Science for management

of the Great Barrier Reef

TERRY DONE

Photo:
Whitehaven Beach, Whitsunday Island
Yann Arthus-Bertrand,
Earth from above / UNESCO

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PREFACE

The world's largest marine Heritage Area was established in 1981

Two initiatives have combined to give scientists opportunities to become more responsive to the needs of users and managers

The Great Barrier Reef off the Queensland coast of Australia is managed with a goal of maintaining and enhancing those qualities which made it the world's first (1981) and largest (348,700 km^2) marine World Heritage Area while keeping it accessible for multiple uses, notably tourism, fishing and shipping.

Basic and strategic research, ranging from the Great Barrier Reef Expedition of 1928 to the present, have provided a substantial knowledge base on the nature and function of the Reef.

Most recently, two initiatives have combined to give scientists opportunities to become more responsive to the needs of users and managers: the development of the *Twenty-five Year Strategic Plan for the Great Barrier Reef World Heritage Area*, and the establishment of the Co-operative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef. The completed Plan includes a vision, principles, objectives and strategies based on the cumulative insights coming from all parties.

Three issues of widespread concern have become major foci of research -

1. the sustainable limits to commercial and recreational fishing,

2. the effects of runoff of silt, nutrients and contaminants from the land,

   and

3. the provision of highly protected areas for biodiversity protection.

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INTRODUCTION

Figure 1a The four sections of the GBR Marine Park and World Heritage Area, stretching over 2,000 km of the Queensland coast.

Map above in greater detail

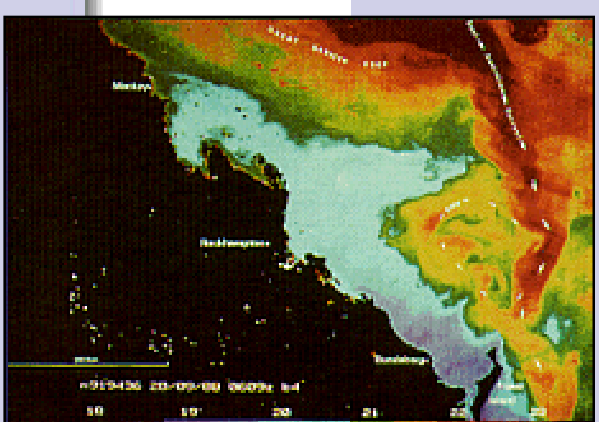

Figure 1b False-colour image of the coast of Australia (black) and major oceanographic features which influence the Great Barrier Reef.

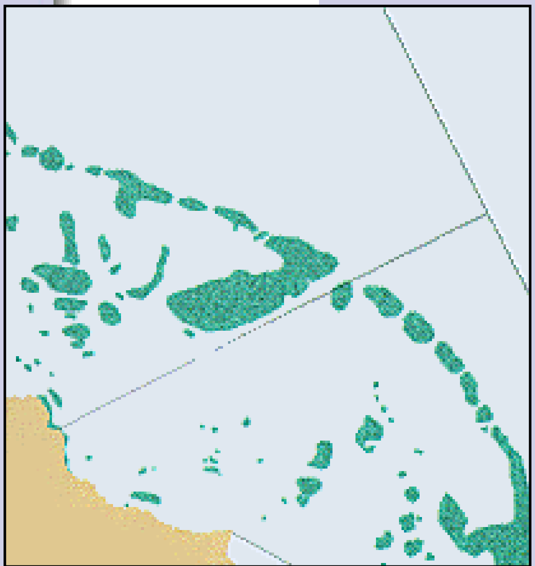

Figure 1c A 100 km section showing coral reefs north of Cooktown, at the boundary between the Far Northern and Cairns Sections.

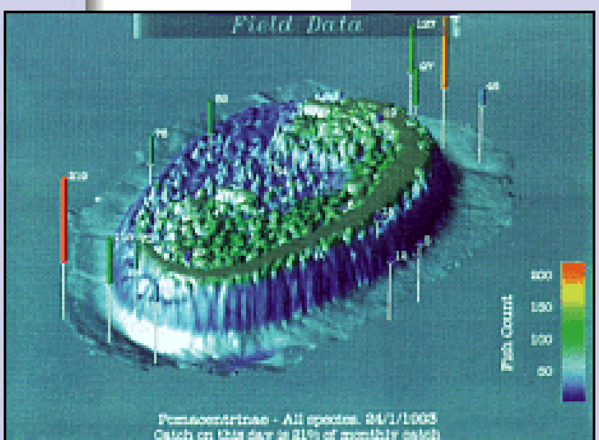

Figure 1d Bowden Reef, about 10 km in the Central Section.

Figure 1e Reticulate reef on the shallow sandy lagoon floor within a 1 km section of Hardy Reef, Central Section.

Figure 1f The scale of a local 'coral community' (up to a hectare), this one composed mainly of branching forms 1-2 m high.

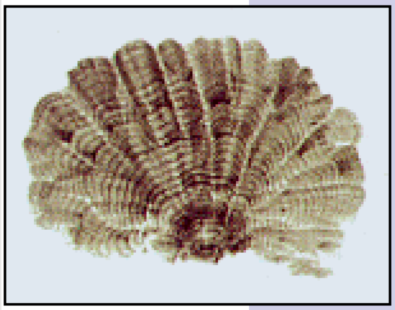

Figure 1g The scale of an individual coral colony, showing annual growth bands which can be used to age the coral and which contain a record of the environment in which it grew. For living ancient corals, this record extends backwards several hundred years before the present.

Photos (b), (d), (f), (g): Terry Done.

Photo (e): Yann Arthus-Bertrand

Earth From Above/UNESCO.

Thanks largely to the accumulated knowledge of basic and strategic research, ranging from the Great Barrier Reef Expedition of 1928 to the present, applied scientists and managers now take a lot for granted about the nature and function of the Great Barrier Reef.

Examples of contributions

The balance of nature?

When the author began to work on coral reefs in the mid-1970s, coral reefs were generally assumed to be very fragile and very stable. With little more than US ecology text books to go on, it was widely assumed that a supposedly benign tropical environment and the high species diversity of coral reefs would combine to dampen out major fluctuations in the abundance of the corals, fish and other creatures which live on reefs. With such background stability, it would be easy to distinguish human-induced instability from nature's balance. There are indeed parts of coral reefs - very sheltered areas in particular - where those concepts do sum up the situation very well.

The destructive influence of cyclones on coral reefs is very patchy due to sheltering effects and differences in the vulnerability of different coral community types and ages

However, it is misleading to suppose that the concepts apply to all parts of all reefs. For a manager asked to 'do something' because a reef has degraded, there is a need to be reasonably sure the degradation is not natural. Some of the research findings relevant to this issue relate to variability in space and time.

For a manager asked to 'do something' because a reef has degraded,

In terms of spatial variability, seventeen different types of 'coral community' have been identified on reefs at different there is a need to be reasonably sure the degradation is not natural

Features of recovery of coral communities following the 1980s outbreak of crown-of-thorns starfish.

