immediately mineralised and transformed into food for the surface roots. Once this cycle is disrupted by clearing and burning minerals are lost by leaching and erosion into the streams and thence into the adjacent seas. The alluvial fans at the mouth of many of the rivers along the coast of north-eastern Australia amply testify to the sediment loads from deforested catchment areas. Less obvious, and probably of more importance biologically, are the invisible chemicals rinsed out of agricultural soils — whether they be fertilisers, soil sterilants or pesticides.

Bedarra Island — a small continental island in the Family Group — which has a rich display of tropical rain forest and vegetation down to the water's edge.

Although the boundaries between tropical corals in the sea and tropical forests on land seem obvious enough, not all boundaries are the same. They are considered by modern ecology as belts of tension 'where two organisations meet and exchange their respective components', and the most important boundaries are those separating systems of different maturity. For example exchange of energy, food materials, minerals and detritus occurs between organisms living along shore-lines,

Dr L. J. Brass, who led the Archbold expedition in the most comprehensive biological survey yet undertaken of Cape York Peninsula in 1948, commented as he flew over Cairns that the alluvial fan of the Barron River is 'growing faster than it should by deposit of eroded materials from the fertile Atherton Tableland, which has suffered at the hands of maize farmers and dairymen a pioneer exploitative phase of land usage that has had little regard for posterity'.

That was 22 years ago. Three years ago Dr A. B. Costin estimated that the tobacco soils of Mareeba, on the highlands just west of Cairns in North Queensland, receive annual applications equivalent to approximately 55 litres of insecticides and fungicides and 90 litres of soil sterilants an acre. The extent of chemical pollution via drainage water, and the accumulation of non-biodegradable chemicals in food chains in adjacent soils, rivers, estuaries and the sea is open to conjecture, and has not yet been monitored. These examples do however illustrate the extent to which the marine environment which shelters the fringing reefs, inner platform and other reefs, and ultimately the outer barrier reefs, is affected by what happens on the adjacent mainland.

Until more is known about the ecology and population dynamics of the so-called 'crown-of-thorns' starfish the influence of human interference cannot be assessed. However Pearson and Endean in a paper published last year noted that there is some evidence that the crown-of-thorns infestations of the Great Barrier Reef 'may have been initiated through human interference'.

They added: 'Only those reefs close to the coast and near centres of coast and near centres of population are known to be infested. No infestations have been observed on reefs between Lizard Island and the tip of Cape York . . . . In this region the reefs are close to the mainland but there are no centres of population north of Cooktown . . . . Although no information is available on the possible effects which agricultural chemicals and other pollutants, such as sewage and the effluents from sugar mills and other industries, have had on the nearby coral reefs there seems little doubt that pollutants can be carried to the reefs.'

There is in fact plenty of evidence just waiting to be collected on the pollution of waterways in North Queensland which may have detrimental effects on the adjacent coral reefs. The Director of the Queensland Littoral Society (Mr E. Hegerl) listed examples encountered during a month's tour and noted that 'seemingly, almost anything that rots is thrown into Queensland's waterways. Organic wastes, whether from sugar, fruit, meat or dairy processing can cause extensive water pollution, not generally by directly poisoning aquatic life but by providing a source of nutrients for micro-organisms when they consume the dissolved oxygen in the water.' Industries are obvious sources of pollution but there are other sources which are not so easily recognised — for example the harbour dredges at Townsville, Mackay and Bundaberg, which 'drop their loads of silt on or near small inshore reef areas'.

In the absence of ecological data we can only speculate about the transmission of these pollutants within food-chains vital for the healthy maintenance of the Great Barrier Reef ecosystem. There are plenty of well-authenticated examples elsewhere however which give us an idea of the kind of pattern to expect, and the outlook is not consoling unless adequate monitoring and pollution control are begun before further accumulation in food-chains occurs.

So much for ecological interdependence between terrestial and marine ecosystems in the tropics. But every tourist, let alone the specialists, will tell you that coral reefs and tropical rain forests have a beauty and interest in themselves apart from their ecological relationships.

Although tropical rain forest vegetation looks much the same anywhere to the untrained eye (which cannot see the trees for the wood!) there are many different rain forest types characteristic to different soils, altitudes, drainage patterns, and rainfall regimes.

