Vol 23 No.2 June 1993

SPUMS JOURNAL

ISSN 0813 - 1988

South Pacific Underwater Medicine Society Incorporated

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Publication Number VBH3527

PRINTED BY *Snap Printing*
344 Burwood Road
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OBJECTS OF THE SOCIETY

To promote and facilitate the study of all aspects of underwater and hyperbaric medicine.
To provide information on underwater and hyperbaric medicine.
To publish a journal.
To convene members of the Society annually at a scientific conference.

OFFICE HOLDERS

MEMBERSHIP

Membership is open to medical practitioners and those engaged in research in underwater medicine and related subjects. Associate membership is open to all those, who are not medical practitioners, who are interested in the aims of the society.

The subscription for Full Members is $A80.00 and for Associate Members is $A40.00.

The Society's financial year is now January to December, the same as the Journal year.

Anyone interested in joining SPUMS should write to

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INSTRUCTIONS TO AUTHORS

The SPUMS Journal welcomes contributions (including letters to the Editor) on all aspects of diving and of hyperbaric medicine. Manuscripts must be offered exclusively to the SPUMS Journal, unless clearly authenticated copyright exemption accompanies the manuscript.

Minimum Requirements for Manuscripts

All contributions should be typed, double-spaced, using both upper and lower case, on one side of the paper only, on A4 paper with 45 mm left hand margins. All pages should be numbered. No part of the text should be underlined. These requirements also apply to the abstract, references, and legends to figures. Measurements are to be in SI units (mm Hg are acceptable for blood pressure measurements) and normal ranges should be included. All tables should be typed, double spaced, and on separate sheets of paper. No vertical or horizontal rules are to be used. All figures must be professionally drawn. Freehand lettering is unacceptable. Photographs should be glossy black-and-white. Colour prints or slides will normally be printed as black and white. Colour reproduction is available only when it is essential for clinical purposes and may be at the authors' expense. Legends should be less than 40 words, and indicate magnification. Two (2) copies of all text, tables and illustrations are required.

Abbreviations do not mean the same to all readers. To avoid confusion they should only be used after they have appeared in brackets after the complete expression, e.g. decompression illness (DCI), and thereafter czn be referred to as DCI.

The preferred length of original articles is 2,500 words or less. Inclusion of more than 5 authors requires justification. Original articles should include a title page, giving the title of the paper and the first names and surnames of the authors, an abstract of no more than 200 words and be subdivided into Introduction, Methods, Results, Discussion and References. After the references the authors should provide their initials and surnames, their qualifications, and the positions held when doing the work being reported. One author should be identified as correspondent for the Editor and for readers of the Journal. The full current postal address of each author, with the telephone and facsimile numbers of the corresponding author, should be supplied with the contribution. No more than 20 references per major article will be accepted. Acknowledgements should be brief.

Abstracts are also required for all case reports and reviews. Letters to the Editor should not exceed 400 words (including references which should be limited to 5 per letter). Accuracy of the references is the responsibility of authors.

References

The Journal reference style is the "Vancouver" style, printed in the Medical Journal of Australia, February 15, 1988; 148: 189-194. In this references appear in the text as superscript numbers.[1-2] The references are numbered in order of quoting. Index Medicus abbreviations for journal names are to be used. Examples of the format for quoting journals and books are given below.

1 Anderson T. RAN medical officers' training in underwater medicine. *SPUMS J* 1985; 15 (2): 19-22
2 Lippmann J and Bugg S. *The diving emergency handbook*. Melbourne: J.L.Publications, 1985: 17-23

Computer compatibility

The SPUMS Journal is composed on a Macintosh using Microsoft Word and PageMaker. Contributions on 3.5" discs, preferably in Microsoft Word for Macintosh (MSDOS or Windows can also be read) or in any program which can be read as "text" by Microsoft Word, save typing time. They must be accompanied by hard copy set out as in **Minimum Requirements for Manuscripts** above.