All corals

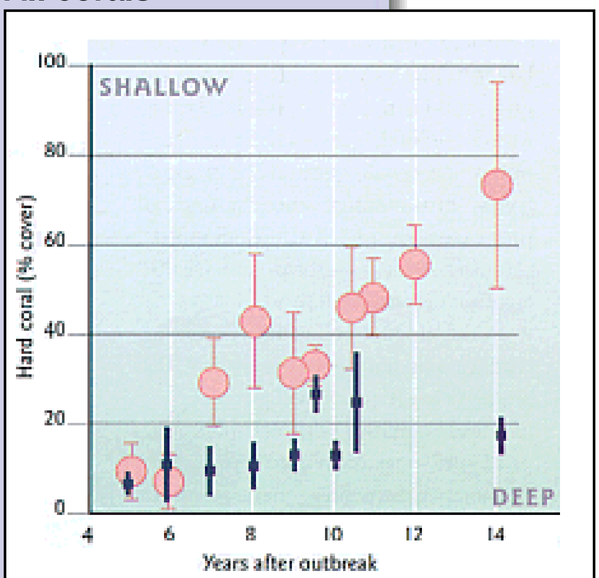

Figure 2a Good recovery of hard corals in shallow water following the 1980s outbreak of 1-3m but slow increase in deeper water of 6m.

(composite of several reefs).

Plate corals

distances from land, and across depth zones and reef-tops within individual reefs[5]. Like vegetation types across a landscape, the abundance of different plants and animals in these communities varies according to many factors: wave energy and turbidity; the types and numbers of fish and other grazing organisms; the ecological succession, and the history of disturbance; the quality of the water flowing onto the reefs[6].

As regards temporal variability, GBR coral reefs are periodically disturbed by events like cyclone waves, floods and crown-of-thorns starfish.

- Cyclones and floods are directly generated by global weather systems and their frequency and severity are greatest in anti-El Nino years[7].These events also affect ocean productivity and other aspects of the ecosystem function, possibly including the generation of crown-of-thorns outbreaks.
- It is also plausible that the frequency and severity of floods and outbreaks of crown-of-thorns starfish may have been changed by humans: by damming and land and water use in the case of floods, and by unknown factors affecting survival of one or more stages of the starfish's life cycle.
- Shallow monitored sites on reefs which had had their entire perimeters badly damaged by crown-of-thorns starfish became picture post-card beautiful' in around a decade, whereas deeper and sheltered sites have often been slow to even begin recovery, due to either poor supply of coral larvae, poor survival, or both (**Figures 2a and 2b**).

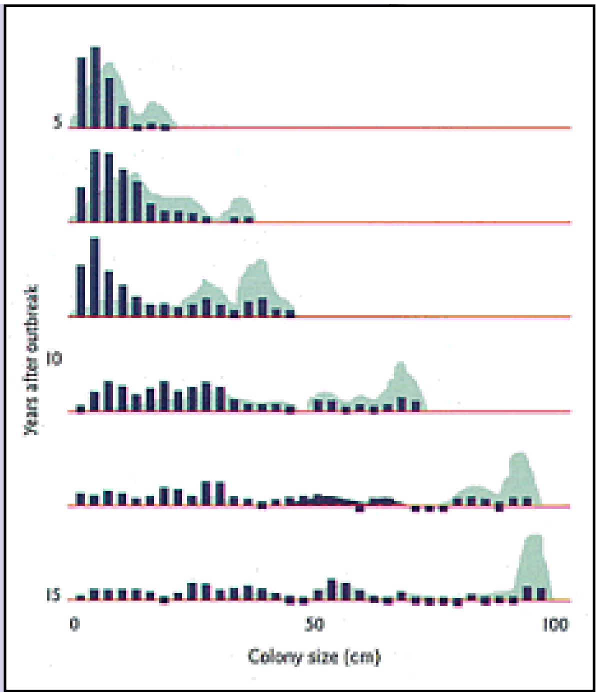

Figure 2b Changes in the size distribution of a major coral type, the plate corals. Bars show increasing range of sizes over a 15-year period post-disturbance. Shading shows the proportion of bottom cover in corals of the different sizes.

Brain corals

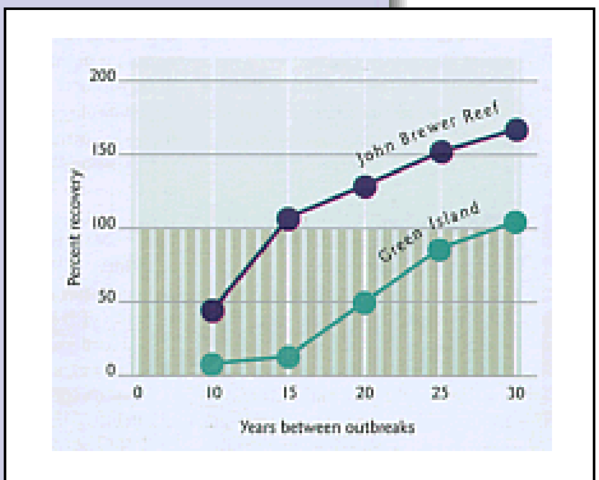

Figure 2c Computer simulation showing implications of increased frequencies of outbreaks for the slow-growing brain corals. At John Brewer Reef, an outbreak of the 1980s intensity could occur as frequently as every 15 years without permanently reducing the abundance of colonies greater than one metre diameter, but at Green Island, the 1980s intensity could be sustained only every 30 years. Recently, in 1997, a third outbreak in 30 years was reported for Green Island.

- Concerns about losses among the slower growing components of the coral community are underscored by data suggesting that the recently observed 15-year interval between outbreaks may only be sustainable at some locations. At others, it would lead to fairly rapid reduction and eventual loss of all the impressive ancient colonies - like a forest without its ancient trees (**Figure 2c**).
- On the Great Barrier Reef, unlike reefs in calmer equatorial latitudes, wholesale destruction of large areas of corals by cyclone-generated waves is a normal occurrence[10]. Calculation suggests that a coral that would have a 50% chance of reaching 60 years of age at Lizard Island (latitude 16°S) would have only a 10% chance if it had happened to settle instead on a reef off Mackay (latitude 2I°S).

The destructive influence of cyclones on coral reefs is very patchy due to sheltering effects and differences in the vulnerability of different coral community types and ages.

The least vulnerable communities, making up about 30% of the surface area of most reefs, are small robust corals forming an interlocking framework which is adapted to strong surfs, and ancient corals weighing many tonnes, bigger than any normal cyclone wave can budge.

The other 70% - diverse shapes and ages of a few years to a few decades - are highly vulnerable and apparently disturbed by cyclones, in a very patchy manner, every few decades.

With such wide ranging background variability, managers asked to 'do something' in response to reports of change in coral reefs must first make some difficult assessments: whether or not human influence has prematurely initiated an otherwise 'normal' change; or whether or not human influence has caused an abnormal change. They may, for example, institute some form of management or mitigation of human influence (for example in terms of anchoring, divers, land or sea-based pollution, over-fishing, destructive fishing, collecting or harvesting).