Along the eastern Queensland coast monsoon forests extend in patches, often in fire-protected niches, from Cape York to just north of Cooktown. From about Cooktown-Bloomfield River southwards to the Tully-Hinchinbrook Island area humid tropical lowland rain forest occurs at altitudes below 300 and 600 metres on a variety of well-drained soils from basalt, granite and schists, and forms intricate mosaics and boundaries with eucalypt and acacia forests which tend to occupy the poorer soils exposed to wildfire. South of the Cardwell Range opposite Hinchinbrook Island the rain forests become subtropical in character and are interrupted in places by dry east-west corridors and unfavourable soils. In fact farther south the complex subtropical rain forests become restricted to soils from rocks such as basalts, rich in phosphorus, and calcium.

Most ecological work has been done on the mainland rain forests and little or no botanical work has been done on the continental and oceanic islands which support vegetation. The flora of the continental islands is much more similar to that of the mainland than is the flora of the coral islands. The sea-coast or strand flora is relatively simple compared with the vegetation farther inland. Most strand species are adapted to dispersal by floating in sea-water, consequently they are widespread. Limited botanical collecting suggests however that there are numerous plant species restricted to particular habitats along the coast and on the larger islands, and a comparative study of these species patterns would provide valuable clues about past climatic history and biological evolution in eastern Australia.

The tropical rain forests of North Queensland have, in fact, many unique features not shared with rain forests elsewhere in the world. One feature is of course the proximity of such a vast area of tropical coral reefs. Another is the relationship with the hard-leaved (sclerophyll) vegetation of eucalypts, acacias, etc., so characteristic of the Australian scene. But perhaps the most attractive quality of the tropical rainforest in Queensland is its accessibility.

It is easily reached by the tourist or the scientist; there are no political or health problems — indeed the only real problem is to preserve enough of it for the enjoyment and enlightenment of future generations. As was pointed out in the recently published *Last of Lands* (Jacaranda Press) not another acre should be alienated nor another native habitat gutted until we take stock.

The Australian rain forests in the tropical north provide a model for scientific study and an unusually beautiful and interesting landscape which, taken in association with the superb coral reefs to the east, make this area one of the biological treasure-houses of the world.

The rain forests of North Queensland have been the subject of increasing study over the past few years by ecologists using the computer and modern numerical analysis, and several new ecological principles have been established. Despite the complexity of the species composition it seems that there are definite species associations which characterise different soils and topography. For example in only one acre of complex rain forest near Cairns four distinct forest types were mapped by the computer and correlated with different environmental factors. It has also been shown that a 'computer questionnaire', using only some two dozen features of forest structure and life-forms (e.g. leaf-size, presence of tree-ferns, plank

Continued on page 28

The Australian Museum for some years has worked on coral reef ecology on One Tree Island, about 16 km from Heron Island, at the southern end of the Great Barrier Reef system. The reef here is 5 km long and 3 km wide. The island leased as a base by the Museum is of coral rubble, and the vegetation is sparse.

By F. H. Talbot
Director, Australian Museum
Sydney

The Great Barrier Reef VI: Coral reef ecology

SOME 20 scientists, research assistants and technicians have taken part in the project. Their work has covered the ecology of the herons; mollusc growth rates, recruitment and loss; the systematics of the fishes, the species and biomass distribution of the fishes, the systematics of corals, the primary productivity of the reef, and the addition of isotope labelled nutrients to semi-closed lagoon areas.

This work has been done from a camp of a dozen or so tents — mess tents, sleeping tents, cooking tents and laboratory tents — which is not ideal for delicate electronic equipment. More weatherproof housing is now being planned.

The work is by separate scientists who study different aspects of the reef and cover a number of research areas. This kind of loose collaboration, with much joint discussion, is getting them closer to answering some of the puzzling questions about coral reefs — and, as such studies do, is opening up whole new areas of inquiry.

To marine biologists a coral reef has great scientific interest. It presents also a strange paradox, because the tropical waters in which the most flourishing coral reefs grow are in general the poorest in nutrients — basic ingredients such as phosphates and nitrates which are needed to sustain life. Yet coral reefs are by far the richest in species of any marine habitat.

