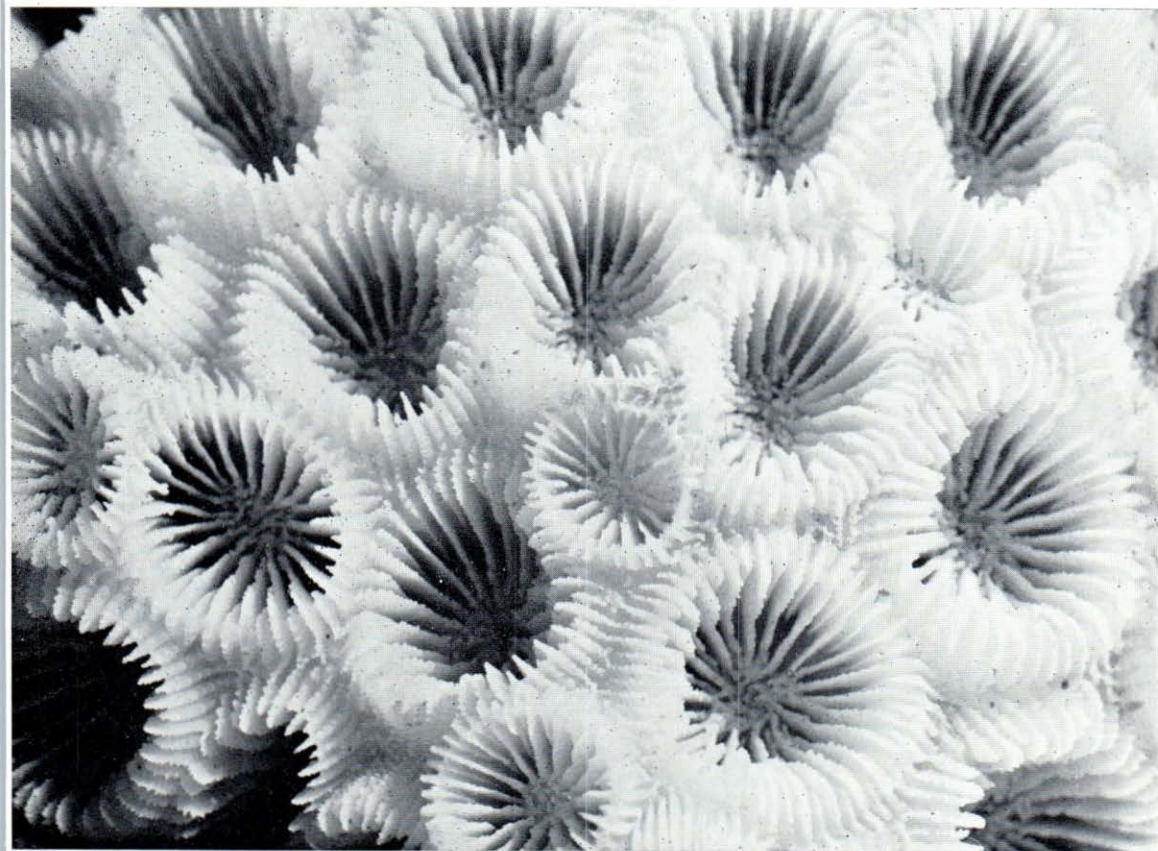


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This special issue is devoted to the natural history of the Great Barrier Reef of Australia. It contains eight extra pages.

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● **FRONT COVER:** These white corallite cups, each formed by an individual polyp of the colonial stony coral or scleractinian, *Plesiastrea versipora*, typify the living animal origin of the Great Barrier Reef. The radiating calcareous ridges in each of these quarter-inch-diameter corallites supported, in life, the tissue of the coral polyp. In all true scleractinians, the characteristic colours of the corals are confined entirely to this living tissue and disappear once the corals are removed from the sea and the polyp flesh has died and decayed. [Photo: Anthony Healy.]

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## ***INTRODUCTION TO THE GREAT BARRIER REEF***

By C. M. YONGE

Research Fellow, Department of Zoology, The University, Glasgow, Scotland

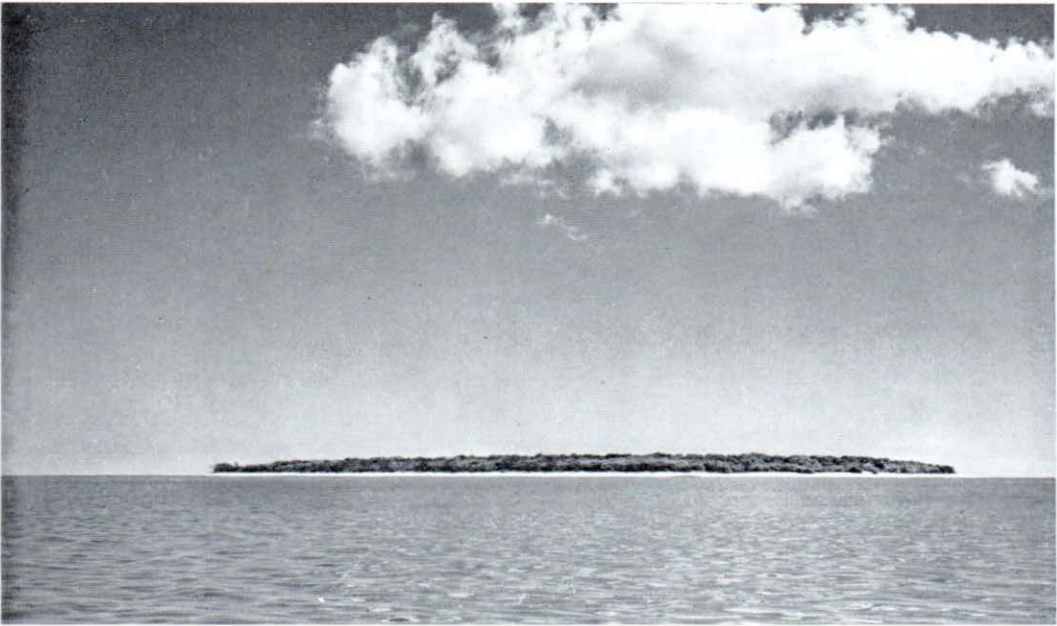
I have been asked to write about the Great Barrier Reef in general introduction to this issue of *Australian Natural History*. I do so with some nostalgia. It is now 38 years since, at the age of 28, I led the Great Barrier Reef Expedition which worked for 13 months on Low Isles, some 7 miles off Port Douglas. What we did in the way of observation, experimentation and collection forms the subject matter of the six massive volumes of the Scientific Reports of the Great Barrier Reef Expedition published (and still in final residue, being published) by the British Museum (Natural History).

It was from the sand cay on Low Isles, only some four very densely populated acres when the tide was in, that we surveyed the largest of all coral formations. Of necessity our sights were set on adjacent reefs and we could only form a very general idea about the bewildering complex of reefs stretching from the Capricorns almost to the shores of New Guinea and in places up to 50 miles wide. I did see, during the course of the expedition, something of the reefs in the Torres Strait as far eastward as the Murray Isles and, on

the homeward journey, visited Heron Island and other reefs in the Capricorns, and what I saw in these regions helped to fill in the picture. But our major concern was with adjacent reefs from Cooks Passage in the north to Trinity Opening opposite Cairns. Above all we were preoccupied with Low Isles Reef, an admirable headquarters that had been chosen by the Great Barrier Reef Committee at Brisbane, which was at that time under the vigorous chairmanship of H. C. Richards, Professor of Geology in the University of Queensland.

### **Influence of winds**

At Low Isles we lived on a manageable coral formation which lay in the middle of the steamer channel between the mainland to the east and Batt Reef, the innermost of barrier reefs in this region, to the west. From unknown beginnings this small coral formation had established itself in these relatively sheltered waters. Although the South-east Trades blowing unceasingly for nine months in the year could only raise moderate seas in the restricted waters within



North-west Island, a typical vegetated "low island" sand cay situated in the Capricorn Group of the southern Great Barrier Reef. Such cays are formed by the accumulation of coral and debris at the leeward end of the roughly circular, sheltered coral reefs growing on extensive limestone banks within the Great Barrier Reef system. Wind-borne and sea-borne seeds and others brought by birds give rise to the characteristic vegetation of such cays—pale-trunked *Pisonia* trees (*Heimerliodendron*) up to 40 feet high, low-spreading *Tournefortia* trees (*Messerschmidia*), buttressed *Pandanus* palms, and the graceful, drooping *Casuarina* beach-oaks. [Photo: Keith Gillett.]

the shelter of the Barrier, nevertheless their influence was supreme in the moulding of the reef. Widely exposed at low water of spring tides, the reef surface was surmounted by the sand key on which we lived and by a considerably larger, but quite uninhabitable, mangrove island.

We came to know Low Isles Reef intimately. It contained an amazing diversity, being different on weather and lee sides and different again on the upper surface and on and around the two islands. Towards the south-east it faced the trade winds with a steeply sloping and unbroken convex front. The normally sheltered northern surface contained a shallow embayment which formed the usual anchorage for our vessels. Here the submarine slope was much more gentle. We had here the clearest demonstration—and we had no previous experience of reefs—of the manner in which corals and the associated animals and calcareous plants which form the reef mass are moulded by the forces of wind and sea

against which the reef reacts by vigorous growth.

#### Secret of success

This, indeed, is the fundamental secret of reef success. The more rigorous the weather the greater the reaction of the reef against it. From these wind-driven seas the corals obtain food in the form of minute planktonic animals. These waters are also exceptionally clear, so that light penetrates deeply for the benefit of the microscopic brown plant cells—the so-called zooxanthellae—which occur in countless millions within the tissues of all reef-building corals. Their study was one of my major personal responsibilities during the expedition and I concluded that, though of no food value, they yet gave major assistance to coral growth by acting as automatic organs of excretion—removing, for their own use, the waste products formed in the tissues of the corals. This may well be partly true. However, of recent years Dr Tom Goreau, of the University of the

West Indies at Jamaica, using modern methods involving radio-active tracers, has shown that the plant cells actively assist the coral in the formation of the limy skeleton. So the clearer the water the faster the corals will grow outward against wind and weather.

On these exposed surfaces the common corals were often rounded and massive but on the sheltered side their place was largely taken by stagshorn or by other branching and foliaceous types of coral. These corals grew in profusion under no constraint by the forces of wind and sea. Such sheltered regions yield most to the modern aqualung diver: we viewed them from within diving helmets, breathing air pumped from above. Their deep crevices and extensive overhangs provide homes for innumerable types of coral fish, each vying with its neighbour in originality of form and vividness of colour.

But this profusion of coral growth in the lee of the reef courts destruction, particularly in the cyclone belt, in which the greater part of the barrier reefs lie. The south-eastern shores of Low Isles Reef were bounded above low-water level by high ramparts of closely interlocking coral fragments, all that the constant beating of the sea could break away from the firmly growing coral colonies. But the edge of the sheltered northern side of the reef surface was marked by a formidable line of great boulders representing masses of coral which had grown up below tidal levels and had been thrown on to the surface of the reef during one of the occasional, but devastatingly powerful, cyclonic storms during the summer months.

### **Many problems**

On the exposed reef surface or reef flat—part sand, part coral rock, part pools containing living coral and many other plants and animals when the tide was out—we found problems enough to occupy generations of biologists. Life is prolific of species in the tropics, and the reef, on weather side, lee and surface, presented all manner of environments, for life in which different species had become fitted.

During the year we spent on Low Isles, we studied this microcosm in all the detail we could. This included study of the surrounding sea and of the contained planktonic animals which are the food of

corals. Gradually we built up a mental picture of the continual interplay between the growth of corals and other reef builders and the physical forces of the sea out of which, paradoxically, lime is extracted to form the resisting skeletons. Other forces had also to be resisted: the effect of exposure to the air during low tides and the constant action of many animals, and even plants, which bore into coral limestone for shelter and even for food.

Translating this microcosm into the macrocosm of the Great Barrier in all its immensity was less easy. Arising probably on a wide continental shelf, the most seaward reefs are the lowest. They are fully exposed to the greatest surf in the world, the product of rollers generated by winds blowing across the full width of the Pacific. Their upper surfaces, consolidated where the surf breaks by calcareous plants so that they are as firm as a paved highway, are only briefly exposed at the lowest spring tides. Seaward the bottom drops away almost at once to depths of hundreds and then thousands of fathoms. Within the shelter of these outermost reefs there is an intricate maze of inner barrier reefs through which one navigates in a small vessel by following the channels of blue water that wind between the wide expanses of green or yellow denoting shallow water over reefs. Much of this region, "reported full of coral patches", has never been surveyed. Owing to the greater shelter these reefs grow somewhat higher and may be widely exposed at low water of spring tides. On such occasions we could walk for miles over the flat expanse of Batt Reef.

### **Innermost reefs**

The innermost of these reefs have sand cays on the lee. Built up of coral fragments and sand, these little islands maintain themselves even during northerly gales in the summer by a surrounding buttress of beach rock representing layers of sand which have become consolidated around low-water level by processes still imperfectly understood. The islands are covered with little more than coarse grass with the ubiquitous convolvulus along the strand line. Like Michaelmas Cay opposite Cairns, they may be the scene of intense and raucous activity during the breeding season of Sooty and Noddy Terns.

The sand cay on Low Isles, in still more sheltered waters, is higher and more variously vegetated with trees and shrubs. The mangrove island is a consequence both of the greater height and of the proximity to land. The mangroves have become established in the shelter of the ramparts of coral fragments thrown up along the weather side of the reef, the seedlings having probably originally drifted there from the extensive mangrove swamp at the mouth of the Daintree River some 10 miles away. Further offshore the force of the sea is too great for coral ramparts to form. In the Gulf of Mexico I have seen the abortive efforts of mangroves to establish themselves in the absence of such protection. The mangroves on Low Isles, and on a few similar reef formations further north on the steamer channel, formed an almost impenetrable growth and carried an associated animal and plant population totally distinct from that of the reef or the sand cay.