Long-term monitoring of GBR coral reefs indicates that it is not reasonable to expect coral reefs to be 'picture-post-card beautiful' in all places at all times

Long-term monitoring of GBR coral reefs indicates that it is not reasonable to expect coral reefs to be 'picture-post-card beautiful' in all places at all times, but monitoring alone cannot answer the questions: 'Can this reef state be considered satisfactory at this place and time?' and, for large sections of the GBR, 'How many reefs in various states and stages of recovery are expected?' These questions require an understanding of reef ecology and environment based on ongoing multi-disciplinary research.

SOME EXAMPLES OF CONTRIBUTIONS OF BASIC SCIENCE and Technology to the Management Knowledge Base of the GBR

- There are good maps available due to ongoing hydrographic surveys and advances in satellite remote sensing, aerial photography and airborne sensor technology.
- The species of the major groups, especially corals and fish, have been thoroughly determined, although there are still major gaps for many minor groups, affecting our capacity to document and protect biodiversity.
- Surveys have shown the many different types of sea-floor and reef communities needing to be represented in biodiversity conservation.

Surveys have shown the many different types of sea-floor and reef communities needing to be represented in biodiversity conservation

- The basis for distinguishing human impact from natural change has been developed through surveys and monitoring of corals, fishes and seagrasses over a wide area. Such studies show that recovery periods for naturally disturbed habitats can range from years to many decades.

Studies show that recovery periods for naturally disturbed habitats can range from years to many decades

- The discovery in the mid-1980s of mass spawning and wide dispersal of coral and fish eggs and larvae led to recognition of coral reefs as a network of interconnected and interdependent patches.

In 'good years' about 10-100 times more small juvenile fishes reach coral reefs than in 'bad years'

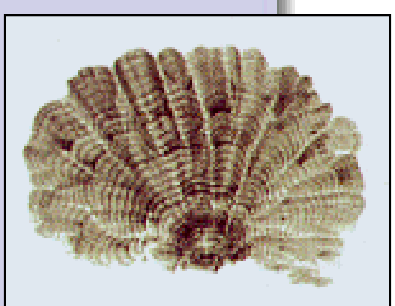

Figure 1g The scale of an individual coral colony, showing annual growth bands which can be used to age the coral and which contain a record of the environment in which it grew. For living ancient corals, this record extends backwards several hundred years before the present.

Photo: Terry Done.

- Habitats separated by tens to hundreds of kilometres are now considered as 'sources' (of eggs and larvae) and 'sinks' (of juveniles ready to settle down and grow to maturity) for each other, and these ideas have become a major consideration in planning for use and protection of habitats.
- It is now possible to reconstruct the distance and direction of movement of eggs and larvae each breeding season over the last several decades. These reconstructions rely on decade-long data from current meters, correlated with sea levels routinely measured in ports.
- Long-term monitoring has shown that in 'good years' about 10-100 times more small juvenile fishes reach coral reefs than in 'bad years'.

- The basis for managing fisheries was given a boost when scientists learned to age fish by reading growth rings in their ear bones.
- Banding patterns in centuries old corals, reminiscent of tree rings **(see Figure 1g)**, have been shown to be libraries of information about past environmental conditions, including temperature and river runoff.
- No convincing signal of widespread environmental degradation has been detected in coral bands. However, it has been shown that the growth of today's corals is within the bounds of variation of the past several centuries.

A NEW ERA

Starting in late 1992, two initiatives combined to give scientists opportunities to become more responsive to the needs of users and managers of the Great Barrier Reef. the development of the Twenty-five Year Strategic Plan for the GBR World Heritage Area (published in 1994), and the establishment of the Co-operative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef (the CRC Reef Research Centre, July 1993).

The strategic planning process regularly brought representatives of the science and management communities together with leaders of all major interest groups: conservationists; recreational and commercial fishers; Aboriginal Australians and Torres Strait Islanders; tourism representatives; local government; and state government departments. Divergent issues and perspectives were brought to the table by different groups:

The strategic planning process regularly brought representatives of the science and management communities together with leaders of all major interest groups

- Fishers (recreational and commercial) expressed concerns about continued reasonable access to a reliable resource;
- Indigenous people wanted to be involved in policy setting and management, and have their traditional uses of the sea respected;
- Conservation groups stressed the need to preserve opportunities for wilderness experiences;

  and

- Tourism operators felt concerned about a shortage of suitable 'sites' for development of visiting and viewing facilities at coral reefs, and for the security and amenity of these sites in the context of destructive acts of nature.

The completed Plan[11] includes a shared vision, principles, objectives and strategies based on the cumulative insights coming from all parties.

There are fifty-seven, five-year objectives grouped under eight broad headings: conservation; resource management; education, communication, consultation and commitment; research and monitoring; integrated planning; recognition of Aboriginal and Torres Strait Islander interests; management processes; and legislation. Three of the five-year (1995-2000) objectives (with the lead agency for implementation) are as follows:

The completed Plan includes a shared vision, principles, objectives and strategies

- To develop, implement and evaluate management plans for harvestable resources, ie. sustainable fishing (Queensland Fisheries Management Authority)
- To have catchment management strategies planned and their implementation commenced in those priority river catchments that will adversely impact on the GBR World Heritage Area (Queensland Department of Primary Industry)
- To protect representative biological communities throughout the Area to act as source areas, reference areas and reservoirs of biodiversity and species abundance (Great Barrier Reef Marine Park Authority).

The remainder of this article provides a glimpse of some of the scientific activities currently under way in support of these three objectives.

Towards sustainable fishing

GBRMPA works through the Queensland Fisheries Management Authority (QFMA) which has responsibility for management of all the diverse fisheries of the GBR Region (trawl, reef line, net and harvest and collection). Their legislation stipulates regard for principles of an ecologically sustainable development, specifically conservation of biodiversity and ecosystem processes as can be illustrated by reference to two fisheries: trawl and reef.

In prawn-trawling areas, previously undisturbed sea-bed habitats are now disturbed on a regular basis by trawling, leading to particular concerns about the amount of by-catch, the fate of biodiversity and ecosystem processes, and the grounds' continued capacity to support the fishery **(Figure 3)**. Research by CSIRO and the Queensland Department of Primary Industry (QDPI) reports that each trawl across the sea-bed removes 5-20% of the sponge, sea-whip, sea-fan, and coral biomass in its path, not to mention the abundant epifauna and flora which live on these animals[12]. Because of a scarcity of taxonomic experts world-wide, complete inventories of sea-bed biodiversity do not exist, and it is, therefore, a case of not knowing exactly what is being placed at risk. The risk itself is also very hard to quantify, because statistics are lacking on the average time between sweeps of the same patch of sea floor, and the extent and amount of undisturbed areas. This will soon be rectified by the fitting of accurate position-fixing transponders to trawlers, but in the meantime, the trawling activity is widely considered to be urgently in need of better information and management.

FIGURE 3

Reasons for research to ascertain sustainable fishing levels.