Temperate waters are green because of their rich load of plankton — their total plant and animal matter is high. But the glorious blue tropic waters are that colour because they lack zooplankton and plant plankton, and they lack them because they are low in 'fertilisers'. The reason for this lies in the continued movement of water of the world's oceans, with fast surface and slow deep currents (often going in quite different directions) and areas of huge sinking and rising water masses.

What happens in the Pacific is typical of this pattern. Winds along the Peru and Chile coasts drive surface water northwards and offshore, and this is replaced by water upwelling from deeper levels — water rich in nitrates and phosphates. This gives rise to the huge fisheries of the area — making Peru one of the top fishing nations in the world. This water continues northward and then turns out across the Pacific to form the South Equatorial Current. As it goes it loses richness — animals die, sink, their carcasses are fed on by others, these die, sink and so on. This causes a slow loss of the nutrients from the surface water.

By the time this water has crossed the Pacific and reached our coasts, it is not rich, and yet our Great Barrier Reef is a most amazingly rich area.

It has a huge number of species of plants and animals — quite how huge we do not yet know, for many species have yet to be named. Its coral reefs have a standing crop of fishes (total weight per hectare) which is more than twice that of a typical temperate area. In addition the rate of photosynthesis, which determines the rate at which carbohydrates (the basic food of animals on land and sea) are produced by green plants, is also tremendously high — the values obtained are about 100 times that found in open tropical ocean waters.

So we have a paradox — this amazingly rich area set in a sea that is a relative desert. But coupled with this is a further paradox — in spite of this huge biomass of fishes and rapid carbohydrate production the reef supports a very small fishery.

We are now beginning to understand the reasons for these paradoxes. It seems that, at least in part, the reefs are a closed system recycling their nutrients. As the oceanic waters wash the reef its plants, and through them its animals, take nutrients from the water and accumulate them in the living system of the reef. With this accumulation continuing for hundreds or thousands of years, a coral reef can be rich within poor waters.

When you are on a coral reef, or swimming over it with goggles, it is difficult to see how it could have such a tremendous photosynthetic rate when there are so few plants visible. Unlike temperate areas coral reefs have few large-bodied plants, but minute single celled or filamentous algae are on almost every area not covered by coral.

Often lagoon sand has quite a decided greenish tinge and is highly productive. Large areas of the reef are covered by a hard reddish veneer almost like a ceramic, and this is a calcareous algae, *Lithothamnion*. In addition many animals (including most corals) contain single celled algae or *Zooxanthellae* in their tissues.

Professor Stephenson of the University of Queensland has studied the algal 'turfs' at Heron Island, where intertidal rock is covered in a low felt of algae. He found that this was heavily

Australian Museum scientists at their camp on the beach at One Tree Island.

cropped almost daily (chiefly by fishes but also by molluscs). This is likely to be typical for the reef, and the great algal production is rapidly converted to the next stage in the food cycle — in this case to fish.

The whole system is cycling rapidly — things grow fast and get cropped or die fast. Bacterial breakdown of dead animals and plants is also rapid and the nutrients released by this are as rapidly absorbed. If phosphates were labelled with a radio-active tracer (which is possible) it would be found that they would move from lagoon plant to grazer (perhaps a mollusc); mollusc to small fish; small fish to big fish predator; and on the death of the big fish, to solution in the water by bacteria, and back to plants by absorption.

It must be assumed therefore that this complex community of inter-related plants and animals (scores of thousands of them) absorb nutrients from the sea, and cycles them rapidly; and it cannot lose more than it gains from the ocean if it is to keep this high-revving system going. Because of the slow addition of nutrients from the waters bathing the reefs it is easy to overfish coral reefs.

With the huge standing crop (total weight of living matter) of animals and plants found per square metre of reef, all of which respire continuously, a large amount of oxygen is needed both day and night. The open sea, with its green plants photosynthesising and producing oxygen, has no lack of this vital gas in solution.

During the day the plants on the reef produce an excess of oxygen as they photosynthesise in the water. In quiet lagoons the water often becomes super-saturated, and sometimes oxygen may even bubble through the surface.