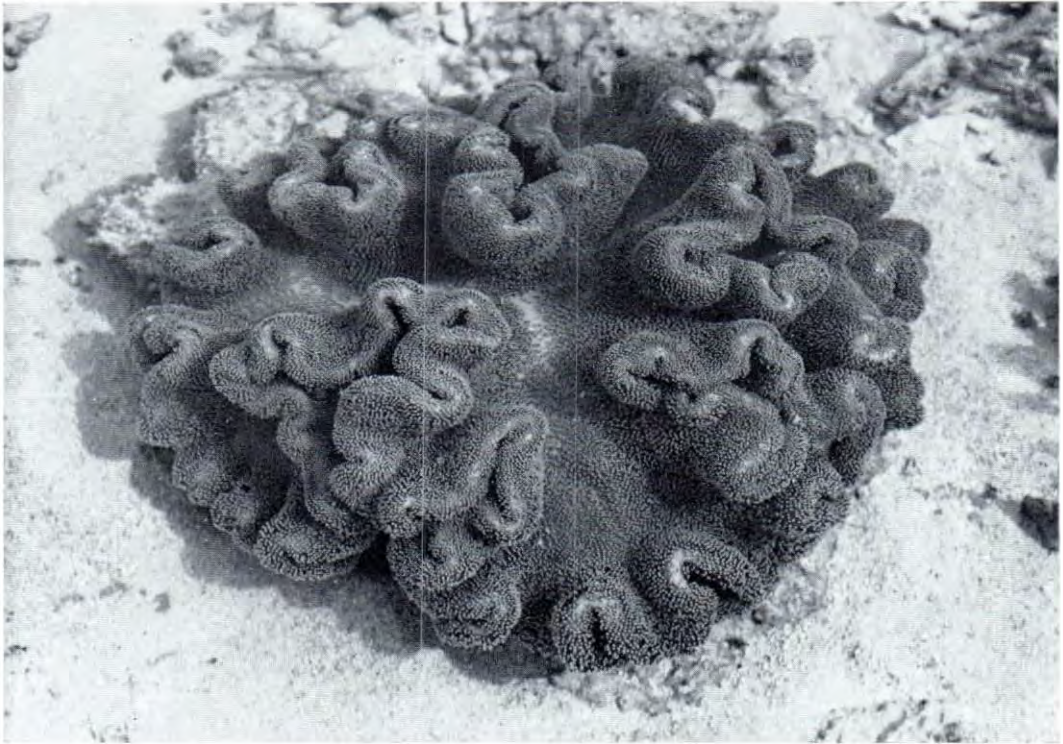
Completion of the story, from outermost barrier reefs westward, brings us to the coast, which is here frequently bordered by typical fringing reefs, platforms of coral growing seaward from the shore and found the world over along suitable tropical shores.

### Starfish depredations

Details of reef topography will now be far better known than they were 40 years ago. Many aeroplanes must have flown the length of the Great Barrier and innumerable photographs been taken. But the great mass of the reefs must always remain inviolate because even their upper surfaces are so infrequently and so briefly exposed. Even at this distance from Australia one hears of the inevitable effect of tourist activity on those regions which are accessible, but these are only a minute fraction of the whole. What might possibly prove a greater menace is the recent spread of the large red spiny starfish, *Acanthaster planci*, which

moves remorsefully over coral colonies digesting the living polyps. Although a single specimen is reported as having been taken by the expedition at Low Isles, I do not remember seeing it and certainly this starfish must then have been very rare. Once seen it is unmistakable, as I discovered early last year when I observed its devastating effects on coral colonies off the coast of North Borneo. Obviously this starfish must have increased greatly in numbers during recent years. Perhaps it is surprising that it did not do so earlier; it has an unlimited food supply and is so well protected by a covering of long, extremely sharp spines that it is hard to see how it can be effectively attacked.

Maintenance of a reef depends, as we have seen, on the establishment of an unbroken front which advances steadily against the forces of wind and sea. Destruction of any part of this outer surface could well endanger the whole, and the attacks of this great starfish might cause such a breach. This could have devastating effects. However, such scourges often carry the seeds of their own eventual control and it could well be that this starfish has waxed and waned in numbers over the centuries. It was at a low ebb 40 years ago, it may now be increasing to a maximum. There is nothing stable in the sea; the longer our records continue the greater evidence we get of perpetual change, of constant ebb and flow. Following the 13 months we spent upon it, Low Isles Reef became the most thoroughly studied coral area in the world. It has since been restudied at least three times and new maps have been prepared showing changes due to cyclones and to the passage of new ramparts over its surface. The longer such studies can continue the more we shall learn about the formation and maintenance of reefs and the greater light will be thrown on the immense problem of the Great Barrier Reef. This is essentially a living thing; were the corals killed the vast reefs they have formed would rapidly be destroyed.



# ***SOME STRIKING INHABITANTS OF THE REEF***

By J. C. YALDWYN

Curator of Crustacea and Coelenterates, Australian Museum

On this and the next four pages is shown a selection of Great Barrier Reef animals that are of particular interest either because of their striking appearance or their remarkable way of life.

## **ALCYONARIAN SOFT CORALS**

The photo above shows a single colony, several feet across, of the alcyonarian soft coral *Sarcophyton*, in shallow water within the lagoon system at Heron Island in the Capricorn Group. The convoluted surface is yellowish-green, and when submerged is clothed with a mass of dark-green expanded polyps as shown in the photo. The polyps of soft corals typically have eight pinnate, or "feathered," tentacles in contradistinction to the multitentacled (often in multiples of six) equivalent in the true stony corals (scleractinians). Even the softest of the alcyonarians has an unsuspected and abundant

scattering of complexly-shaped, calcareous spicules within its tissues, and it is this skeleton that betrays the close relationship of the alcyonarians to the scleractinians. Related to these large, fleshy, soft corals is a whole range of other reef alcyonarians with quite firm, or even massive, skeletons, which characteristically retain their colour when dead and bleached. Well known examples are the arborescent sea fans, such as red, orange or yellow forms of *Mopsella* and the black coral *Antipathes*; the organ-pipe coral, *Tubipora*, with its bright-red lamellated pipe stacks, and the blue coral, *Heliopora*, where the skeletal colour is most strongly displayed in a broken specimen. The characteristic colours of alcyonarian skeletons, contrasting so strongly with the pure white of cleaned "true" corals, are due to various complex iron salts bound into the predominantly calcium carbonate structure. [Photo: Keith Gillett.]

## BANDED MAGIC CARPET WORM

The brilliantly-coloured polyclad flatworm shown below is one of the freeliving "magic carpet" turbellarians found widely throughout the warmer waters of the Indo-Pacific area. Its name, *Pseudoceros corallophilus*, refers not only to its coral reef habitat, but to the characteristic horn-like, tentacular flaps at the anterior end of the body.



The 1½-inch-long example shown here was photographed on Heron Island at the southern end of the Great Barrier Reef. In life, the opaque, wafer-thin body is basically creamy-white, with a border and narrow central stripe of pure white. The vividly-contrasting marginal bands are a rich orange-brown and an intense black, with an extreme outer edging of bright yellow. The marine turbellarians are carnivorous, ventrally-mouthed flatworms which normally move with a sinuous gliding motion throwing the edge of the body into a series of small folds, but are capable of swimming with the graceful, undulating movements suggested by their common name of Magic Carpet Worms. [Photo: Anthony Healy, Australian Museum Swain Reefs Expedition, October, 1962.]

## PLUMED TUBE WORM

One of the many beautiful tube worms of the Barrier Reef waters is shown, in the next column, with its half-inch-diameter crown of spirally arranged gill plumes projecting from the mouth of its firm limy tube. These creamy white plumes form a complex breathing and food catching apparatus which can be rapidly withdrawn into the tube at

the least sign of danger or disturbance. This serpulid worm, photographed at Heron Island in the Capricorn Group, is one of the polychaete annelid worms which are characterized by a rounded segmented body and a series of bristles, or setae, projecting through the skin. Other reef polychaetes include the sabellid or feather-duster worms in their sand grain or parchment tubes, and the freeliving bristle worms such as the stinging *Eurythoe* and its allies. [Photo: Keith Gillett.]



## OPPOSITE

### VOLUTE SHELLS

Volute shells of the genus *Cymbiolacca*, from Queensland waters, are shown on the next page. The shells illustrated are typical of the localized populations found in restricted areas. They vary in details of size, shape, colour and pattern, and are difficult to classify. Like most Volute, they spend much of their time buried under the sand in coral reef lagoons or in the deeper waters between reefs. They emerge from time to time to hunt for their prey, which usually consists of bivalves and other molluscs. The localities from which the shells illustrated come, and the names which have been given some of them, are as follows, commencing from the top row, left to right: *Cymbiolacca wisemani* (Brazier), Michaelmas Cay Lagoon, off Cairns. *Cymbiolacca* sp. ?, lagoons of reefs off Mourilyan Harbour, near Innisfail. *Cymbiolacca craxenta* McMichael, 17 fathoms off Townsville. *Cymbiolacca peristicta* McMichael, Big Sandy Cay Lagoon, Swain Reefs. *Cymbiolacca pulchra* (Sowerby), Heron Island Lagoon, off Gladstone. *Cymbiolacca pulchra* (Sowerby), Fairfax Island Lagoon, off Gladstone. *Cymbiolacca pulchra* (Sowerby), South Keppel Island, off Yeppoon. *Cymbiolacca complexa nielsenii* McMichael, Hervey Bay, off Bundaberg. *Cymbiolacca complexa complexa* (Iredale), trawled off Southport. [Photos: Howard Hughes and C. V. Turner.]







#### STRIPED AND COLOURED SEA-SLUGS

The delicate sea-slugs, or nudibranchs, one of which is shown above, provide an unexpected, and often striking, splash of colour both on coral reefs and in more temperate Australian waters. These shell-less molluscs have an elongated slug-like body with a pair of tentacles, or rhinophores, on the head, and a set of branched and "naked" gills (from which their general name "nudibranch" is derived) projecting from the upper surface near the hinder end of the body. *Chromodoris quadricolor*, illustrated here from Heron Island, has a blue-black body marked with two irregular sets of concentric, narrow, white stripes, set off with rhinophores, gills and the outer margin of the body in deep orange. [Photo: Anthony Healy, Australian Museum Swain Reefs Expedition, October, 1962.]

#### RED AND WHITE-SPOTTED HERMIT CRAB

The brilliantly-coloured *Dardanus megistos* (below) is the largest and most spectacular hermit crab known in the whole area of the Barrier Reef. Many examples grow to a length of 8 inches or more, including the powerful anterior legs and nippers. The colour is a rich orange-red becoming a true red on the soft abdomen or "tail". The body has an overall scattered pattern of very distinct white spots, black-ringed on the carapace and legs, but tending not to be so ringed on the abdomen. *D. megistos* is one of the few hermit crabs, or pagurids, to be pigmented over the whole body surface



including the abdomen and reduced abdominal appendages. Most pagurids lack colour pattern, or even surface pigment of any kind, on the asymmetrically-twisted hinder end of the body normally retained within the mollusc shell characteristically occupied by these animals. The red and white-spotted *Dardanus* has a wide distribution in the tropical and temperate Indo-Pacific, ranging from eastern Africa and the Red Sea in the west to Hawaii and Tahiti in the east, and from Japan in the north to Australia in the south. On the east coast of Australia it extends well down into temperate New South Wales. The illustrated specimen came from Gillett Cay in the southern Barrier Reef. [Photo: Anthony Healy, Australian Museum Swain Reefs Expedition, October, 1962.]

#### RETICULATED CORAL CRAB

The xanthid crab, *Trapezia areolata*, shown on the next page, was found living commensally among the branches of *Pocillopora*-type corals, and was photographed on Gillett Cay in the southern Barrier Reef. Its reticulated pattern of red on a white background is not unlike the colour pattern on the surface of these corals, formed by the pink, circular, regularly-spaced, living polyps against the pale connecting flesh of the finger-like branches. The walking legs and the palms of the hands of the crab are pale yellow. Several other species of *Trapezia*, including the uniform reddish-brown *T. cymodoce*, are found associated with true stony porcelliporid corals, while the rather similar coral crab, *Tetralia*, appears to be exclusively associated with living acroporid corals. Of the latter genus, *T. glaberrima*, with its beautiful, porcelain-like, pale pinkish-blue



body and dark frontal band, is the best known species. Crabs of these two groups, up to three-quarters of an inch in body width, do not appear to harm or modify their host corals in any way and can not be regarded as parasitic. They are in fact true commensals, appearing to share both the shelter of the living corals and presumably the minute food caught by the host corals themselves. [Photo: Anthony Healy, Australian Museum Swain Reefs Expedition, October, 1962.]

#### SEA ZEBRA

*Hippocampus zebra* (next column) is a strikingly patterned sea-horse with alternating zebra-like stripes of white and dark brown-black. The eyes are blue and there are yellow areas around them, under the chin and along the belly. Though closely related to other species of *Hippocampus* from Queensland, northern Australia and Malaysia, this rare fish is probably the most unusually coloured of all the sea-horses, and is, as yet, known from only two specimens. The one illustrated here, with an overall length of a little under  $3\frac{1}{2}$  inches, was dredged in 38 fathoms off Gillett Cay in the southern Barrier Reef. Sea-horses belong to the family Syngnathidae, or fused-jaw fishes, and, with their relatives the sea-dragons and pipefishes, usually live in, or associated with, seaweeds and other marine growths. They normally feed on small crustaceans from the surface of the weed (in aquariums they feed on brine shrimps), and the male is provided with an abdominal brood pouch into which the female transfers her eggs for paternal care and protection. After a period of about a month the fully developed young are expelled from the pouch to fend for themselves. It can be assumed that the elusive sea zebra has similar habits. [Photo: Anthony Healy, Australian Museum Swain Reefs Expedition, October, 1962.]



#### SEMINAR AT MUSEUM

A seminar on "The Role of Museums in Education" was held at the Australian Museum from 26th to 29th September. Besides museums and art galleries, many other organizations were represented, including the Australian College of Education, the National Trust and the Australian National University. Special visitors were Mr T. A. Hume, Director of the City of Liverpool Museums, England, and Dr R. C. Cooper, Auckland Institute and Museum, New Zealand. The seminar was sponsored by the Australian National Advisory Committee for UNESCO; its purpose was to provide an opportunity for discussion on the present and future role of museums in education and to demonstrate to educational authorities at all levels the contribution which museums can make to educational programmes.