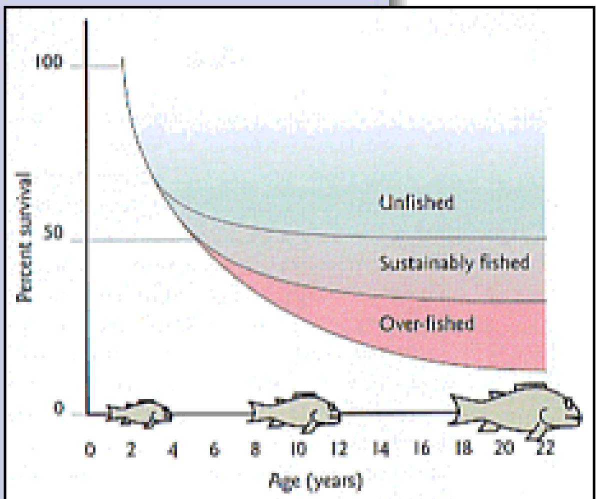

Figure 3a Removal of fishes reduces the proportion of a population which grow to large size and old age.

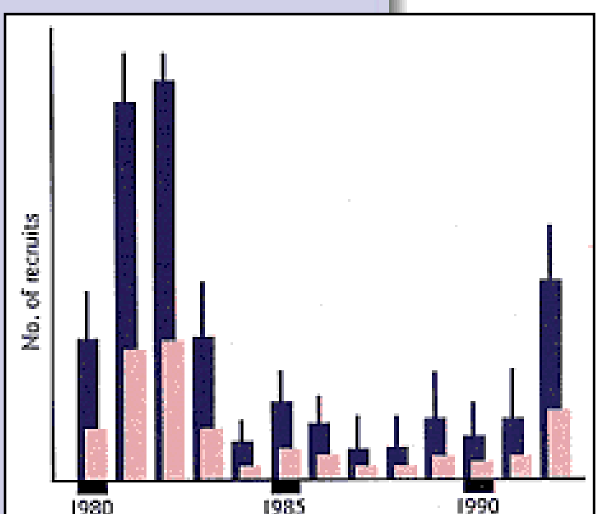

Figure 3b Too great a reduction in the abundance of adult fish reduces the number of eggs to be fertilised, and this may carry through to the number of small juvenile fish settling on reefs. This number is already very variable, probably as a result of factors unrelated to

fishing.

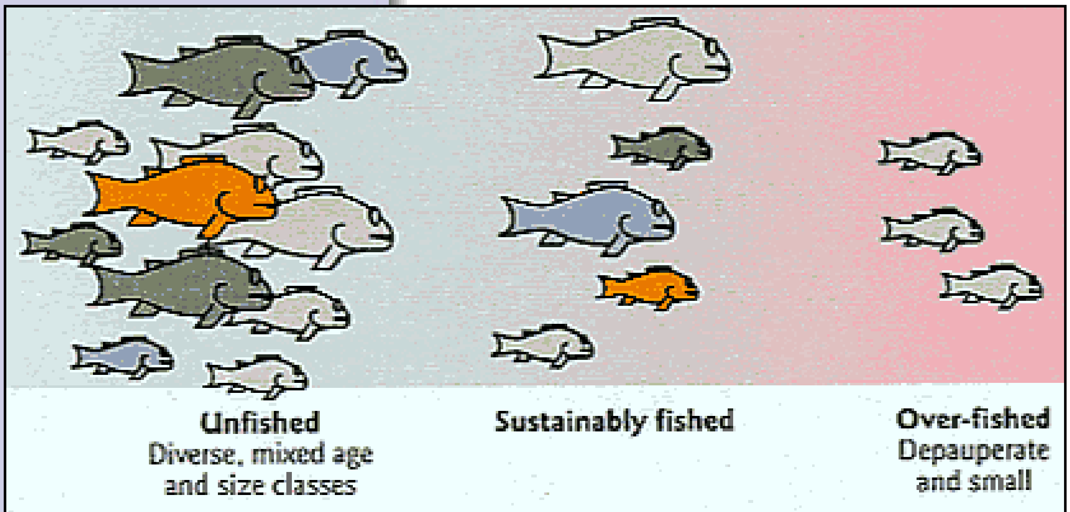

Figure 3c A reduction in (hypothetical) numbers of small juvenile fish may compound the direct effect of removal of adult fish.

The pressure can be taken off sea-bed biodiversity by switching more to mariculture prawns reared and fed in artificial ponds, though this approach brings its own issues of habitat destruction, pollution, and environmental best practice.

Fishing on coral reefs using a hand-line or rod and reel is a major recreational and commercial use of the Reef. The CRC is currently running an 'Effects of Line Fishing Experiments'[13] to provide data on both the effort (distribution, frequency, intensity) and the response (in target and non-target species, and in the broader ecosystem). This project, which involves fishing on eight out of 486 reefs previously zoned as 'no fishing' zones, was commissioned by the GBRMPA and QFMA, which need more information to set safe future levels. The researchers gained wide support for the experiment from commercial and recreational fishing groups, but the opening of the no-fishing zones was opposed by some local conservation groups, sections of the media, and

The pressure can be taken off sea-bed biodiversity by switching more to mariculture prawns reared and fed in artificial ponds

political parties.

The potential benefits in gaining a quantitative understanding on both effort and response sides of the sustainable fishing story applicable to the wider GBR were seen by managers, industry and the broader community to outweigh the temporary and localised depletion of fish numbers that the experiment will promote.

There are many other propositions about the ways the GBR fishing scene could unfold which still need to be assessed scientifically. Two important questions which have been highlighted by QFMA and elsewhere in this article are:

- How can 'source-sink' concepts be best incorporated in the management of sustainable fisheries?
- Are there vulnerable keystone species (for example: those that control nuisance-seaweed increases or even crown-of-thorns starfish numbers) whose populations are intentionally or inadvertently reduced by fishing to levels at which there are flow-on effects to other aspects of the ecosystem structure or function?

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CATCHMENT MANAGEMENT STRATEGIES
for priority river catchments

Aspects of the effects of river runoff into the Great Barrier Reef.

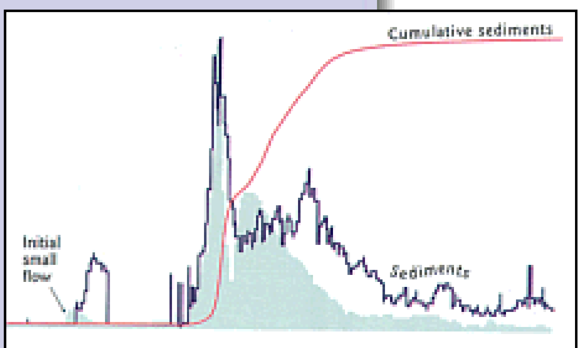

Figure 4a Records from an automated river logger recording continuous river flow and sediment loadings, Burdekin River, 20 December 1995 to 12 February 1996[24].

Figure 4b The Daintree River drains agricultural land in the Atherton and Evelyn Tablelands and tropical forests of the Wet Tropics World Heritage Area (WHA), before entering the Great Barrier Reef between Cooktown and Cairns. The concept of integrated

This objective of the Twenty-five Year Strategic Plan was largely a statement in support of the existing integrated catchment management initiatives established by the Queensland Department of Primary Industry in the interest of the catchment users themselves. The Plan spelled out the health of the GBR, the ultimate downstream sink, as yet another good reason for development of best practice in catchment use. Statistics do suggest there is significant potential for harm resulting from the cumulative effects of increased runoff of nutrients and silts into the Great Barrier Reef over the last century (**Figure 4**)[14]. However, as was pointed out by a QDPI land use manager in a rigorous round-table discussion with researchers: "If you want us to change the way people farm, you had better give us some ammunition", ie. The onus of proof was placed on the researcher and GBR managers.