At night there is quite a different picture. The large biomass of animals and plants continues to respire after the sunlight has gone and photosynthesis has stopped. Oxygen is used rapidly, and in quiet-water lagoons where at low tides there is little admixture of open sea water, the oxygen concentration gets low and oxygen begins diffusing back through the air-water interface.

In measurements on One Tree Island reef Mr Don Kinsey has found that at times the diffusion of oxygen from the air is only just keeping pace with the use of oxygen by the animals and plants. This interchange is greatly helped by the surface waters being ruffled by wind, but in still conditions it is likely that some of the active high-oxygen users among the animals must be getting close to conditions of stress.

He suggests that coral reefs in back reef lagoon areas may have reached the limit, or close to it, of total possible biomass, and that this limit in quiet water lagoons is due to the diffusion rate through the surface.

Another finding has been that the brightly-coloured fish population is markedly restricted in its distribution. Areas as little as 90 metres apart — a minute's swim — have populations where up to 40 per cent of the species are different. This is due to physical and biotic factors such as

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A number or rivers discharge their waters into the channel between the mainland of Queensland and the outer barrier reefs. This may explain the relative richness of the reefs on the Great Barrier Reef.

By J. M. Thomson
Professor of Zoology, University of Queensland

The Great Barrier Reef VII: Estuaries and beaches

CORAL reefs on oceanic islands depend upon the generally low levels of nutrients in open ocean water. But along the Great Barrier Reef the oceanic nutrients are augmented by dissolved matter discharged from the Queensland rivers which come from fertile country where farm fertilisers add to the potential nutrients that wash into the rivers with every fall of rain. There are only two major river basins along the coast — the Fitzroy, which drains some 140 000 sq. km and is about 960 km long including the Fitzroy proper, and its main tributary the Dawson; and the Burdekin, which drains 130 000 sq. km. There is a number of smaller streams such as the Herbert which drains 1 000 sq. km, the Pioneer River which is only 80 km long and the Endeavour, shorter still at 32 km. Most years these rivers are intermittent — that is they run only after rain, drying up to a series of long waterholes in the dry winter season. But they lie in the heavy summer rainfall belt, so that they discharge a considerable volume of water over part of the year.

With the water go soil, organic particles from animal and plant matter, sticks and twigs, and a number of substances dissolved from the rocks and soil from the beds and banks of the rivers. Clearing of the land upstream has increased the soil or silt loads of the rivers because the foliage that protected the earth from the battering of falling water-drops has been removed.

Some of this may drop to the bottom where the river runs more slowly, but during the height of the rainy season there are few places where the rivers run slowly. The silt is deposited where the rivers broaden out and periodically stop running, where the tides push in the opposite direction — such places are the river estuaries, and the masters of the ports on these rivers know only too well of the hundreds of thousands of tonnes of soil that wash down each year.

Coral reefs flourish in warm clear water that is free of silt. Some former coral reefs on the mainland shore have been smothered by the increased silt brought down since the pioneers opened up the tropical Queensland coast. They can still be found several centimetres down beneath the mud-flat surface on the coast near several rivers.

The advent of Man has brought about other changes in the quality of the tropical rivers, some good some bad. Agricultural practices have provided fertilisers, part of which inevitably wash into the creeks and rivers. Much of this will help to fertilise the waters of the Great Barrier Reef, but some will drop in the estuaries — for instance phosphates are known to become absorbed on clay and other silt particles that drop where the salt waters influence the estuaries. This creates a store of fertilising material to enrich the estuaries.

But on the debit side the rivers also carry another type of agricultural chemical — the insecticides, weedicides and wormicides etc. which the farmer and grazier use on their properties. Fortunately the danger of persistent pesticides leaching into the environment has been recognised and a switch to non-persistent pesticides is taking place. One difficulty is that efficient non-persistent pesticides are still lacking in some fields.

The concentration of pesticide material in the estuaries and rivers is not very great, but it does vary seasonally depending upon when the pesticide is used and on the subsequent rainfall pattern. From work in America and Europe we know that the persistent pesticides can accumulate in certain animals and plants in levels much higher than their occurrence in the sea or river. There is no evidence of this from the tropical estuaries of Queensland, and tests on reef animals have shown traces of pesticides that are only just at detectable levels.