#### PROTECTION OF ABORIGINAL RELICS

The Curator of Anthropology at the Australian Museum, Mr D. R. Moore, has been appointed to a new committee set up by the New South Wales Minister for Lands to investigate and report on what action should be taken for the preservation and protection of Aboriginal relics and sites throughout the State.



The bright green filamentous alga *Chlorodesmis comosa*, known on the Reef as Turtle Weed, is widely reported as being used as food by turtles. Also seen in this photo from Heron Island is the small portunid crab *Caphyra rotundifrons*, habitually associated with these algal clumps. A protective pattern of irregular green lines across the crab's carapace and legs matches the weed. [Photo: Harold G. Cogger.]

## ***SEAWEEDS SPARSE BUT INTERESTING***

By A. B. CRIBB

Senior Lecturer in Botany, University of Queensland, Brisbane

ONE of the things which probably strike a naturalist on his first visit to the Great Barrier Reef is the apparent scarcity of seaweeds—such a marked contrast to the Reef's superabundance of animal life both in quantity and variety. Actually, quite a large number of algal species are present, though the majority are small and inconspicuous, many of them forming a nondescript fur over dead coral, causing a darkening of the beach rock, or even penetrating dead coral and shells, to which they impart a blue-grey colour.

Part of the reason for the sparseness of algal cover probably lies in the fact that some Reef fish are vegetarians, and their browsing keeps the sward of algae low. This has been shown to be the case on some coral reefs, and it has even been suggested that the poisonous nature of some coral reef fish may be due to the particular algae they ingest, though the case against algae here does not seem to be satisfactorily proved. But there are certainly several other factors concerned with the sparseness of algal vegetation, one being that macroscopic algae

Three common tropical algae attached to a small coral fragment at Darwin, Northern Territory. A red, slender and branched seaweed, *Galaxaura*, is at the bottom left of the clump; the bright-green *Halimeda*, with cactus-shaped sections joined to form its characteristic thallus, is in the centre, and at right the brown fan-shaped *Padina australis* can be distinguished from *Halimeda* by the concentric lines marking its curled fronds. *Padina* is probably the commonest brown alga in Reef pools. [Photo: Elizabeth C. Pope.]



don't seem to become established on living coral, so that, in general, where coral growth is richest algae are sparsest.

### Handsome species

Although the seaweeds must therefore take second place to the animals in the eyes of most visitors, there are a few species which cannot fail to be noticed, and even admired. One of the most striking is *Chlorodesmis comosa*, which forms dense tufts of green filaments with a quite remarkable brilliance. Belonging to the same major group, the green algae, are the species of *Halimeda* and *Caulerpa*, both characteristic plants of coral reefs. *Halimeda* is easily recognized, with its branched chains of disc-like segments: two of the commonest species are *H. opuntia*, forming dense grey-green clumps of irregular segments, usually rather rigid because of heavy calcification, and *H. discoidea*, which has brighter green and less rigid segments. The *Caulerpas* all have a creeping part which at intervals sends up green branches with an amazing variety of form. Some, like *Caulerpa cupressoides*, with its vaguely cypress-like branches, spread over the sandy floor of the reef flat, but most grow over dead coral. One of the commonest of these is *C. racemosa*, with its erect branches like little clusters of small green grapes. This alga has been a minor source of food in some areas, and its turgid "grapes" have a pleasant salty tang. An unusual green alga,

often overlooked because it nestles in coral crevices or is attached to the under surface of coral boulders, is *Valonia ventricosa*, a dark blue-green, egg-like structure, often with a metallic sheen and occasionally as big as an inch diameter. Most of this structure is a single cell containing a large quantity of watery cell sap which is ejected like a jet from a water-pistol if the vesicle is punctured. The heavy, irregular, spongy, green lumps often seen as drift on the beach are another green alga, *Codium spongiosum*.

### Brown algae

The group known as the brown algae provide the giants among seaweeds in cold waters, but the largest on the Great Barrier Reef are mostly not over a couple of feet in length. These are usually the species of *Sargassum*, many of which bear some resemblance to land plants, with their branched stems and leaf-like appendages. The small pea-like floats detached from *Sargassum* often form thin lines on the beach, marking the upper limit of the wave surges. A related seaweed, very common in some parts of the Reef, is *Turbinaria ornata*, which has spiny, rigid, top-like branches closely spaced along its stem. These short branches are often hollow and buoy up the plant, so that, as the water level falls on the outgoing tide, the domed tips of the plants are amongst the first algae to appear above the surface.

The fan-shaped *Padina gymnospora* and *Pocockiella variegata* (distinguishable from each other by the inrolled margin of the former) and the tangled, cushion-like clumps of *Chnoospora implexa* are amongst the brown algae often common on the landward part of the reef flats, where the proportion of dead to living coral is high. Somewhat tar-like encrustations on dead coral, protruding slightly above the general upper level of the coral, are formed by the brown alga *Ralfsia*.

### Red algae

Members of the large group known as red algae which, particularly on the Great Barrier Reef, often don't appear red at all, play an important part in the fur that covers dead coral and in the inconspicuous mat of algae often found near the outer edge of the Reef in the general area of the negro heads. The beautiful, large, membranous forms common in cold waters are, however, virtually absent on the Great Barrier Reef, though sometimes on the under side of coral boulders there may be a few small, attractive and obviously pink or red forms. Amongst the red algae the most important from the point of view of reef structure are those with a high degree of calcification. Some of these, with erect staghorn-like branches, produce small coral-like clumps, but the majority form a stony, pink encrustation over dead coral. The members of this encrusting group are often difficult to identify and may be grouped together under the generalized term lithothamnia. These plants are particularly well developed at the outer edge of the Reef, where they play an important part in consolidating the structure and resisting the pounding of the surf.

### Unlimited scope for study

Scope for study of the seaweeds of the Great Barrier Reef is still virtually unlimited. Besides the basic problems of systematics and ecology, there are the fascinating problems of the association between various algae and animals. Sometimes the relation between the two may be fairly simple, perhaps just a case of the alga being a source of food for the animal; or the alga may



A somewhat stunted example of the distinctive common brown alga *Turbinaria ornata*, generally found on parts of the Reef where *Palythoa* zoanthid anemones occur. The distinctive pectop-shaped side branches are inflated and serve to buoy the plants up in the water while numerous root-like holdfast branches anchor it firmly to the bottom. Certain corals with a similar epergne-like shape are also called *Turbinaria*. [Photo: C. V. Turner.]

provide shelter, as seems to be the case with the well-camouflaged crabs associated with *Halimeda* or the prawns which live in a web of blue-green algal filaments. Then there are the more complex and intimate associations of sponges and algae, the composite body often having the general appearance of the animal partner. Finally, there are the highly complex associations in which unicellular algae live actually within the tissues of corals and clams. In fact it looks as though, for a long time now, problems will appear far more quickly than they can be solved.

# GEOLOGICAL QUESTIONS POSED BY THE REEF

By O. A. JONES

Chairman of the Great Barrier Reef Committee

LOOKING at a map of Queensland, with its 1,000 miles of coral-girt shoreline, a geologist asks himself why is all that coral there? In what geological age did these reefs first appear? What is the vertical thickness of the coral? Of what kind of rocks and of what age is the foundation on which the reefs rest?

Seeking an answer to these questions he must study:

(1) The geology and geomorphology of that part of the Queensland coast which lies opposite the reefs, i.e., between latitudes 10° S. and 24° S., and

(2) The geology of the continental islands which lie between the reefs and the coast, both of which studies bear on

(3) The origin, nature and history of the platform on which the reefs are built, which in turn involves

(4) Such movements of sea-level relative to the land as have occurred since the growth of the reefs began.

Between latitudes 10° and 24° S. rocks of almost all geological periods except Cambrian to Devonian (from 600 to 400 million years ago), together with many large granitic masses, are found along the coastline, but marine rocks of Cainozoic age (dating from 70 million years ago to the present) are notable by their absence.

All physiographic and geological studies show that, as geographer Steers wrote after spending some months along its length, "the Queensland coast is a typical drowned coast. Throughout its entire length there are numerous deep embayments which are only partially filled with river alluvium. Only the Burdekin has made a delta which forms an excrescence on the coast. All the other streams have not yet had time to fill up the embayments into which they flow. Looked at on a big scale the coast is steep to. The hills plunge straight down into the

lagoon. Where flat low-lying areas fringe the shore they are all of recent alluvial materials."

W. H. Bryan has set out evidence that during the Palaeozoic (which lasted from 600 to 220 million years ago) and Mesozoic (which began 220 million years ago and ended 70 million years ago) the Australian continent stretched far to the eastward to include New Zealand and Fiji and that this easterly extension began to be dismembered in early Tertiary times (about 70 million years ago). But although there is evidence that this land mass of 80 and more million years ago has provided the "basement" rocks of the continental shelf, we are more concerned here with the more recent movements which have affected the coastal regions and with the sediments which, on the shelf, mantle much of these "basement" rocks.

## "Faulted coast" theory

Often it has been postulated (David, Andrews, Sussmilch and others) that the eastern coastline of Queensland is a faulted coast with a considerable downthrow to the east. Whitehouse considers "this hardly likely. The coastline and the structures on either side of it (the island festoons to the east and the scarped uplands to the west) are all part of the one topographic plan in which the significant orogenic features are gentle, monstrous 'ripples', convex to the east, denuded along the tensional cracks of the structures. Faulting of about Pliocene age (about 12 million years ago) definitely is evident in many regions (e.g., the horst of the Bartle Frere-Bellenden Ker Block and the long fault valley occupied by the Tully River and Hinchinbrook Channel) but is exceptional".

On this view the late Tertiary faulting is to some extent responsible for the cutting of the continental shelf and the drowning of its plains and valleys, but erosion during the

Pleistocene ice age and the rise in sea-level after that "deep-freeze" is mainly responsible.

Evidence of the drowning is to be found in the over-deepened lower courses of the major coastal rivers, such as the Brisbane and the Burdekin, in the great thickness of geologically recent sands in many of the present coastal plains (over 100 feet at Townsville) and in the nature of the continental or high islands, which from Gladstone northwards are numerous close to, and up to distances of 50 miles from, the coast (the Percy Islands south-east of Mackay). The continental islands are clearly high parts of the drowned land mass; the rocks found on these islands range in age from Precambrian to Cretaceous and include ancient schists and gneisses, stratified and welded tuffs, marbles and flat-lying sandstones, as well as granites, rhyolites and andesites. Similar rocks of all these types except the welded tuffs are known in the neighbouring coastal areas; like the coastline, the islands are deeply embayed and most drop steeply from considerable heights into the sea.

### Three bores sunk

Three bores have penetrated into the "platform" on which the reefs are built. Those on Michaelmas Cay (16° 36' S.) and Heron Island (23° 26' S.) were sunk by the Great Barrier Reef Committee and the third, on Wreck Island, seven miles north of Heron, was an oil exploration bore.

The Michaelmas Cay bore penetrated reef material to 476 feet, then quartz sands, in part glauconitic and containing shell fragments and foraminifera, to 600 feet, the bottom of the bore. The Heron Island bore revealed coralline material to 506 feet, then foraminiferal quartz sand with shell fragments to the bottom of the bore at 732 feet. The Wreck Island bore was drilled to 1,898 feet, penetrating reef material to 398 feet, marine Pleistocene (?) and Tertiary strata to 1,795 feet, where volcanic tuffs of uncertain age were encountered and continued to the bottom of the bore.

Data on the nature of the "platform" is thus scanty but the available evidence suggests that it consists of a seaward continuation of the rocks of the coast, overlain in places at least by marine Tertiary strata and by more recent little-consolidated marine sands. This "platform" shows in

places considerable above-water and under-water relief, for the continental islands rise to as much as 3,650 feet above sea-level (Mt Bowen, Hinchinbrook Island) and recent geophysical surveys have shown the existence of a deep narrow trench off the coast near Mackay.

Reef-building corals do not flourish in water more than 120–180 feet in depth. Even if coral growth began in this area at the maximum possible depth, say 150 feet, the Michaelmas Cay bore proved an *additional* thickness of coralline material of 326, that on Heron Island 356 and that on Wreck Island 248 feet.

The age at which the reefs were initiated is not known with certainty, although most authorities consider the whole thickness of coral-bearing material to be of Recent age. If this is the case, there must have been subsidence of the "platform" relative to sea-level of 326 feet at Michaelmas Cay, 356 at Heron Island and 248 at Wreck Island.

### Pleistocene origin possible

The possibility that the reefs originated in Pleistocene times should, however, be considered. During the Pleistocene the sea-level would have been, in the region being considered, 200–300 feet lower than at present, due to the locking up of water as ice in the polar ice-caps and their extensions. Thus the opportunity would have been provided for a "platform" to be cut by sea action, a "platform" from which the reefs could have grown up when the climate became warmer and the ice melted and sea-level gradually rose. An attractive hypothesis, but one not borne out by such evidence as we have.

But what of the sediments resting on the "platform" beneath the reef material, 124+ feet at Michaelmas Cay and 224+ feet at Heron Island? These consisted largely of incoherent sands with a few thin hard bands, and the whole thickness, in both bores, has been regarded as Recent (i.e., post-Pleistocene) in age. If this is so, then the total subsidence of the hard rocky "platform" during Recent times must have been at least 600 feet.

In sharp contrast, however, the 132 feet of quartz sandstone immediately beneath the coralline material in the Wreck Island bore has been determined, on the basis of contained foraminifera, as Pleistocene in age.



Perhaps, then, part of the Michaelmas Cay and Heron Island sediments are also Pleistocene, in which case a portion of the 600 feet of apparent subsidence would have been due to the rise of sea-level at the end of the Pleistocene ice age.

A revision of the forams from the cores of the two bores now nearing completion should throw light on this problem.