Proof has so far eluded scientists. According to some researchers, phytoplankton blooms and seaweed abundance on some coral reefs are clear evidence of adverse effects caused by human populations on the coast and in the catchments[15], though this is widely debated.

Some pertinent points are:

- Long-term studies by the

catchment management has been adopted for sediment and water quality control within the Wet Tropics WHA.

Photo: Yann Arthus-Bertrand Earth From Above/UNESCO.

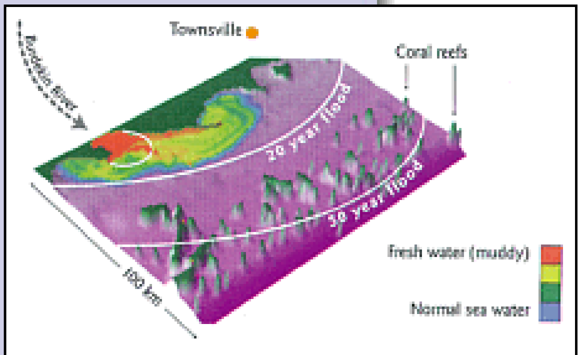

Figure 4c Three dimensional representation of a 200 x 100 km section of the Queensland coast and the Great Barrier Reef and a computer visualisation of a numerical model of a Burdekin River flood plume in 1981, showing that this small flood did not reach the coral reef tract which is a great distance offshore[25]. The dotted line represents the extent of the plume in a hypothetical 50-year flood.

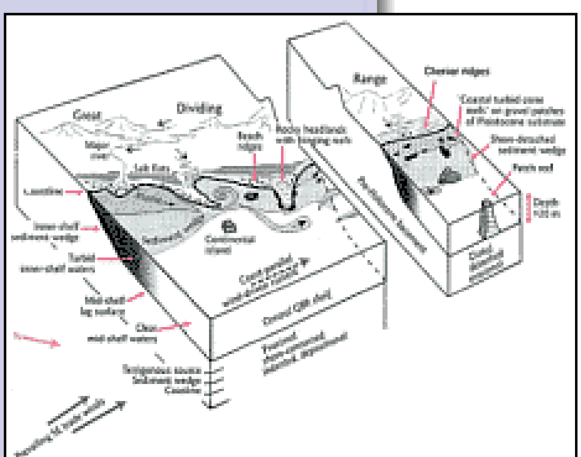

Figure 4d Geologists' block diagram showing how sediments entering GBR waters from rivers are incorporated in a coastal wedge on open coasts and mangrove areas in estuaries[26].

Image above in greater detail

Australian Institute of Marine Science (AIMS)[16] have shown that 'green water' indicative of phytoplankton blooms, is a common natural occurrence in GBR waters. However, except within local and enclosed waters, it has not been possible to demonstrate that any human modification to runoff has significantly increased their intensity, frequency or duration, compared to the contributions of the natural recycling nutrient pool, plus nutrient imports from and exports to the north, east and south of the GBR.

- There are important regional differences along the 2,000 km length of the GBR. For example, the water is deep and the coral reefs are far from the Burdekin River, which has the biggest floods but many dry years. By contrast, reefs grow at the mouth of some of the more predictable smaller rivers north of Port Douglas.
- When a flood plume reaches a coral reef, the freshwater alone can kill the corals, molluscs and other animals, irrespective of the silts or nutrients it carries.
- The dead coral skeletons tend to be overgrown by seaweeds (plants which do not have roots and can attach to dead coral). But at reefs or parts of reefs where there are abundant fish or sea-urchins, the latter can eat the seaweeds almost as quickly as they grow, leaving the area bare except for sparse and wispy shoots of new growth[17].

Where these grazers of the reef are absent or uncommon, seaweed growth can outrun the capacity of the grazers to eat it, and dense seaweed growth (anything from a centimetre to more than

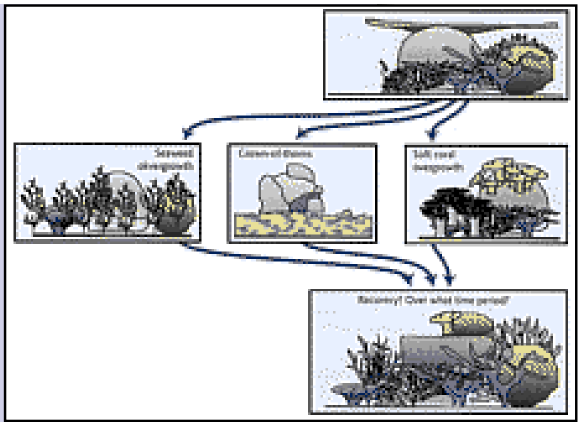

Figure 4e Diagram indicating three types of responses of coral reefs attributed to river runoff (though not proven) (left to right): algal overgrowth (see text); mass coral death when enriched runoff enhances survival of larval crown-of-thorns starfish which increases adult abundance; and soft coral overgrowth (reflecting increased organic matter or possible feeding on phytoplankton).

Image above in greater detail

a metre high) can overwhelm the area. (In Jamaica, there is compelling evidence that overfishing of grazing fish and/or their predators can change the whole coral/seaweed balance on coralreefs[18], but with its perceived relatively light fishing pressure, this is not considered a factor in Australia.) Other observations suggest that 'too many' fish or sea urchins can eat into the fallen rubble and/or reef structure itself (like soil erosion in an overstocked paddock) and that 'too much' phosphorus and nitrogen flowing into GBR waters can aid the seaweed growth and weaken the coral skeletons.

Moreover, while the seaweed can visually dominate an area for many years, it appears to represent one of two states:

- ***Indefinite occupancy*** where seaweeds exclude coral from settling or growing indefinitely;
- ***Transitional occupancy*** where a coral 'understorey' can develop, first noticed as saucer sized encrustations, but over a decade, growing into crowded tables and bushes that exclude the algae completely.

Seagrasses have roots and grow on sand and mud. Unlike seaweeds, they are considered 'good' because some of their type provide nurseries for fishes and prawns and/or food for the endangered dugong. However, they are also vulnerable to the effects of runoff. Interpreting changes in seagrass areas poses similar difficulties to interpreting increases in seaweed abundance. In 1992, over 1,000 km^2 of seagrass died in Hervey Bay due to storm waves (shallow seagrasses) and persistent light deprivation (greater than 10 m deep) caused by the turbid plume of a 100-year flood and resuspension of sediments in

Figure 5a: Long-term monitoring of corals is conducted along fifteen 50 m long video transects at around fifty different reefs spread over 1,000 km of the Great Barrier Reef. Thirty permanent photo-transects are used for spatial temporal monitoring of changes in benthic communities in six reefs subject to various disturbances, such as predation by crown-of-thorns starfish, siltation and storm damage.