Another threat to the well-being of the tropical estuaries is the method used by many sugar mills to dispose of unwanted wastes. Being plant products and hence organic material these wastes are subject to decay. When dumped in convenient nearby creeks and rivers — often in the form of a sludge — decaying material uses up all the oxygen dissolved in the waters so that the creeks and rivers near the mills become foul and incapable of supporting life. As the cane cutting and crushing takes place outside the rainy season there is seldom any water movement to move the decaying material downstream. When the rains finally come the stagnant water is moved downstream as a wedge of deoxygenated water which kills all animals in its path. As fish automatically tend to head into water currents rather than retreating downstream, the catastrophes can be large.

Sugar mills are not the only sources of pollution — wood wastes from timber mills and cabinet makers, tailings from tin and other mines, material from secondary industries all serve to make the estuaries less productive than they were. The situation is improving; some mills already have stopped dumping in the water, and under recent legislation in Queensland an Environmental Council has been set up whose duty it is to eliminate such abuses.

Although we human beings have tended to make estuaries sewage outfalls and channels from which to get rid of industrial wastes they remain one of the most productive areas for inshore fisheries. The famed barramundi is caught in the rivers of the Barrier Reef region as well as elsewhere in the tropical north. The barramundi is one of the comparatively rare species of fish that can pass between fresh and salt water and live equally well in both. The fish spawns in sea water but the young work their way up the rivers and on to the flood plains, where they grow in the ponds and waterholes left in the dry season. A year or two or three later when the rains rejoin the pools to the river or force the growing fish from the remaining waterholes in the river bed the fish head to sea to spawn. The estuaries are the gateway to and from the sea and here most of the barramundi is caught. The barramundi is an inshore fish seldom seen out in reef waters. But species of mullet which also enter rivers and are caught in the estuaries at times may cruise far out among the reefs. They are not very obvious but shore-line traps and set nets can catch them from time to time.

But by and large there is not much interchange between the estuaries and the reefs. A few species of sweetlip do make their way into the lower estuaries but generally reef fish are expected only on the reefs and the estuarine fish — barramundi, threadfins (Burnett salmon), whiting and others are a rarity around the reefs.

It is the reef fish that attract public recognition but some 400 000 kg of fish are marketed each year from the estuaries and nearby mainland beaches in Barrier Reef waters.

The contrast between the estuaries and the reefs is tremendous. Mud is the dominant substance in the estuaries — mud in the water lifted by tide or river currents, mud on the banks and on the stones. The worms and the shellfish on which the fish feed can only be those that can live in muddy waters or muddy fathoms. The experts can tell you that they are quite different species from the rather similar worms and shellfish you can find on the reefs.

The reef waters are clear and support a far greater variety of animal and plant life, but they are some way off; it takes boats and fine weather and the expenditure of money on fuel and food to go there. But the estuaries are close-by the towns of the Queensland coast and provide sport and food to the keen fisherman without any great expenditure of time and money in travel.

The estuaries are the sites of the Queensland ports — with growing tonnages of shipping, and where there are ships there are always dangers of pollution: carelessly discharged oil from bilges or tanks, deliberately thrown out garbage and so on. Few ports are very elegant gateways to estuaries. The tide carries the carelessly dumped flotsam from ship or town upstream or down to the sea where it is cast upon the beaches or tangles in the mangrove thickets.

The mangrove thickets are the most obvious difference between tropical rivers and those of the cooler southern parts of Australia. It is true that two species of mangrove extend down to Botany Bay and one species is a relict survivor of warmer times in South Australia, but in the tropics there are two dozen or so species of trees and shrubs in the mangrove forest, which may be from a few metres to 3 Km wide from open water to the solid shore.

It has been claimed that per acre a mangrove swamp is the best primary producer in the world. The mangroves shelter their own special fauna and flora — a host of crabs, including the ludicrous semaphore-crabs and the pop-eyed mud-skippers — fish that hop over the mud and live in burrows. But also during high tide, when the plant-rich mud between the strong aerial roots of the trees is covered by water, fishes large and small forage in their larder and retreat to deeper channels when the tide begins to drop. Some of the mangrove areas such as those around the Hinchinbrook Channel are very large indeed.