### Oil exploration

During the last few years considerable interest has been taken in the oil possibilities of the reef area and extensive geophysical work has been carried out. As more data

from this work becomes available, and especially if additional exploratory bores are drilled, our knowledge of the nature and history of the "platform" and of the deep, hidden parts of the reefs should increase rapidly.

Already it has been shown that in one area at least—the Capricorn Channel and nearby—the rocks of the "platform" may be of an age and kind not represented on the neighbouring mainland. The Wreck Island bore on the western margin of the Capricorn Channel penetrated (from 530 feet to 1,795 feet) 1,265 feet of limestone, calcarenite, sandstone and siltstone determined on its

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## PIONEER REEF PHOTOGRAPHER



The pioneer Barrier Reef photographer W. Saville-Kent taking vertical photos of tropical bêche-de-mer, or sea cucumbers, near Lizard Island, north of Cooktown, in the 1890's. With a relatively simply constructed camera, using a wide angle lens and sometimes mounted (as in this case) on a tetrapod, he was able to obtain a striking series of detailed plates of reef structure, living corals and other reef animals. These remarkable plates have set a standard of comparison for all modern reef photography. [Photo from the book *The Great Barrier Reef of Australia*, W. H. Allen & Co., 1893, by W. Saville-Kent.]

fossil content as marine Tertiary; the rock from 1,895 feet to the bottom of the hole at 1,898 feet was determined as volcanic breccia. Some geologists have thought this to be Cretaceous in age. More recent geophysical work in the Capricorn Channel itself is interpreted as showing volcanic flows interbedded in sediments. It is possible that the volcanic breccia of the Wreck Island bore is one of these flows, and that it, the volcanic flows and the sediments, about 8,000 feet in all, are of Tertiary age. It is this area of beds and the possibility of other similar areas which are of major interest to oil companies.

Coral reefs in general have an interest for petroleum geologists, for some of the Canadian oilfields are associated with fossil (ancient) coral reefs, the oil being in either the porous reef itself or in the contiguous disturbed strata. This, of course, leads to interest in the kind of sedimentation taking place now within and around modern reefs.

Maxwell, Jell and others have shown that the sediments forming in the lagoon and on the reef flat of Heron Reef have been derived mainly from the breakdown of calcareous algae, corals, molluscs and foraminifera. These sediments have been lithified to reef rock (algal-coral limestone) from a depth of about 17 feet downwards. The reef rock is for the most part covered by a veneer of sand or the living coral.

### Beach-rock

At the surface between high and low tide levels, a belt of beach-rock has been formed adjacent to much of the present beach of the island. The process of lithification which produces this beach-rock is not known with certainty, but it involves the precipitation of calcium carbonate between the sand grains, which are themselves calcium carbonate. The surface of the soft rock thus formed is coated with and hardened by algae. Beach-rock forms one of the main bulwarks against erosion and redistribution of the sand of many of the coral cays.

Some work has been done on the sediments forming on the shelf (as distinct from the reefs) in an area of 12,000 square miles between 22° and 24° S. latitude. Analysis of 208 bottom samples shows that the

sediments range in size from very coarse sands to mud and are composed of terrigenous material in the near-shore zone, carbonate detritus in the areas close to reefs and a mixture of the two facies elsewhere.

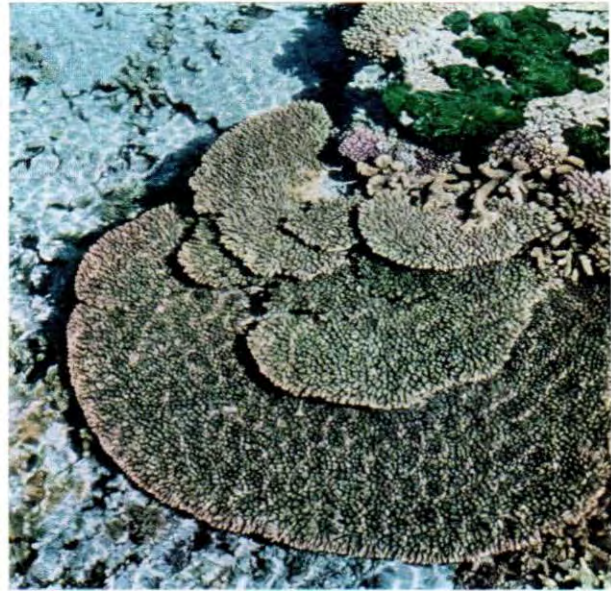
There is much evidence of changes of sea-level since the reefs grew to maturity—wave-cut benches at approximately the high water level of neap tides and others 8 to 10 feet above this. The higher series is certainly the result of a drop of sea-level relative to the land, the lower series possibly a second movement in the same direction. Such movements mean breakdown of the higher parts of earlier formed reefs and contribute to the coral sand, which is the bulk of the material of coral cays.

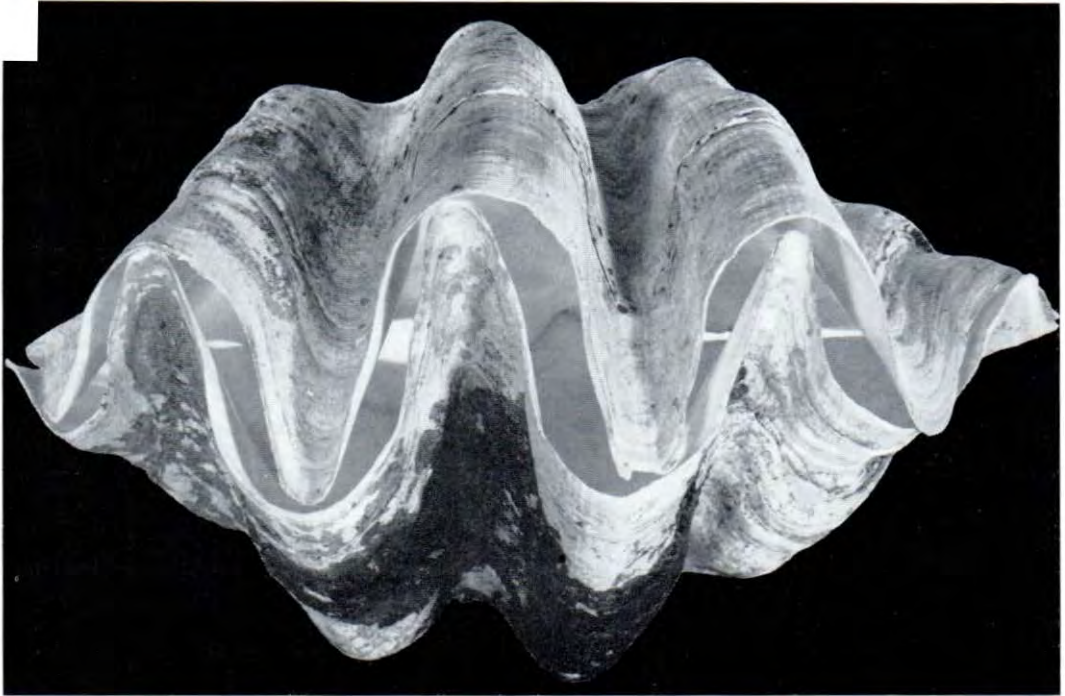
The general picture, then, is of the continental shelf, the "platform" cut either during the ice age or soon after, then while this "platform" slowly sank, deposition on it of some hundreds of feet thickness of sediments composed of material derived from the continent and from earlier (Miocene) coral reefs, then the upward growth of coral at a rate at least equal to the sinking of its foundation. Recent slight relative fall of sea-level materially assisted the always active processes of destruction and thus added to the material provided by the latter to form the very numerous coral islands. The upward growth of coral and the breakdown of the reefs are now, as far as one can see, in an overall state of balance, though one predominates here, the other there.

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### OPPOSITE

*Some common Reef corals and their allies. Left to right, from top: Xenia elongata has polyps that never retract, and is the softest and most delicate of Reef Alcyonaria; Fungia fungites, a solitary stony coral with polyp tentacles retracted during daylight; Millepora platyphylla, one of the few kinds of stinging coral (Hydrozoa) occurring on the Reef; Acropora surculosa, a common tabular type of true stony colonial coral growth; Goniastria pectinata, a stony brain coral with expanded polyps that are seen only at night; Acropora sarmentosa, a short-branched type of true stony coral found abundantly over great areas.*





Dorsal view of a 15-inch-long specimen of *Tridacna gigas* from the Philippines, showing elongate-triangular valve interdigitations. [Photo: Smithsonian Institution.]

## THE GIANT CLAMS

By JOSEPH ROSEWATER

Curator-in-Charge, Division of Molluscs, U.S. National Museum, Smithsonian Institution,  
Washington, D.C., U.S.A.

MEMBERS of the bivalved mollusc family Tridacnidae are endemic to the Indo-Pacific faunal region and all six recent species occur on the Great Barrier Reef. Often called "man-eating" clams, they, like most other bivalves, are actually feeders on minute matter which they filter from the surrounding water. In addition to the normal feeding mechanism, a supplementary source of food is provided by zooxanthellae, unicellular algae "farmed" by the clams in their mantle tissues. The epithet "man-eating" is attributable to the supposed danger to divers of being caught between the closing valves of large specimens, but there are few documented cases of such occurrences.

Tridacnidae are true giants of the bivalve world. So far as is known the size of the largest species, *Tridacna gigas*, has never been equalled in this class of molluscs, and is exceeded in the phylum only by some of the giant Cephalopoda. The largest pair of valves known measure 4 feet 6 inches in length and the heaviest weigh nearly 553 pounds.

### Evolution and morphology

Giant clams are believed to have evolved from an early middle Tertiary form much like the modern genus *Cardium*. Members of the family have developed a unique anatomical orientation to the substrate.



The small clam *Tridacna maxima* is renowned for the brilliance and variability of the colour patterns of its fleshy mantle. So different are the combinations of hue that it is almost impossible to find two exactly alike. Aiding in the production of this strikingly ornamental display are certain minute plant cells which live in the mantle tissues of this and the other kinds of clams. These symbiotic algae are comparable to those found in living coral growths.

probably due to pressures of natural selection associated with the presence of the symbiotic algae. Mantle-siphonal tissues, usually posteriorly located in most bivalves, have broadened and grown dorsally and anteriorly, providing a large area which is exposed to light and which supports growth of the zooxanthellae. In connection with changes in the tissues the shell has undergone what could be called a revolution, resulting in the displacement of dorsally located parts to a ventral position and vice versa.

#### Age and growth

A question which frequently arises concerns the possible ages of giant clams and their rates of growth. Few reliable data are available on this subject, although estimates range from less than ten to several hundred years. Studies carried out recently in the

Marshall Islands indicate that *Tridacna gigas* may grow at a rate of as much as two inches a year, and, if growth were constant, a metre-long specimen could be only 20 years old. Many conditions probably affect growth and increments may be small in larger individuals. Nevertheless, the largest known specimen may be less than 30 years old, a span of life certainly not unusual among bivalves.

#### Distribution

A few fossil species of Tridacnidae have been found in European and West Indian Tertiary deposits, indicating a once-flourishing tropical reef habitat in these areas. All living species are now restricted to the Indian and Pacific Oceans. Species distributions follow common patterns for

(Continued on page 254)





Viewed from a height of 3,000 feet, Heron Island becomes dwarfed against its 5-mile-long background of coral bank, submerged by shoal waters of a receding tide.

molluscs of the area. Species that grow to a large size, such as *Tridacna gigas*, *Tridacna derasa* and *Hippopus hippopus*, are restricted to the western Pacific and range from southern Japan to Australia, as far eastward as Micronesia and as far westward as the south-west coast of Sumatra. *Tridacna crocea*, a smaller species which burrows into coral, has a similar distribution. The furbelowed clam *Tridacna squamosa* has a range similar to the preceding, but extends westward to east Africa and the Red Sea. The most widely ranging species, *Tridacna maxima*, which contradicts its name by attaining only moderate size, ranges throughout the Indo-Pacific faunal region, from east Africa to eastern Polynesia. Although little is known of the ecological requirements of Tridacnidae, it is likely that these are related to conditions favouring growth of

reef corals. Certainly the distribution of Tridacnidae coincides with coral atolls and reefs in the Indo-Pacific.

### Habitat

A considerable diversity of habitat is evidenced by the several species of giant clams. All are attached by a holdfast or byssus at early stages in life, but the byssus atrophies in mature *Tridacna gigas* and *Hippopus hippopus*. These species are inhabitants of lagoons and reef flats, where they live unattached, usually on sandy bottoms between the heads of coral. Here position is maintained against current and wave by virtue of sheer weight. All other species are byssally attached as adults but by varying degrees of fastness, and all live on coral. *Tridacna squamosa* is loosely attached by a gelatinous-textured, rather weak byssus. *Tridacna derasa* is also believed to be in this category, although few direct observations are recorded for this species. Perhaps, by reason of their size, the two smaller species, *Tridacna maxima* and *crocea*, are always firmly attached to coral by massive byssi: the former occurs in shallow pockets in coral which it is thought to excavate by abrasion with its hard shell; the latter lives deeply ensconced in coral burrows, the upper edges of its valves often flush with the substrate. To collect the last two species, one requires a bar and hammer and even then the stout byssus must be undercut to free the animal from the substrate. One wonders why the range of *Tridacna crocea* is so narrow since this species, in its burrow, is almost immune to predation, even by man. Perhaps its immunity to collection affects our concept of its distribution, since specimens left in the field seldom are documented in monographs.

### Coloration

No discussion of Tridacnidae would be complete without mention of colours of mantle tissues. The colourful appearance of the living giant clam prompted Charles Hedley to remark: "Between the jaws are living jewels of green and gold, thick strewn on living velvet." He said of the strawberry clam: "*Hippopus* lacked the jewelled 'eyes' of his great brother." Many recent books on marine life, especially of the Pacific area, have at least one coloured illustration of a living giant clam.



Dorsal view of a living, 9½-inch long *Tridacna squamosa* from the Marshall Islands, showing mantle pattern and siphons: the incurrent opening is above and the excurrent below. [Photo: Author.]



Smaller species, such as *Tridacna maxima* and *T. crocea*, and even larger ones, such as *T. derasa*, seem to display an endless variety of colours. These usually range through all hues from light tan, through greens and blues, to deeper violet with mixtures of all.