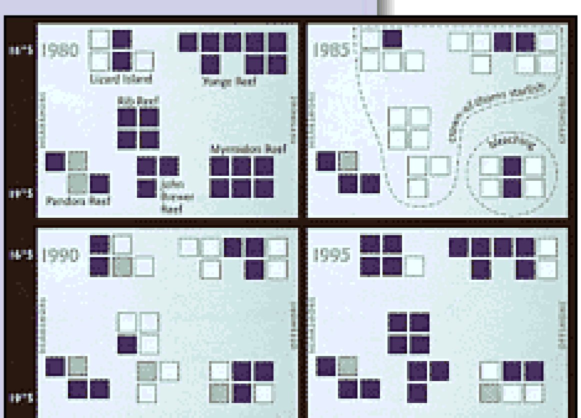

Figure 5b:

Image above in greater detail

The approximate latitudes of the reefs and locations on the continental shelf are indicated on

cyclonic seas[19]. This event led to starvation, deaths and emigration in an important dugong population that will take 25 years to recover[20]. While 'runoff' was clearly a major cause of this event, it remains to be established whether agricultural or other land use in the catchments emptying into Hervey Bay caused the plume to be more turbid, to cover a larger area, or to persist longer than it would have, prior to the area's development for agriculture.

The seaweed and the seagrass stories recounted here thus do provide ammunition for the DPI catchment manager. The mechanisms by which runoff can do damage are understood, but we have been forced to acknowledge that 'other factors' (for example, existing nutrient pools, export and import of GBR nutrients, disturbance, and grazers as co-determinants of algal abundance) may equally influence ecological outcomes and management responses. The need to separate natural from people-generated changes remains unresolved.

Part of science's responses to this need is the continuation of scientifically unfashionable but important broad-scale ecological surveys and long-term monitoring programmes including the use of photo and video transects in spatial-temporal monitoring (**Figure 5**)[21]. These show us 'how, and how fast' things change in different parts of the GBR, and stimulate ideas and research about the 'why'. The way forward for conveying geographically explicit information and advice to managers, currently under development, is seen to be through the use of advanced databases, knowledge-bases, Geographic Information Systems, risk assessment approaches and links to decision support processes.

the edges of the boxes. The number of squares at each location indicates the number of photo-transects (each 10-32 m^2). Colours indicate the overall benthic dominance of the transect:

dark blue = coral dominated;
white = predominantly 'bare';
green = 'other' dominated.

Source: Done (1997)[21].
Photo: Terry Done.

REPRESENTATIVE PROTECTED AREAS.
A key tool for management

The long-term monitoring of winds, tides and currents in and adjacent to the GBR is providing invaluable data

Work is currently underway to quantify the level of risk at different places in the GBR

Current and future arrangements for management of the GBR involve the majority of the World Heritage Area remaining available to regulated, multiple uses. Embedded within the multiple use area are a number of protected areas (about 4% of the whole, and 16% of the reefs) from which any fishing or collecting is prohibited. The adequacy of this arrangement has never been assessed scientifically, and a revision is currently under way. A mixture of cultural, socio-economic and scientific approaches will identify, evaluate and refine options for the next network of protected representative areas.

For selecting representative areas, we are using existing knowledge to provide the basis for dividing the GBR into 'bioregions', with the strong cross-shelf pattern in flora and fauna guiding the identification of the bioregions. These exist for a variety of biotic groups of coral reefs (notably corals, fish, sea-weeds, and sponges) and of the seafloor (seagrasses, seaweeds, sponges, echinoderms and molluscs). For planning, the better known groups are assumed to be surrogates for those unstudied. We are currently investigating the best means of extrapolating from studied to unstudied or thinly studied areas on the basis of factors such as depth, sediment types, and shelter.

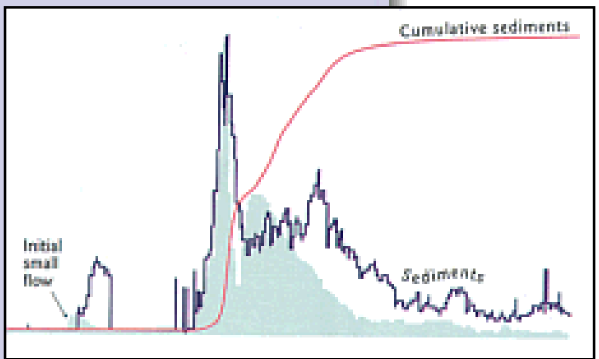

Figure 4a Records from an automated river logger recording continuous river flow and sediment loadings, Burdekin River, 20 December 1995 to 12 February 1996[24].

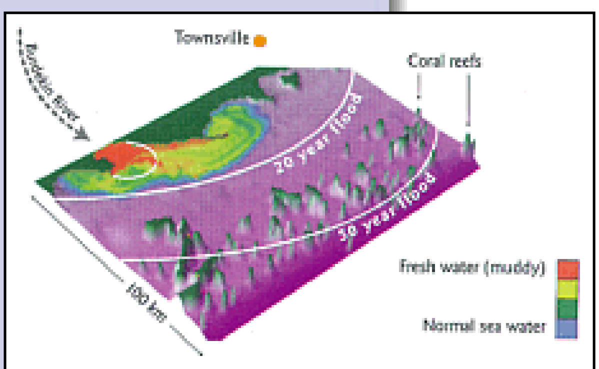

Figure 4c Three dimensional representation of a 200 x 100 km section of the Queensland coast and the Great Barrier Reef and a computer visualisation of a numerical model of a Burdekin River flood plume in 1981, showing that this small flood did not reach the coral reef tract which is a great distance offshore[25]. The dotted line represents the extent of the plume in a hypothetical 50-year flood.

For optimising connections, AIMS and James Cook University are investigating the utility of the 'source-sink' concept for evaluating options for protected area networks. The long-term monitoring of winds, tides and currents in and adjacent to the GBR[22] is providing invaluable data to build predictive current models and to 'drive' computer models of fish and coral dispersal. 'Virtual' computerised coral reefs on computerised maps release clouds of computerised eggs and larvae of fish, corals and crown-of-thorns starfish[23]. The underlying mathematical models, which simulate sea currents meandering among the coral reefs, are driven by tidal projections and by wind data from the AIMS network of GBR weather stations.

In spreading of risks, the design of the system of marine protected areas needs to insure against the likelihood that areas within it may from time to time be compromised by a single crown-of-thorns starfish outbreak, cyclone, or flood plume. Work is currently underway to quantify the level of risk at different places in the GBR.

- For flood plumes, a programme of measurement and modelling (**Figure 4a**)[24] is in place to quantify long-term delivery regimes of freshwater, nutrients and sediments to river mouths. Hydrodynamic models (**Figure 4c**)[25] are being used to define risks of exposure of any given place to the flood plumes, with geologists' block diagrams being used to show how sediments from rivers are incorporated in a coastal wedge on open coasts and mangrove areas in estuaries (**Figure 4d**)[26].
- For cyclones, the meteorological record of cyclone tracks and

central pressures is being used with wind prediction algorithms and field observations to characterise parts of the GBR in terms of their risk of cyclone damage to coral reefs.