Here is the last refuge of the large freshwater crocodile of Australia — it has been ruthlessly hunted in the rivers of northern Australia but a reasonable population survives in the tropical east coast mangroves.

Another disappearing animal that survives in the remote corners of estuaries and bays is the dugong or sea-cow, which feeds on sea-grass growing in shallow waters. Once hunted ruthlessly, this animal is now strictly protected except that under Queensland law the Aborigines can hunt them.

The zoogeographers can distinguish between the animals and plants of the reef and those of the mainland shores. Nevertheless there are numbers of species that occur in both habitats, and there is some movement between the two zoogeographic provinces. But most important of all, the estuaries are a drainage system for the land behind and discharge both fertilisers and pollutant materials into reef waters. At present these influences are slight; their future influence depends upon Man's wise use of the land.

The Great Barrier Reef VI: Coral reef ecology

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temperature range, wave action, depth and food. It was of course expected that such differences would occur, as they do on land, but the degree of difference between adjacent areas and the rigorousness of the limits of restricted species are quite astounding. A species which is abundant and may be present in hundreds in one coral area will not be found even as stray individuals 90 metres away in a different set of conditions. Other species range far, and a few are cosmopolitan to the different areas on a typical coral reef.

Oxygen experiments would suggest that the lagoon species, particularly of fishes and crustacea, may be more resistant to fluctuations in oxygen tension and to low oxygen tension than those of the outer reef slopes.

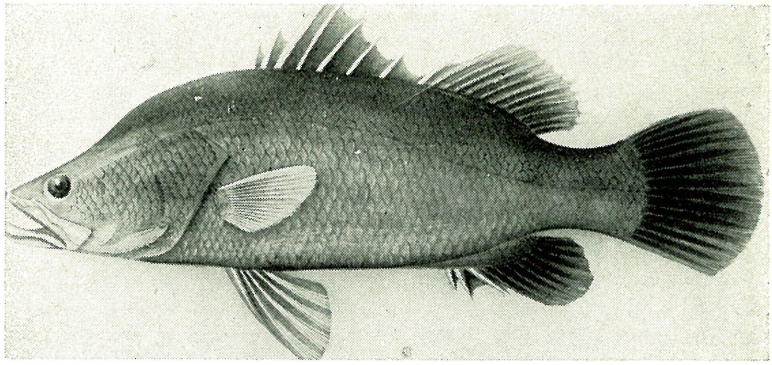
Future research

Understanding of coral reefs as functioning systems is at its very beginning. Much work by biologists, chemists, geologists and others is needed before a sound framework of information will be available.

Questions are being asked about the effect of oil pollution on coral reefs, but there is not sufficient information on this subject to give accurate answers, although some work is now being done.

Perhaps the only advice a coral reef biologist can give is to suggest great caution in dealing with such a complex, interesting but ill-understood system.

The reef systems provide little protection to the Queensland shore-line except in the region north of Cooktown. In most areas they are too dispersed to provide an effective barrier to oceanic wave trains, and in the south they are so far from the land that strong winds can generate heavy seas on their leeward side. The Queensland shore-line finds its main protection in the great width of the shelf rather than in the reefs that are dispersed across it. Without its reefs Queensland would be no more vulnerable to marine erosion than is the rest of eastern Australia. Reefs themselves provide localised areas of protected water where large aprons of sediment may form. These sediment banks provide the elevated foundations favoured by reef organisms and inevitably are colonised to form reef extensions or possibly new reefs.



Giant perch or barramundi *(Lates calcarifer)* found in the sea, brackish and freshwater streams of Queensland north of and including the Mary River at Maryborough.

The Great Barrier Reef V: Tropical rain forest

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buttresses, etc.), and which can be filled in by botanically untrained personnel, can produce a general forest classification which is not inferior to that using species composition. This method offers great advantages in tropical countries where the flora is little known and where it is of extreme urgency to classify forest types as a basis for land use, including the reservation of representative areas as national parks. Studies of succession, i.e. progressive regrowth on cleared and disturbed rain forest sites, have traced the development of the forest canopy, and suggest answers to long-standing problems about the mechanism of regeneration and seedling survival.

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