### COLOUR PLATES

The colour plates in this issue are from "The Great Barrier Reef and Adjacent Isles", by Keith Gillett and Frank McNeill, and were made available by courtesy of the publishers of that book, the Coral Press Pty Ltd, Sydney

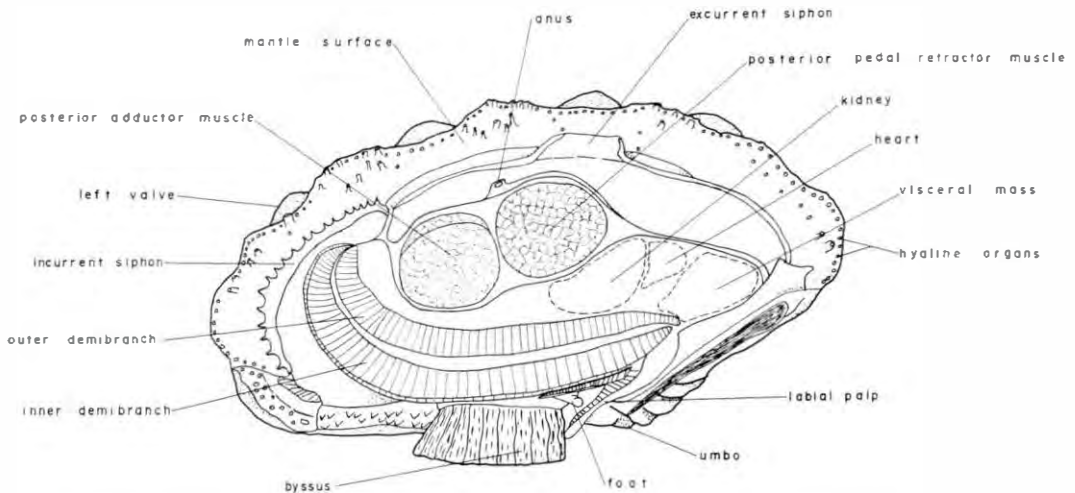
In other species colours are apparently more stable, although even in *Tridacna squamosa* there is some variation from a deep-violet background with bluish-white spots. The mantle of *Tridacna gigas* almost always has a mustard-yellow background set with vivid blue-green spots. In *Hippopus*, the plainest species, one can usually be confident of seeing a rather "olive drab" animal decorated conservatively with whitish vermiculate markings. It is believed that the colours of the more spectacular species, at least, are caused by the presence in the tissues of the zooxanthellae, although the cause of the

great variations in colour within a single species is unknown. Animals partially shaded from light have been observed to lose colour in the shaded portion of the tissue, probably because the algae were not able to grow there.

The theory that Tridacnidae "farm" the zooxanthellae in their mantle tissues and utilise this extra food source for metabolism has been argued considerably. Some experts consider that the presence of zooxanthellae is fortuitous and not connected with the nutrition of the clams. Nevertheless, it has been shown that algal cells are present in the digestive system of the clam. Also, the evolution of the family seems to have been so influenced by forces favouring this relationship that it is difficult to believe there is no connection.

### Economic importance

Because of their size, their epifaunal habitat, and the relative ease of capture of most species, the Tridacnidae are a popular food item from south-east Asia to Polynesia. They are eaten raw or cooked, and there is some commerce in dried *Tridacna* flesh. The large adductor-pedal retractor muscle complex is the portion most often consumed because the mantle has a tendency to be tough and has an unpleasant flavour due to the presence of the algae.



Sketch of *Tridacna maxima*, with the right valve and half the mantle removed to show the organs of the mantle cavity. [After Stasek, 1962.]



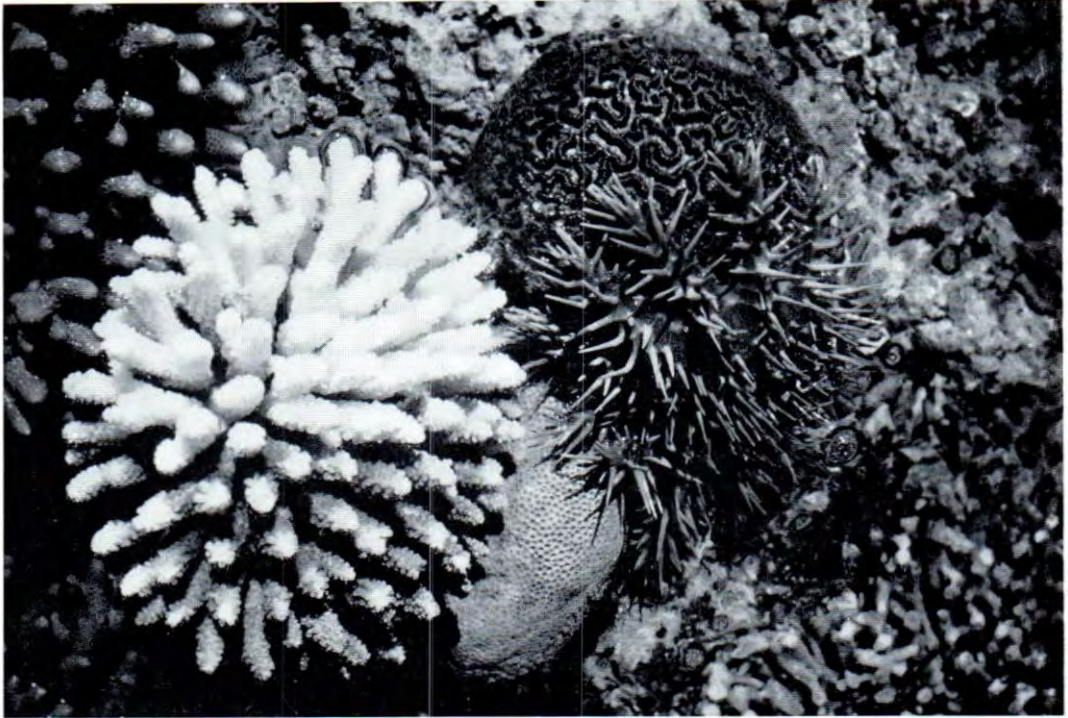
Spring tides expose rich growths along the edge of Heron Island's coral bank.

The large, durable valves of *Tridacnidae* are used for various purposes by islanders: for making tools, money, ceremonial fetishes, and as catch basins for water. Probably the most commercially important use to which the valves are put is as curiosities which ornament homes and business places the world over. Historically, the most famous pair are those which, for several hundred years, have served as holy water fountains in the Church of St Sulpice in Paris.

### Natural history

One's first encounter with a large *Tridacna gigas* in nature is a startling experience. Mine occurred while swimming in the warm waters of an atoll lagoon in the Marshall Islands. I had come to study living *Tridacnidae* and so was actively looking for the several species which abide there. Small *Hippopus* and *Tridacna maxima* were much

in evidence on coral heads in inter-island channels and in the same habitat in the lagoon. Suddenly, I saw something unusual. On sand beside a coral head lay what I then believed to be the largest *Tridacna gigas* in existence! Its valves were gaping widely and the exposed expanse of mantle appeared sufficiently broad and long to serve as a bed. The clam seemed to sense my approach and, as my shadow passed over it, the valves closed slightly and then reopened. Later, in the laboratory, it was possible to verify this response by the clams to possible danger from browsing fish or predators. There are, apparently, light-sensitive structures in the mantle tissues which respond to changes in light intensity, a condition not unusual among bivalves. A measuring rope satisfied my curiosity about the clam's size. The magnifying effect of my face mask lens notwithstanding, it measured less than a metre in length. Hardly large enough for a couch, and probably much less comfortable!



Disturbed by the falling tide, *Acanthaster* withdraws from a part-eaten madreporarian coral. The whitened area consists of skeletal framework from which all living tissue has been digested. Damage of this kind is irreparable. [Photo: Lloyd Grigg.]

## *The Crown of Thorns Starfish as a Destroyer of Coral*

By JOHN H. BARNES  
Cairns, Queensland

CORAL is the basis and the framework of the Great Barrier Reef and, on its surface, the dominant growth. It thrives only in a limited range of depths but despite the effects of subsidence, exposure and all other vicissitudes it has continued to grow, and dominate. We have come to regard it as the permanent feature around which other occupants have adapted their behaviour, and have been complacent in our belief that dependent life-forms would be compatible with its continuing existence. To find that the little-known inhabitant *Acanthaster*

*planci* had the capacity to destroy its own habitat came as a surprise to many, and there was, in the early stages of destruction, a general reluctance to accept the evidence. Unfortunately, the facts are now beyond dispute and after five years of population expansion this large spiny seastar, often called the Crown of Thorns, is now consuming coral and disturbing the ecology over a wide area.

Although similar gross disturbances must be far from unique in the long history of tropical reefs, a massive environmental

upheaval due to *A. planci* seems to have no recorded precedent. Some observations on the current episode should therefore be of interest, and perhaps stimulate investigations in other localities not yet considered to be involved.

The phases of the infestation are at present best known for the Green Island reef, which is more accessible and more consistently observed than any other on the Queensland coast. Ten years ago experienced divers regarded the Crown of Thorns seastar as a rarity in those waters, and as recently as 1960 demonstration visits were made to a large specimen which seemed to have permanent residence in a patch of low coral about 1 mile south-east of the island (sector A in the accompanying map.) A few corals in that sector showed circular dead patches, bone white and about the size of the star, which were regarded as long-term resting places.

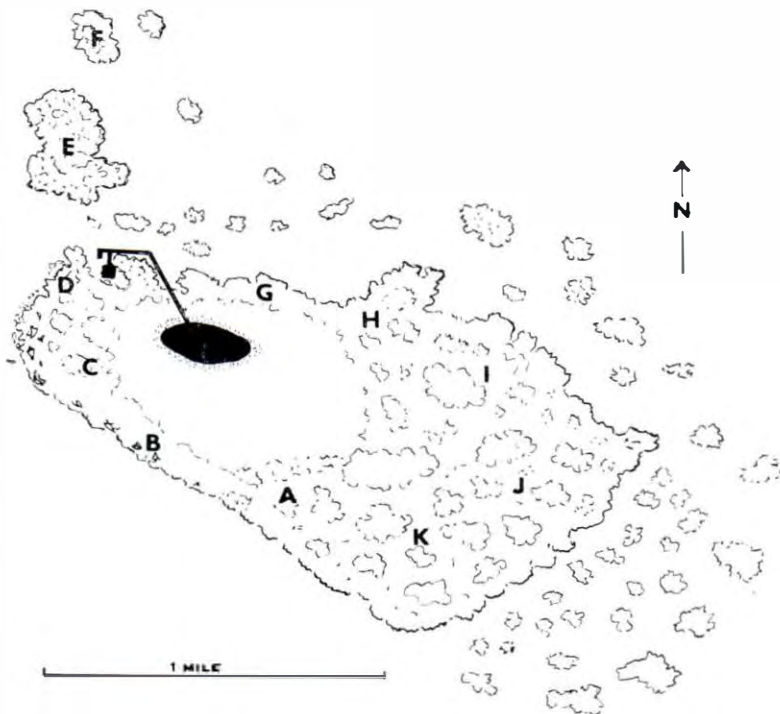
In 1961 there were many more scars in sector A and some in neighbouring beds to the north (B in the map), suggesting the presence of additional specimens, although

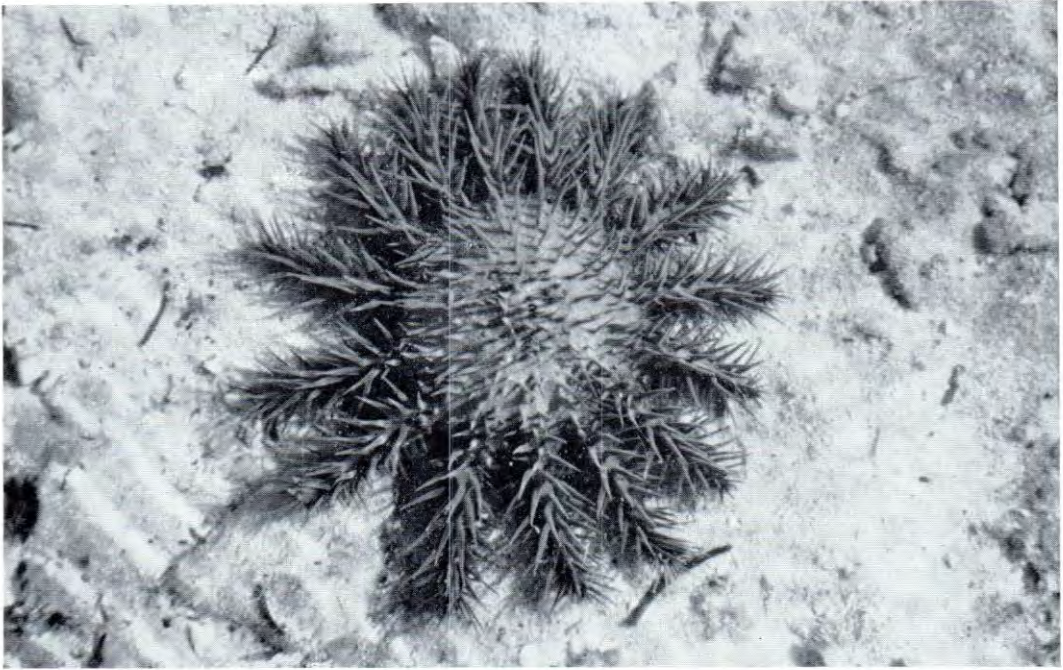
no stars were sighted during the inspection. In the following year, 1962, interest in *Acanthaster* was stimulated by reports of human injury and illness caused by the spines of this animal (E. C. Pope, 1963, J. Barnes and R. Endean, 1964). For the investigations prompted by these reports, specimens of *A. planci* were readily obtained from York Island (latitude 10° 41' S., longitude 142° 32' E.), Green Island (latitude 16° 47' S., longitude 145° 58' E.) and Heron Island (latitude 23° 20' S., longitude 152° E.), respectively representing northern, central and southern zones of the Great Barrier Reef. At Green Island Mr Lloyd Grigg, of the Underwater Observatory, collected five specimens in less than an hour, and was able to tell of *Acanthaster* in large numbers in sector B, moving northward on a distinct "front" and now approaching the jetty from sector C.