- For crown-of-thorns starfish, field observations are combined with connectivity modelling to map and predict the geographic distribution of impact and risks of damage[27].

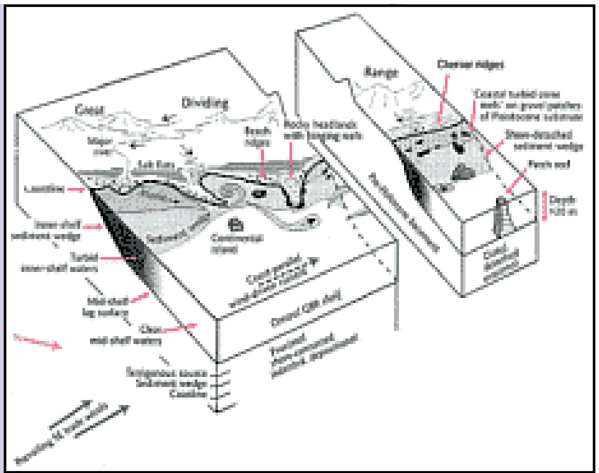

Figure 4d Geologists' block diagram showing how sediments entering GBR waters from rivers are incorporated in a coastal wedge on open coasts and mangrove areas in estuaries[26].

Image above in greater detail

DISCUSSION

Use of the Reef and the adjacent land has been increasing for some time

Learning to understand, predict, use and protect the nature and functioning of this vast piece of the globe stretches the limits of imagination, science and technology, as well as the patience of the manager who needs to make decisions here and now. In the past, it may have been safe to assume that the enormous size and remoteness of the GBR would cause any human impact to pale into insignificance compared to changes wrought by cyclonic waves and floods, or natural variations in the populations of fishes from place to place and year to year. However, the intensity of our use of the Reef and the adjacent land has been increasing for some time, and it is time to assess whether this trend is taking the ecological systems anywhere near the brink of irreversible damage, or whether indeed there is capacity for continued growth, and if so, where it should be located.

Management of the GBR as a substantial contributor to Australia's wealth and prestige is now providing funds and impetus for challenging and rewarding applied science

On the stock market, investors expect the share price of the individual listed companies to rise and fall, but we hope that the leading index of economic well-being will be stable or rise slowly. To a tourism operator, the ecological performance of the one-hectare patch which sustains the business is of as much relevance as any leading ecological indicator for the entire GBR. For the recreational and commercial fisher who ranges more widely, the well-being of the mosaic, more than the individual patch, is what matters. For the Authority, acting on behalf of the community, there is the balancing act of optimising access and exploitation across scales, recognizing intrinsic variability and the role of acts of nature beyond human control.

Management of the GBR as a substantial contributor to Australia's wealth and prestige is now providing funds and impetus for challenging and rewarding applied science. Back in the days when GBR science was allowed more latitude to follow up serendipitous findings and its own hunches about what was useful or interesting, managers gained invaluable insights they now simply take for granted. Being taken for granted is probably as good an endorsement for basic strategic science as there can be!

The Great Barrier Reef ... at a Glance

There is still much about the biology of the GBR that we can barely begin to comprehend, let alone manage appropriately. The more inaccessible of these areas may not be threatened by anything we are currently doing to the environment. However, in our heavily-trawled areas, the spectre of losing substantial biodiversity before it has even been described, let alone how it contributes to human needs, is real.

For science in support of management, there is an important need to set the right mix between applied, strategic and basic research. Towards the applied end, the mix needs to include capacity building in 'system level' assessment as discussed above, for example in the area of assessing 'connectivity's' and the geographic extent of influence of land runoff and of levels of risk from a wide spectrum of natural and anthropogenic threats, including the impact of fishing practices. Towards the more basic end, there is a need to re-tool for taxonomy and inventory of basic biology. Even on coral reefs, if one looks far beyond corals, fish and sea-shells, there are groups whose taxonomy is poorly known,

Electronic publishing and the Internet are consolidating the position of the settled taxonomic groups

or is the sole domain of one or two specialists world-wide. On seafloor habitats, the continental slope habitats and the deep reef habitats, the undoubtedly rich biodiversity is essentially unknown.

Electronic publishing and the Internet are consolidating the position of the settled taxonomic groups, but even there, due to limitations in language and technology, the species level expertise often resides only with individual specialists. Due to the run-down in support for training of taxonomic specialists, and the ageing demographics of those currently working, world science is currently at a low ebb in its capacity to make these descriptions. This is particularly serious for Australia, with its new responsibilities not only for the GBR World Heritage Area, but also for our vast Exclusive Economic Zone[28].

THE GREAT BARRIER REEF … At a glance

About two million people visit the Reef and its adjacent coast annually and in recent years the number of visitors has been increasing

The Great Barrier Reef - the largest system of coral reefs in the world - is more than 2,000 km in length and comprises 2,900 separate reefs and 940 islands. Its high species diversity includes more than 400 species of coral, 4,000 species of molluscs, 1,500 species of fish, six species of turtles, 35 species of seabirds and 23 species of sea mammals.

The idea that the Great Barrier Reef should become a marine park was mooted as early as1963 by the Wildlife Preservation Society of Queensland. Concerns over the level of foreign fishing and tourism industries highlighted the lack of protection for the Great Barrier Reef in the 1960s. The prospects of oil drilling and limestone mining upon the reef were pivotal in initiating a campaign that culminated in the Great Barrier Reef Marine Park Act 1975 (Commonwealth), the legislative basis for the Great Barrier Reef Marine Park Authority.

The Great Barrier Reef was accepted for inclusion upon the World Heritage List in 1981, meeting all four of the natural heritage criteria. A multiple-use, protected area of 348,700 km^2, the Marine Park is the world's largest marine protected area, and is Australia's premier marine tourism destination.

Pressure

Perceived pressures on the Reef include declining water quality in inshore areas, due mainly to elevated sediments and nutrients from changes of land use in coastal catchments; fishing (particularly trawling of the seafloor and overfishing of some reef species):coral mortality caused by outbreaks of the crown-of-thorns starfish (the causes of which still remain unknown): storm events: the threat of oil and chemical spills and ballast water introduced from shipping: and the effects of tourism.

About two million people visit the Reef and its adjacent coast annually and in recent years the number of visitors has been increasing by 10% each year (30% in the Cairns area).

State

The size of the GBR World Heritage Area, from the low water mark on the mainland coast to past the edge of the continental shelf, and from the tip of Cape York Peninsula to just north of Fraser Island, ensures that a highly diverse suite of habitats and environmental regimes at a range of spatial scales are represented in the one World Heritage Area. This habitat diversity gives rise to a vast number of species and ecological processes.

The Great Barrier Reef is one of the least anthropogenically disturbed coral reef systems in the world and most of it is still in a relatively good condition. There is photographic evidence of coral mortality on the tops of some inshore reefs but the evidence is patchy and not consistent on all reef tops for which historical photos are available. Possible causes include cyclones and increased sediments and nutrients.