#### Damage due to feeding

When blemishes appeared near the Observatory windows Mr Grigg instituted regular day and night inspections, the latter under floodlighting, and soon discovered that

Sketch map of the Green Island reef, showing the island, jetty and Underwater Observatory in solid black, beaches around the island in stipple, and sand flats in white. The irregular markings represent the approximate position and extent of living coral prior to the *Acanthaster* invasion. Coral damage was first evident in sector A, spreading slowly to B and C, then involving D, E, and F almost simultaneously. G represents the area in which destruction was minimized by human endeavour. In August, 1966, coral in sectors H and I was under severe attack, but the large area represented by J and K still showed little evidence of *Acanthaster* activity. [Map by the author.]





*Acanthaster planci* escaping across sand in shallow water after being brought ashore for examination. Note the dangerous array of protective spines on the dorsal surface. [Photo: Author.]

the coral damage was due to feeding, not "smothering" as previously thought. By constant vigilance he was able to offer partial protection to that small area and make accurate observations on the habits of *Acanthaster*.

It is now known that the Crown of Thorns, like other seastars, does open and devour molluscs (R. Pearson, personal communication), but it is clear that under pestilence conditions its staple diet is the tissue component of corals. Feeding mainly but by no means exclusively at night, the animal climbs up from cover and settles on coral of recent growth. It obviously prefers madreporarian species, especially the large blue staghorns. Failing these, it selects smaller branching forms, or plate, shelf and boulder corals, in that order. The only stony coral known to be consistently avoided by *Acanthaster* on the Green Island reef is a large lemon-coloured species, often left as isolated living stands in eaten-out territory.

Soft corals (alcyonarians) seem to be largely immune from attack during the early stages of invasion, and I personally have not seen feeding scars or *Acanthaster* itself upon

them. However, the scarcity of alcyonarians at a later stage suggests they may be eaten or otherwise damaged by the hungry stragglers. In captivity *A. planci* is an indiscriminate feeder, and may even resort to cannibalism (K. Donnelly, personal communication).

To secure its food the Crown of Thorns extrudes a voluminous digestive membrane, sealing off an area approximately equal to its surface coverage, and liquefying the enveloped polyps and connecting coenosarc in situ. Within hours only the clean white calcareous skeleton remains, now porous and exposed to invasion by algae and other marine growths. Under their influence the scar turns grey, then green, then dirty yellow-brown, and on branching corals the decay may spread downward, even to the base. However, until as late as 1963 there was, to the casual observer, little change in the underwater scene. The stands of coral were still there, some different in colour and the sharpness of their outlines, but still harbouring fish and sheltering the more delicate inhabitants of the reef. The surface area of madreporarian corals is enormously greater than that of the reef they occupy.

Algal growth on dead corals may therefore make a substantial contribution to the diet of herbivorous fish, and could be the origin of ciguatera-type neurotoxins now present in the flesh of some species. The eating of ciguatera-bearing fish causes a distressing illness in man.

### Enormous infestation

Within the next 12 months the infestation assumed overwhelming proportions, fanning out into coral westward, northward and eastward of the jetty (sectors D, E, and F). Before the advent of *Acanthaster* this coral was particularly varied and colourful, and, because of its proximity, an important tourist attraction. Glass-bottomed boats reached these grounds in all weathers, comfortably and quickly, giving thousands of people an opportunity to see a truly representative sample of the complex reef environment. When injury to this coral became evident the boat crews worked strenuously to preserve the area, every week removing hundreds of stars for burial ashore.

The magnitude of the *Acanthaster* influx can be judged from the total ineffectiveness of these measures. Coral destruction accelerated month by month and by the end of 1964 the northern patches were desolated and the glass-bottomed boats were diverting further eastward ahead of the advancing horde.

By 1965 the "glassies" were working well out in sector G, still finding attractive coral, but operating in more exposed waters and nearing the practical limit of their travel. Realizing the futility of a dispersed effort, Mr Blake Hayles, manager of transport and accommodation facilities at Green Island, at that stage decided to concentrate his defence on a selected area in sector G, where he also stationed a diver whose sole function was to destroy *Acanthaster*. In the ensuing 15 months more than 27,000 stars were taken from that patch alone, 373 as the record for a single day, and at least 100 in every day of favourable weather.

It was found that early morning was the most suitable time for capture of *Acanthaster*, for these animals (and especially the juveniles) tend to avoid strong light and also creep downward as wind and waves increase towards noon. Vibration from the scraping

of metal hooks and accidental breakage of coral elicits the same response. For these reasons, and also because of the exhausting nature of the work, the diver was never able to keep even this small area clear of stars, and considerable damage did in fact occur.

### Basis for regeneration

Many people considered that this expensive operation could only delay the inevitable, but delay in this instance had important and



A dead specimen of *A. planci* seen from the under (oral) surface. This is a typical large specimen with seventeen rays, each equipped with a multitude of hydraulically-operated "tube feet". [Photo: Author.]

perhaps decisive effects. It allowed time for the frontal wave of the invasion to overshoot this strongly defended position and, it is hoped, saved enough coral to form a basis for rapid regeneration. The "glassies" still shuttle over the battlefield, a reef now somewhat pockmarked but making sharp contrast with less vigorously contested areas. In many of the latter the havoc exceeded our most pessimistic expectations.

In earlier inspections we had noticed that on coral eaten by *Acanthaster* the outermost tips frequently escaped injury and, after secreting an isolating callus, continued to

grow on their devitalized supports. We hoped that these living remnants would serve to re-establish the reef, and doubtless they will do so where the damage is relatively slight. However, where virtually every coral stand has been severely attacked (as in the northern patches) the basal portions rot and fall with remarkable speed, crushing and burying their more sessile neighbours, and no longer providing a barrier against turbulent waters. Many of the viable fragments are lost in the crumbling rubble, and more are covered by encroaching sands. The *Acanthaster* rearguard takes further toll of the survivors. Deprived of shelter, the fish and other coral inhabitants move away and for a time the area seems almost lifeless. The first sign of recovery is the appearance of hydroids and plant-like flexible alcyonarians. Meantime, *Acanthaster* expands further into new territories, creeping clockwise around Green Island, and now attacking coral in deeper water to the east.

Contiguous reefs (e.g., Arlington, Michaelmas and Upolu) are known to be similarly affected, and cursory inspections at Clack Reef (latitude 14° 04' S., longitude 144° 15' E.), Batt Reef (latitude 16° 27' S., longitude 145° 45' E.), Frankland Islands (latitude 17° 12' S., longitude 146° 05' E.) and Port Moresby (latitude 9° 30' S., longitude 147° 10' E.) have revealed patchy but high concentrations of *Acanthaster*. Clearly, this is not a localized phenomenon and one might reasonably expect a population explosion of this nature to be widely disseminated, perhaps even to the limits of coral influence. The sparseness of reports from other localities is not particularly reassuring, for *Acanthaster* is likely to be seen only when carefully looked for, and the earlier phases of reef damage are not obvious. The results of critical assessment of other areas would therefore be of great interest to Mr Bob Pearson and co-workers, now conducting investigations on behalf of the Queensland Department of Harbours and Marine.

We are still ignorant of the unusual circumstances which enabled the Crown of

Thorns to escape its normal restraints, and in fact know little of the general biology of this animal, its natural enemies, or its limitations in respect to depth and climatic tolerance. Until more is learned it is difficult to predict where the depredations will end, or what will end them. At this stage only two things are certain. Firstly, this is a plague—a gross imbalance—and as such must be self-limiting. In time, even if not suppressed by other factors, it will exhaust its food supply and then subside. Secondly, the reef habitat is enormous, and resilient beyond calculation. Despite the heavy damage in some sections there are survivors, more than adequate to restock the environment as opportunity offers. Restorative processes are already in operation, and from these it should be possible to gain greater insight into the requirements of various organisms and the relationships necessary to their co-existence on a living reef.

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#### DEATH OF JOYCE ALLAN

A former Curator of Shells at the Australian Museum, Miss Joyce Allan (in private life Mrs H. W. Kirkpatrick), died on 1st September after a long illness. Joyce Allan joined the Museum staff in 1917 as assistant to the then Conchologist, Charles Hedley, and became Curator of Shells in 1944 following the retirement of Tom Iredale. Her writings on shells in the popular field are well known, especially her two books *Australian Shells* and *Cowry Shells of World Seas*. The former is still the only comprehensive book on the subject and has provided many thousands of shell collectors with knowledge of the rich variety of Australian shells and the habits of the animals which form them. Miss Allan's scientific achievements were recognized by her election as the first woman Fellow of the Royal Zoological Society of New South Wales



A three-year-old Green Turtle reared in captivity.

## *Turtle Biology at Heron Island*

By H. ROBERT BUSTARD

Queen Elizabeth Fellow, Department of Zoology, Australian National University, Canberra

HERON Island is one of the Capricorn Group situated at the southern end of the Great Barrier Reef approximately 45 miles east-north-east of Gladstone. It is a small coral cay, total area 44 acres, beach perimeter about 1 mile, with a maximum height of 8 feet above mean tide level. There are a guest house and a research station on the island, the latter operated by the Great Barrier Reef Committee.

Heron Island, along with other Great Barrier Reef islands, forms important turtle rookeries frequented during the summer months (November to March) by nesting female Green Turtles (*Chelonia mydas*) and Loggerhead Turtles (*Caretta caretta*).

In 1964 I selected Heron Island as the site for detailed studies on the ecology and

behaviour of sea turtles, studies which would continue for many years. The small size of Heron Island makes it possible for two trained observers to record data on every turtle which comes ashore to lay its eggs.

The study of sea turtles has been greatly neglected, and present knowledge is largely based on work carried out in Florida and Malaysia. In both locations the turtles and/or their eggs are subject to heavy predation by humans so that it is not possible to carry out a natural ecological study. In Australia the scene is very different since the Government of the State of Queensland applied total protection to the Green Turtle, south of Cooktown, in 1950. Furthermore, the Florida and Malaysian turtles live in an



area where there are many different Governments, which do not always co-operate. For instance, the main Sarawak turtle rookery is just 10 miles from Indonesian Borneo.

### **Tagging programme**

In order to study the movements, nesting returns, and growth of adult turtles I commenced a tagging programme in summer 1964-5. Each adult turtle was numbered by a monel metal tag, which was fixed through the trailing edge of the left fore flipper. The upper surface bears the turtle's identification number and the reverse side the letters A.N.U. (standing for Australian National University). The tagging programme soon brought in some interesting results. For instance, Green Turtles outnumbered Loggerheads by about three to one and the breeding female Green Turtle population using Heron Island numbered about 200. These females were nesting repeatedly throughout the summer at intervals of about a fortnight. This information is known for the other turtle rookeries mentioned above, where it has also been discovered that, after nesting throughout a summer, the female turtles go off to sea, presumably to feed and replace their fat reserves. They nest again 3 years later.

During summer 1965-6 all the turtles at Heron Island, as expected, were unmarked. The Green Turtle population was about three times as large as in the preceding summer but the number of Loggerheads remained very small.

Green Turtles first come ashore to nest when they have a carapace (upper shell) length of about 35 inches. They continue to grow, however, and nesting females average about 42 inches in carapace length, with some individuals up to 47 inches. Large females weigh between 200 and 300 pounds.

### **Two experiments**

In time we will obtain some growth data by recapture of those females marked before they reached full size. However, no one knows how long it takes them to reach first breeding size of 35 inches. To obtain information on this we started two experiments. The first experiment involved rearing selected turtles of the two species in captivity and recording size and weight

increases at regular intervals. These turtles are kept for us by an expert, Mr O. L. Tanis, of Brisbane.

The second experiment was very ambitious. It involved marking juvenile turtles for subsequent recovery as nesting females. Hatchling turtles, even when they enter the water, undergo very heavy predation and only a few per thousand can be expected to live to breed. For this reason, in order to obtain sufficient data, it was essential to mark very large numbers of young. I decided that in order to mark sufficient young (20,000 to 30,000) collecting from the beach was too laborious and uncertain a method. I started a hatchery at Heron Island in December, 1965. This hatchery measures 50 feet x 50 feet and is turtle, rat, and bird proof. It provides accommodation for the natural incubation of up to 50,000 turtle eggs.

The eggs are collected and counted as the turtles lay them; in no case do we disturb the nesting habitat by digging for eggs. They are transported to the hatchery in sealed plastic bags. A sample is weighed and measured before they are placed in freshly dug holes in the ground at a similar depth to natural turtle egg chambers. Since the number of eggs in each clutch is also known and since the eggs were collected from a tagged turtle we have an impressive amount of data on reproduction. We know, for example, that an average clutch for the Green Turtle is 110 eggs but that this number may vary from about 50 to as high as 200. Clutch size also increases with increasing size and, therefore, age of the turtle. This phenomenon has been recorded in a number of other reptile groups.

### **Nesting behaviour**

We have carried out a detailed comparative study of the nesting behaviour of the two turtles. Both species nest under cover of darkness. Perhaps the most obvious difference is in locomotion. The Green Turtle progresses by a series of laborious forward pushes in which all four limbs move synchronously. The Loggerhead "walks" in the normal quadruped manner, using synchronous movements of diagonally opposite limbs, which is much more effective. A female turtle is usually out of the water

A Loggerhead Turtle  
laying at Heron Island.



for about 3 hours when she comes ashore to lay a clutch of eggs, but this time is extremely variable, depending on obstacles such as tree roots or dry sand, which may necessitate her moving and starting again at a new site. During digging the nest and covering in, a female Green Turtle may move well over 1 ton of sand.