Crown-of-thorns starfish have damaged nearly 20% of reefs, largely in the central one-third of the Reef

Recent evidence also suggests that parts of some reefs in the Capricorn Bunker sector of the Great Barrier Reef are showing signs of degradation: hard coral and fish appear to be reduced compared with other parts of the Reef. The causes of this are unknown, but do not appear to be related to the crown-of-thorns starfish or to cyclones. Strong recovery of corals has been recorded in the most recent surveys. Elsewhere on the GBR, crown-of-thorns starfish have damaged nearly 20% of reefs, largely in the central one-third of the Reef. Damage in affected areas ranges from slight to very severe, and the extent and speed of recovery is likewise variable.

Management

The Great Barrier Reef is managed by the Great Barrier Reef Marine Park Authority (GBRMPA), with the Queensland Department of the Environment responsible for day-to-day management. Oil drilling and mining are prohibited in the Marine Park. The establishment of the GBRMPA coincided with a significant period of expansion in tourism, particularly around Cairns. As a result, development and access for visitors has been planned and regulated within the context of a marine protected area. Use of the Great Barrier Reef is regulated primarily under a zone-based planning scheme intended to achieve sustainable use of coastal and marine resources. Among the challenges is that of harnessing co-operation for maintaining environmental protection, particularly in relation to pressures by coastal development, and increasing resident populations and tourist numbers. The involvement of state and local government bodies and industry is crucial to achieving this broad management goal.

Among the challenges is that of harnessing co-operation for maintaining environmental protection

While the agency approach has worked well on a case-by-case basis and has proved effective even in extremely complex projects -such as a now-defunct and removed floating hotel - it has sometimes proved difficult at a local level. For example, the development of strategic management plans for the Whitsunday and Cairns subregions has highlighted the problems of coordinated management and demonstrated the need for co-operative planning of regional tourism. These cases also reveal the complexity of issues that must be addressed if tourism, fishing, shipping, and assimilation of runoff from the land are to be sustainable in areas of high conservation value such as the Great Barrier Reef.

Crown-of-thorns starfish feeding.

The Authority recently coordinated the development of a 25-year strategic plan, involving over seventy user groups, for the Great Barrier Reef World Heritage Area. Variables such as coral cover, crown-of-thorns starfish, dugongs, turtles and nutrients are routinely monitored throughout most of the Great Barrier Reef, and there is progress in the development of indices and indicators of local- and region-scale health of the GBR ecosystems[2].

Précis of principles, vision and broad areas for objectives and strategies.

Shared principles

- Management of the Area as a multi-use marine park
- Meeting obligations under World Heritage Convention to ensure protection, conservation, presentation and transmission to future generations
- Ecologically sustainable use as a corner-stone of planning process
- Recognizing natural variability in the ecosystems
- Responsibility for health, longevity and care of ecosystem
- Adoption of the precautionary principle
- Recognition of special situation and rights of Aborigines and Torres Strait Islanders
- Commitment by all stakeholders to planning and implementation process
- Equitable opportunities for multiple use and enjoyment - this and future generations
- Limits on natural resource use based on ability of environment to sustain such use
- Financial analysis alone not sufficient basis for cost-benefit analyses
- Recognition that financial and opportunity costs of all use and preservation should be met equitably
- Recognition of a wide range of values in making balanced resource allocation decisions.

The 25-year vision

In the Great Barrier Reef World Heritage Area, in 2020 there will be:

- A healthy environment
- Sustainable multiple use
- Maintenance and enhancement of values
- Integrated management
- Knowledge-based but cautious decision-making in the absence of information
- An informed, involved community.

Objectives and strategies under the following eight broad areas:

1. Conservation
2. Resource management
3. Education, communication, consultation and commitment
4. Research and monitoring
5. Integrated planning
6. Recognition of Aboriginal and Torres Strait Islander interests
7. Management processes
8. Legislation

Source:
Great Barrier Reef Marine Park Authority (1994)[11].

CONSERVATION MEASURES

Figure 6a The reef flat exposed at low tide. Scenes like this led Australian Institute of Marine Science scientists to discover and synthesise natural sunscreens which protect the corals.

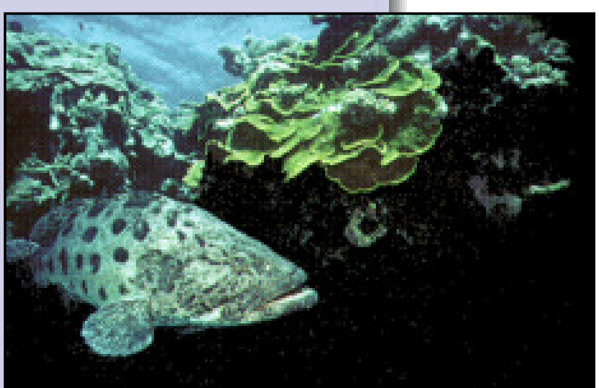

Figure 6b A giant potato cod and coral. A special reserve within the Marine Park protects this fish species.

Conservation measures in the Great Barrier Reef include the prohibition of fishing and collecting in a number of protected areas, which currently cover about 4% of the whole Great Barrier Reef and 16% of the reefs.

The strong cross-shelf pattern in flora and fauna is being used for guiding the identification of bioregions, as a basis for refining the selection of representative areas for future protection.

Associated research efforts include the long-term monitoring of winds, tides, currents and coral condition, and use of the 'source-sink' concept in evaluating options for protected area networks.

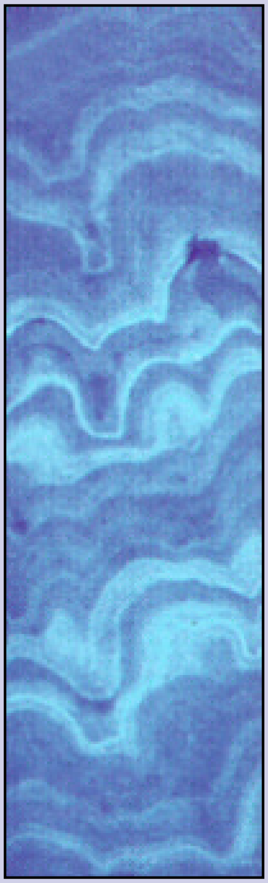

Figure 6c Approximately 40 x IO cm section from a core of the massive *Porites* coral. Fluorescent bands are laid down in those years when floodwaters reach the coral reefs. (See also Figure 1g)

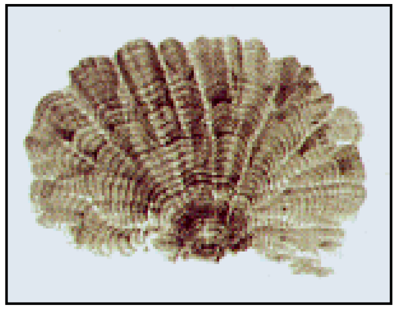

Figure 1g The scale of an individual coral colony, showing annual growth bands which can be used to age the coral and which contain a record of the environment in which it grew. For living ancient corals, this record extends backwards several hundred years before the present.

Photos:
Figures 6a, 1g Terry Done.
Figures 6b, 6c AIMS Photo-library.

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