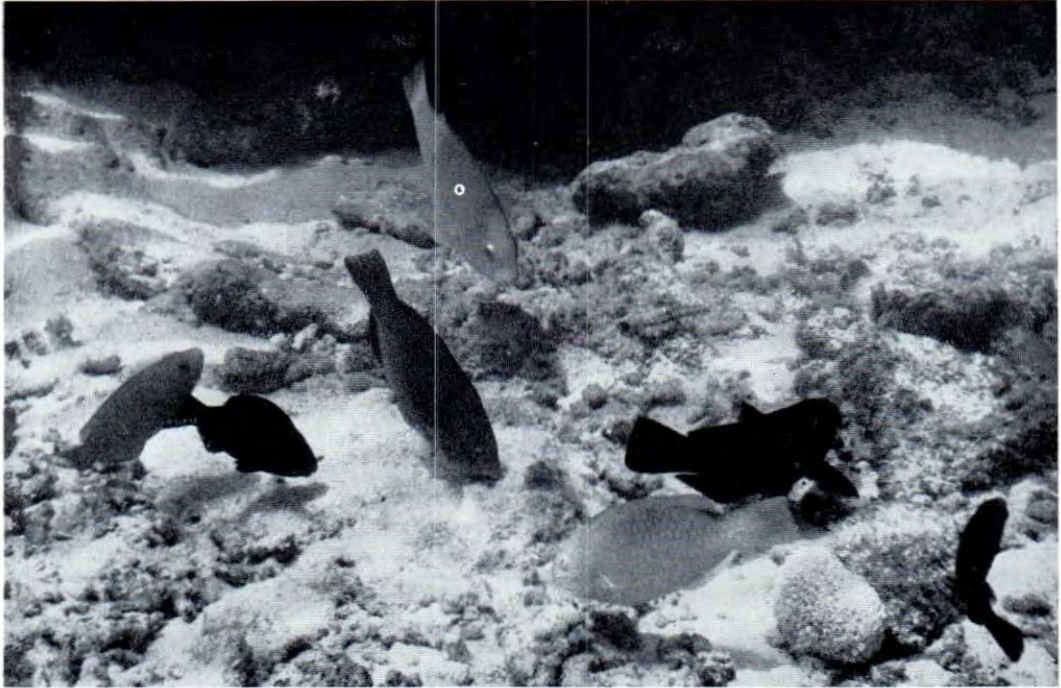
The hatchling turtles have a carapace length of 2 inches. They enter the sea at once, usually all emerging from the nest together under cover of darkness. As mentioned above, the Queensland turtles are protected from human interference and they have other advantages. Apart from gulls, small coral cays like Heron Island possess no vertebrate predators (except introduced rats). In other parts of the world predatory mammals and reptiles occur which dig up and consume many clutches of eggs as well as attacking the hatchlings. There are only two important land enemies of the young turtles at Heron Island—Silver Gulls (*Larus novaehollandiae*) and Ghost Crabs (*Ocypoda*

*ceratophthalma*). The gulls usually eat the few hatchlings which emerge during the day. The Ghost Crabs are voracious nocturnal predators. In the water the young turtles readily fall prey to many forms of carnivorous fish, including the small but numerous Black-tipped Reef Sharks (*Carcharinus spallanzani*).

The protection of the Green Turtles of Queensland is vested in the Department of Harbours and Marine, in Brisbane. All the research work described in this article is carried out subject to permits issued by this Government Department.

I am often asked why I undertook this study. I am interested in the problems it poses and in this protein-hungry world turtles are an excellent form of food. With more detailed knowledge of their biology we can hope to use a large proportion of their eggs without in time exterminating the turtles.

[The photos in this article are by the author.]



A mixed school of parrot fish feeding on the outer reef slope. Three species are represented.  
[Photo: E. Hegerl.]

## *PARROT FISH*

By HOWARD CHOAT

Demonstrator, Department of Zoology, University of Queensland, Brisbane

**C**ORAL reefs support the most abundant and diverse fish faunas of any region in the world. This diversity and also the enormous, often continuous area covered by coral reefs have made the cataloguing and classification of these fish a difficult task. Some excellent surveys, particularly those carried out in post-war years, have indicated the magnitude of the problems involved, and point to the necessity of collecting specimens over the full extent of their range and of gaining some information on their biology. The latter point is now receiving increasing attention and studies covering many aspects of reef fish biology have recently been made, or are presently under way. This article deals with the biology of the true parrot fish, family Scaridae, a group highly

characteristic of coral reefs. Most of the work was carried out at Heron Island, using the facilities provided at the Great Barrier Reef Committee's research station.

Parrot fish are common to all tropical and sub-tropical seas but are especially abundant in the Indo-Pacific region. They constitute a well defined and easily recognizable group, characterized by the fusion of the upper and lower teeth into a beak and by the flattened plates of the pharyngeal teeth (throat-teeth) which form an efficient crushing mill. When attempting to identify parrot fishes two things become apparent. Nearly all species have the same number of fin rays, body scales, general proportions, and shape, and the colour pattern, even in comparison with other reef fish, is extravagantly developed. This

leaves little alternative but to rely heavily on this colour pattern when distinguishing the various species, a procedure which, as will be shown later, has disadvantages. Estimates of the relative abundance and weight of fish inhabiting coral reefs have shown parrot fish to be one of the more important groups, something which is often apparent to even the casual observer. For this reason they are of importance to not only the ichthyologist but also to the ecologist who would attempt to analyse and explain some of the complexity of a coral reef.

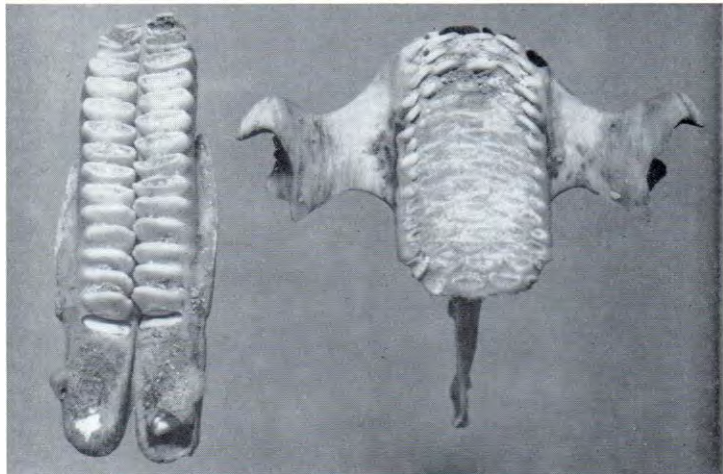
Studies at Heron Island have shown parrot fish to be abundant, gregarious fishes with distinct patterns of diurnal and nocturnal behaviour. They are herbivorous and, except in species which are influenced by the tidal cycle, spend most of the daylight period feeding. The colour pattern undergoes a series of drastic changes during the life-cycle, changes which are stimulated by both developmental and sexual influences. The high degree of structural uniformity is accompanied by ecological and behavioural uniformity, especially in relation to feeding activity. A situation of this nature, with a number of similar species tending to do the same things in the same area at the same time, is potentially interesting to biologists in general. Accordingly, the feeding activity of each species was examined in the following manner: what was eaten, how it was obtained, when and where it was obtained, how these activities compared with similar activities in the other species.

### Feeding

In all species, feeding followed a similar pattern, which consisted of a non-selective grazing of the fine algal "fur" that covered most exposed surfaces of the reef. Patch reefs, such as those in the Capricorn group, have extensive areas of loose and impacted sediment and calcareous debris, all of which support a growth of minute, blue-green, brown, red, and green algae. It is this unobtrusive carpet of vegetation which provides the grazing fodder for the abundant schools of herbivorous fish, such as parrot fish, surgeon fish, and mai mai, which are so characteristic of these reefs.

All parrot fish observed had a similar feeding method. The exposed surface was scraped with the beak, and calcareous fragments containing a high percentage of algae were passed back to the pharyngeal teeth and thoroughly triturated, presumably to break down some of the cellulose components of the algae. The thin-walled, elongate gut was usually crammed with calcareous powder and algal fragments, and it has been demonstrated that parrot fish contribute substantially to the patterns of erosion and redistribution of sediment on coral reefs. In many cases up to eight species of parrot fish were observed in loosely associated schools, all grazing the same calcareous surface. In such instances it was impossible to detect any differences in the pattern or rate of feeding between any of the species, and certainly no difference in gut contents could be detected. It is worthy of note that

The pharyngeal mill of a parrot fish. Algae and calcareous material are ground between the upper (left) and lower sets of teeth. [Photo: O. E. Kelly.]



in no instances were parrot fish observed to graze living coral, a characteristic which they exhibit in other areas, such as the atolls of the Marshall Islands chain.

### Formation of schools

Most parrot fish tend to form schools during some part of their daily activity. These were of two types:

- Loose associations of three to six species, usually in groups of eight to twenty, the individual members of these schools showing considerable variation in size and development.

- Large schools of a single species with 20-200 individuals, usually of uniform size and stage of development.

The species comprising the former group were often solitary, and appeared to join up with other individuals almost at random to form loosely integrated schools. They were abundant on the outer reef slope down to depths of 50-60 feet, but were not observed to venture on to the extensive reef flats which are covered by at least 5 feet at high water. They grazed almost continuously during daylight hours and appeared to remain in a fairly circumscribed area of the reef front. Species in the second category ranged over large areas of the reef flat at high water, moving in large single-species schools. Some were observed to follow a definite route across the reef flat to a preferred grazing area. It has since been demonstrated that parrot fish can orientate themselves by referring to a sun compass. At low water some individuals remained in pools in the reef flat, but the majority congregated on the outer slope adjacent to the reef crest. During this period little or no feeding activity was observed. These patterns of activity may represent some degree of differentiation in the feeding behaviour of parrot fish, although they are by no means clear-cut. Parts of the Reef consist of gently shelving areas which lack the structural distinctions of reef crest, outer slope, etc., and it is here that a great deal of overlap and mingling of the species of each feeding category occurs.

All parrot fish pass the night in a state of almost complete inactivity. Thus the 24-hour period is divided into two distinct patterns of activity, the cyclic nature of which

indicates that light intensity is one of the critical controlling factors. Shortly before sunset large groups may be seen congregating in the vicinity of coral growths, ledges, and crevices in the reef front, which are used as sheltered "roosting sites". There is a tendency for the more integrated schooling species to spend the night in large groups, similar in composition to the daytime feeding schools. Other species were more scattered and formed random associations among the coral. Activity recommences just before dawn, when groups of fish may be observed emerging from their "roosting" areas, although feeding does not commence for approximately another half-hour.

### Colour change

An obvious prerequisite of any field study is the ability to identify readily and accurately the species concerned. Nineteen species of parrot fish included in four genera were recorded from Heron Island, and in most cases colour pattern was the only practical criteria for field identification. A problem encountered here was that some species may undergo as many as four colour changes during their life. However, these changes usually follow a regular and predictable pattern, which allows the recognition of definite stages in the development and activity of each species. The three commonest colour sequences were:

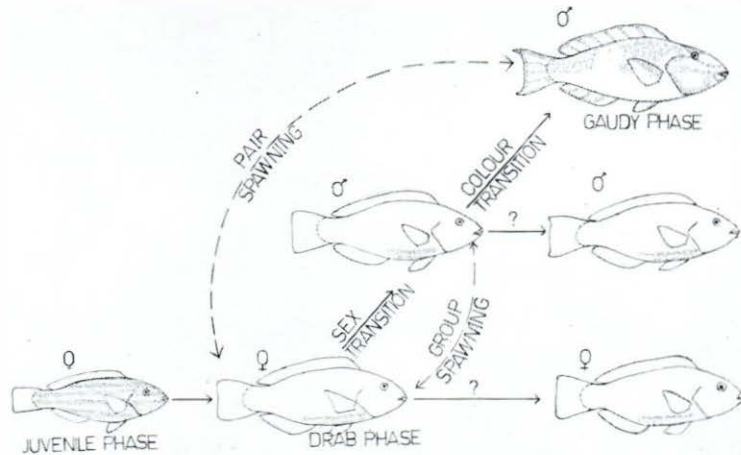
- Juvenile: light grey or brown with pale bands or spots on the body.

- Female or male without developed colour pattern: drab coloration; grey or reddish-brown, usually longitudinal or transverse stripes on some part of the body.

- Male with developed colour pattern: a gaudy distinctive pattern in which blues, yellows and especially greens predominate.

The commonest cause of colour change was sexual dichromatism, the displaying of different colour patterns by the male and female of the same species. It was initially considered that the gaudy pattern was assumed by males on reaching sexual maturity. However, in a number of species drab-coloured male fish with fully functional testes were found. Studies by Dr John A. Randall in the Carribean have shown that when the two types of males occur in the same

Generalized sequence of sex and colour transition in a hypothetical parrot fish. [Diagram by the author.]



population two different spawning patterns occur:

- Group spawning by large numbers of male and female drab-coloured fish, which congregate at definite spawning sites.

- Pair spawning by a gaudy male and a drab female at some random situation on the reef.

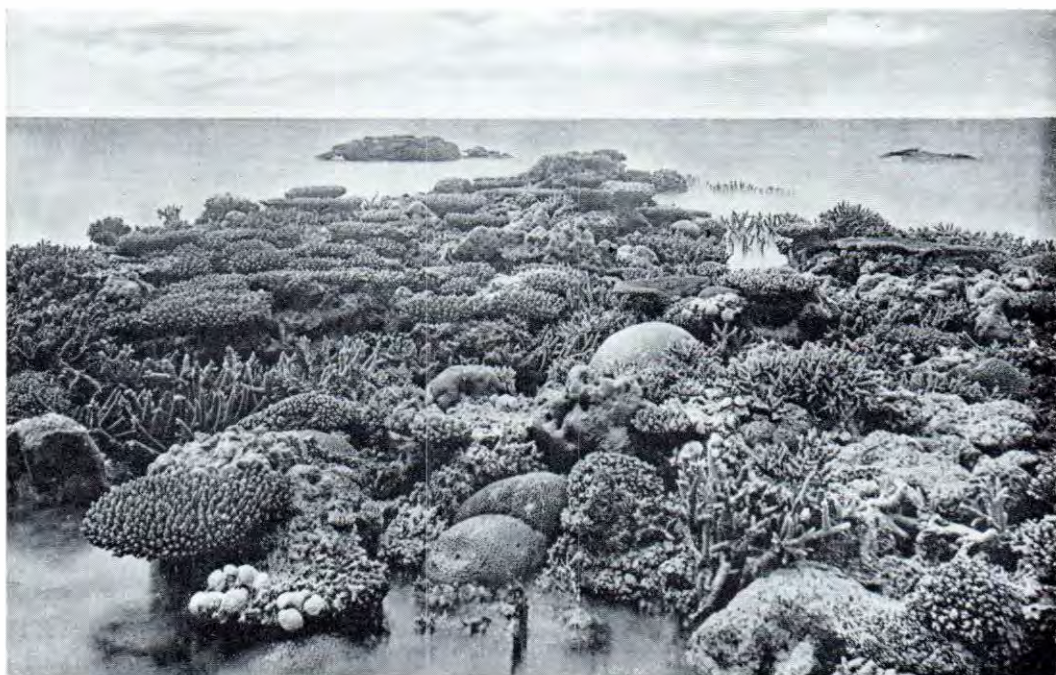
Similar spawning patterns have been observed at Heron Island, although the distinction is not always clear-cut, as gaudy males may sometimes participate in group spawnings.

### Sex reversal

Although large numbers of fish were examined and sexed, small males were always absent from the samples examined. More intensive collecting confirmed that, for the commoner species at least, there were no small males in the population, and therefore the only method by which males could be maintained would be for some females to undergo sex reversal. Such a phenomenon is known as progyne hermaphroditism and has been recorded from quite diverse groups of fishes. All species of wrasses (closely related to parrot fish) examined at Heron were progyne. The present work indicates that in parrot fish sexual transition occurs in the upper limits of the size range, and that before becoming a male the fish can function as a female. No evidence has been found that would suggest that both male and female components of the gonad are simultaneously

active, allowing self-fertilization to occur. The illustration is a very general scheme of the sequence of sex and colour transition, and it is probable that exceptions to it will be discovered when larger samples are collected. Some questions which might arise are:

What percentage of females transform into males? Are all members of the population destined to end their lives as males? Do all males develop the gaudy pattern or do some retain drab coloration? (In this context it is of interest to note that, in species of Mediterranean and Caribbean wrasses, a significant percentage of the juvenile fish are genetic males. Some effort has been expended to collect samples of small parrot fish and wrasses at Heron, but at the time of writing no juvenile males have been recorded from either group. However, the possibility that some species are not progyne is still being considered.) What are the sex ratios in each species during the period of their life when the gonads are functional? To answer questions of this nature one must be able to obtain estimates of growth rates, mortality rates at different stages in the life-cycle, and the fecundity of individuals at different stages during the life-cycle. These are not easy data to obtain from highly mobile aquatic animals inhabiting an area notoriously difficult to sample. However, if more precise information regarding population phenomena of reef fish is required, sampling methods which give adequate and accurate returns must be devised.



This magnificent array of corals was photographed about 1890 by the pioneer marine biologist in Queensland, William Saville-Kent, whose book *The Great Barrier Reef of Australia* remains a classic to this day. This section of Crescent Reef, near Lark Passage, north of Cooktown, was described by Saville-Kent as the "most luxuriant expanse of living coral" he had ever photographed. Rich coral growths of this type are easily damaged by carelessness on the part of visitors, and they are also subject to damage from natural causes, such as excessive quantities of fresh water after heavy rain or intense heat during periods of low tide.

## ***THE FUTURE OF THE REEF***

By DONALD F. McMICHAEL  
Curator of Molluscs at the Australian Museum

RECENT Press accounts of attacks on living coral by a starfish, known as the Crown of Thorns Star, raised the question of possible extensive damage to the Great Barrier Reef. It has been suggested that unless urgent measures are taken to reduce the numbers of this starfish, the whole Reef might be reduced to rubble. While such massive destruction is not beyond the bounds of possibility, it seems unlikely that the starfish will reach plague proportions over the whole Reef area, though in limited areas it may well cause severe damage. When this occurs in a popular tourist area, as happened

recently at Green Island, near Cairns, it becomes a matter of considerable importance.

However, the Press publicity has drawn attention to the need for serious thinking about the future of the Great Barrier Reef. Most people have regarded the Reef as something completely permanent, of great age and with a future stretching ahead just as long as its past. They would probably agree that nothing we could do would conceivably affect the future of this enormous complex of coral reefs. Yet similar views have been held at one time or another concerning many terrestrial communities

which have long since disappeared or been reduced in size to mere fragments of their former extent. The effect of man and his activities on the natural environment is now well known to be almost always destructive. Therefore it is well to think about the future of the Great Barrier Reef at the present time when it is largely unaffected by man, but also at a time when the development of the northern parts of Australia is about to undergo great acceleration.

Already the tourist industry has become of great financial importance to the State of Queensland, while the active search for minerals, especially oil, is having considerable success, leading to even more intensive exploration. Oil surveys have already been carried out over large areas of the Great Barrier Reef and some exploratory drilling has taken place. Other mineral wealth may be sought in Reef waters—for example the coral sands, which consist of almost pure calcium carbonate—and no doubt there will be others of which we are, as yet, unaware. All this activity, both tourist and industrial, is welcomed by Queensland as a contribution to the State's developing economy. Fortunately, from the point of view of the conservationist, there is also a keen awareness of the value of the Great Barrier Reef, both as a natural phenomenon of great scientific interest and as a wonderful tourist attraction.

### Safeguards

This has led Queenslanders to take some positive steps towards safeguarding the Reef's future. These include the proclamation of many of the islands along the length of the Reef as National Parks. This has been done under the Forestry Act and the Conservator of Forests administers these parks, extending protection to the flora and fauna. However, the power to proclaim National Parks extends only to high-tide mark, so that this protection does not cover marine organisms. The control of marine life in Queensland waters is vested in the Department of Harbours and Marine under the Fisheries Acts, and these have been used to protect and conserve marine organisms in a number of ways. The major provision is a complete prohibition on the taking of live coral, except by a few licensed collectors operating in prescribed areas. In addition the taking of some larger species of animals,

such as the Green Turtle (*Chelonia mydas*), is prohibited over much of the Reef. Commercial fish are also protected by the usual system of prescribed minimum lengths, which are designed to ensure that the fish will grow to maturity so that some breeding can occur before they are of a size at which they may be taken.

In addition to these general provisions, it was recently decided that the coral reefs at Green Island and at Heron Island were suffering at the hands of tourists. As these reefs are among the most popular with tourists because of their accessibility and the availability of accommodation, the Department of Harbours and Marine took action to protect them from damage and to preserve them as viewing areas. The taking of any marine organisms (except for fish caught by handline or rod and line) was prohibited over an area extending from high-water mark to some distance beyond the edge of the reef. Although this means that such popular pastimes as shell collecting and spear-fishing are forbidden, it is hoped that the result will be the preservation of a rich fauna which will enable visitors to see the widest representation of coral reef organisms. Whether these restrictions are effective depends on the co-operation of tourists and the effective policing of the regulations. From a scientific point of view, it is very important that persons visiting these two reefs do not interfere with any of the living animals which are found there, because the control measures adopted represent a long-term experiment in conservation. If it can subsequently be shown that a rich fauna is preserved on Heron and Green Islands as opposed to other islands where no controls are in force, then the value of this type of conservation measure will have been demonstrated.

### Environmental changes

Unfortunately, it seems probable that greater threats to the Reef are posed by major alterations to the environment. Such alterations can be natural, or the by-product of human activities. Natural catastrophes have occurred previously; for example, in 1918 there was major destruction of the coral reefs of the Whitsunday Islands and the theory was advanced that this was caused by an excess of fresh water as the result of two



cyclones striking the area within a few days of each other, coincident with a period of extreme low tides. (E. H. Rainford, 1925, *Australian Museum Magazine*, Vol. 2, No. 5.) Rainford reported some seven years later that various reefs were showing signs of regeneration and most of the Whitsunday reefs today show little or no sign of this disaster, though no precise comparative studies have been made. Holbourne Island, off Bowen, which was one of the islands said to have been affected by the 1918 cyclones, is still largely a dead reef, though other factors may have been operative there.

Other natural catastrophes which might cause damage to the Reef would be changes in sea-level, lowering of average water temperatures, or increase in turbidity of the sea-water as a result of increased rainfall on the adjacent mainland. But far more likely threats to the Reef's survival come from man himself, through direct or indirect contamination of the marine environment.

### **The oil menace**

Among the many contaminants which man has added to the oceans, oil is one of the greatest sources of danger to marine organisms because of its tendency to float in masses at the water surface whence it can be deposited in clinging layers over intertidal areas. Recent studies in Great Britain indicate that intertidal oil deposits tend to concentrate at high-water mark, and the organisms living there, such as barnacles and limpets, were not seriously affected. However, it could well be that the effect of oil deposits on living corals and coral reef animals would be much more serious. In addition, oil releases soluble toxic compounds into the water which directly affect marine organisms. The danger of oil pollution has been recognized for a long time, and as long ago as the early 1920's the British and American Governments introduced legislation prohibiting the discharge of oil into coastal waters. The problem is also an international one, so that, in 1954, 32 countries agreed to a *Convention for the Prevention of the Pollution of the Sea by Oil*, to which Australia has become a party. Legislation has been enacted by the Federal and State Parliaments prohibiting the discharge of oil in coastal waters except in cases of emergency, and it is to be hoped that

this will help to reduce the threat from this source. C. E. Zobell, of Scripps Institution of Oceanography, has estimated that between 50,000 and 250,000 tons of oil are discharged into the sea each year, much of it coming from tankers sunk during World War II. Another potential source of oil pollution is submarine oil-wells and it is to be hoped that appropriate measure to guard against leakage of oil from any well which may be drilled in Great Barrier Reef waters will be taken. In Britain during recent years, industrial emulsifiers have been used to clean up oil-polluted shores and these have proved very successful on sand and shingle beaches which are used primarily for recreation. However, on rocky shores, they have caused a heavy mortality of intertidal organisms, because the emulsifiers are themselves toxic. In any case the oil deposited usually disappears in due course without any especially harmful effects. The use of these compounds in any national park area should therefore not be permitted.

### **Pesticides a danger**

Another danger to marine organisms arises from pesticides sprayed on land for agricultural purposes. Larger quantities than are actually required are often used, and the excess slowly filters into the rivers and may be carried down to the sea where it can have serious effects on marine organisms. Recent studies in America have shown that as little as one part of D.D.T. per billion parts of sea-water will kill some species of crabs and prawns, and, when it is remembered that prawns breed in estuaries and river mouths, it is obvious that unwise use of such chemicals could have serious repercussions on these important commercial fisheries. Fortunately, the Reef islands are mostly well off-shore where the pesticide effects would be minimized, but because these compounds tend to accumulate and because they may affect the Reef organisms during phases of their life-cycles spent closer inshore, the situation needs to be watched closely.

Pollution of sea-water by sewage and industrial wastes, including detergents, is a serious problem in the more densely populated areas of the world. For example, it has been estimated that more than one billion gallons of sewage is discharged every day into the sea off the coast of California and this has some devastating effects on the

The dugong or sea-cow (*Dugong dugon*), a member of the mammalian order Sirenia, is relatively uncommon over much of its range (Red Sea to coastal Queensland), but a recent survey of Queensland and northern Australian waters reveals that its numbers appear to be increasing. For many years it was fished in Queensland for its oil and hide, but it is now hunted only by Aborigines. It is found in shallow waters of the Barrier Reef and can be seen in herds grazing on marine plants. [Photo: B. J. Marlow.]



local fauna, especially fish and molluscs. While Queensland's population is still small there is no great problem, but as the State grows and industrial development continues, especially in the northern cities of Townsville, Rockhampton and Gladstone, the danger to the Reef will increase. Serious effects on local faunas have already been caused by the effluent from sugar mills, and following the sugar terminal fire in Townsville in 1963 vast numbers of fish died as a result of oxygen deficiency arising from the decomposition of molasses washed into the sea.

Commenting on the problem of sewage pollution in California, C. E. Zobell has written: "Engineers and health authorities alike are dedicated to the proposition that sewage should neither jeopardize human health nor unduly destroy natural resources. The latter include harvestable seaweeds, fish and other marine fauna, and beneficial uses of beaches, bays and sea-water. The beneficial uses include swimming, skindiving, surfboarding, fishing, boating, aesthetic enjoyment, commercial shipping, naval vessels and water for industrial cooling, cleaning, fluming, flushing, etc. Though difficult to assess in terms of dollars, some people place the premium upon aesthetic values—the sense of satisfaction derived from seeing and smelling good, clean, clear, blue sea-water. It seems though that part of the price to be paid for the privilege of living in populous areas on the seacoast is

the modification of adjacent waters."

Is it then impossible to avoid polluting our coastal waters? Can the Great Barrier Reef of Queensland be saved for posterity against the obviously unavoidable increase in Queensland's coastal population and industries? I think it can, and the answer was given thirty years ago by the American biologist Paul Galtsoff, who was concerned with the effect of oil pollution on oyster fisheries. By substituting pollution in general for the specific oil pollution in Galtsoff's original text, his comments read as follows, and they are as true today as they were when first written: "The way to avoid unnecessary devastation caused by negligence and disrespect toward our natural resources will be easy to find when the extent of damage by pollution is realized and the manner in which the pollutant affects life in the sea is fully understood. There is no doubt that modern technical science can devise methods which will provide full protection to our waters without hindering the development of new industries or curtailing the use of chemicals. The solution is obviously not a biological one but an engineering problem. It will be found as soon as the majority of people cease to look upon our bays, streams and estuaries as huge dumping places for the disposal of sewage and garbage and realize that these are the greatest natural assets which the present generation holds in trust for those who will live after us."

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To teachers and pupils of schools and other educational organizations special facilities for study will be afforded if the Director is previously advised of intended visits. A trained teacher is available for advice and assistance.

Gifts of even the commonest specimens of natural history (if in good condition) and specimens of minerals, fossils and native handiwork are always welcome.

The office is open from 9.30 a.m. to 1 p.m. and 2 to 4.30 p.m. (Monday to Friday), and visitors applying for information there will receive every attention from Museum officials.

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