Consent

Any report of experimental investigation on human subjects must contain evidence of informed consent by the subjects and of approval by the relevant institutional ethical committee.

Editing

All manuscripts will be subject to peer review, with feedback to the authors. Accepted contributions will be subject to editing.

Reprints

The Journal does not provide reprints.

Address for all Contributions

Dr John Knight, Editor, SPUMS Journal, Suite 304, 126 Wellington Parade, East Melbourne, Victoria 3002, Australia. Facsimile 61-(0)3-417 5155.

Telephone enquiries should be made to Dr John Knight (03) 417 3200, or Dr John Williamson (08) 2245116.

SPUMS ANNUAL SCIENTIFIC MEETING 1994

will be held at
Rabaul, Papua New Guinea
Provisional dates **MAY 14th to 23rd 1994**

The guest speaker will be Dr Peter Bennett, co-author with Professor David Elliott, the 1993 guest speaker, of The Physiology and Medicine of Diving.

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FIRST ANNUAL SCIENTIFIC MEETING OF DIVING AND HYPERBARIC MEDICINE

will be held in Darwin, Northern Territory, Australia on July 29th and 30th 1993.

The meeting is sponsored by the
Hyperbaric Technicians and Nurses Association (HTNA)
and the
Australian and New Zealand Hyperbaric Medicine Group (ANZHMG).
Non-members are welcome to attend.

The AGMs of both associations will be held on July 31st.

The main topics will include, but are not limited to, wound healing, decompression illnesses, hyperbaric treatment profiles, recreational nitrox diving, new technical developments and current hyperbaric research.

For further information contact

Ms Jodie Perris
Royal Darwin Hospital Hyperbaric Unit,
Rocklands Drive,
Tiwi,
Northern Territory 0810, Australia.

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PROJECT STICKYBEAK

This project is an ongoing investigation seeking to document all types and severities of diving- related accidents. Information, all of which is treated as being **CONFIDENTIAL** in regards to identifying details, is utilised in reports and case reports on non-fatal cases. Such reports can be freely used by any interested person or organisation to increase diving safety through better awareness of critical factors.

Information may be sent (in confidence) to:
Dr D. Walker
P.O. Box 120, Narrabeen, N.S.W. 2101.

The Editor's Offering

This issue of the Journal is different from all others. It is the first one that has had a theme. The theme, explained below by Dr John Williamson, is the Great Barrier Reef (GBR). This was the theme of the Annual Scientific Meeting (ASM) in 1992, held at Port Douglas.

Readers have already seen most of the papers presented at the Symposium on Diving Safety on the Great Barrier Reef. We have held off printing the marine scientist's papers until now so that we could try out the idea of a theme issue on our readers. One of the reasons for the delay was that some of the speakers at the ASM were less than prompt in providing the texts of their papers. Some still have not done so. This means that the majority of members, who cannot attend the ASM, will miss out on interesting and informative papers. It does have its good points though. If we had more material to print the cost of postage of this issue would have increased as the Journal, with the Diving Doctors list and envelope, is only just under 250 g in weight. Another 4 printed pages, the minimum increase, would take it over 250 g and then postage costs double.

As a result of putting all the available Barrier Reef papers into one issue there is little room for anything else. We just had room for a fascinating paper by Brian Hills, suggesting that it is surfactant, acting as a flap valve, that keeps air out of pulmonary blood vessels and allows oedema fluid into alveoli. Surfactant used to considered as the material which stopped our lungs collapsing when we breathed out. Since Brian Hills showed, many years ago, that it really kept fluid to the corners of alveoli, so reducing the distance oxygen has to diffuse, it has been found in many unexpected places including the stomach and in joints. A truly versatile molecule.

However we have not given up hope that some, and hopefully most, of those who have not yet sent in their GBR manuscripts may achieve it one day. In the meantime we have put into this one issue enough material to have provided three issues of the Journal if it had been combined with our usual amount of reprinted articles and abstracts from medical Journals.

As always we need more papers if we are to keep up the standard of the SPUMS Journal. We need letters to the Editor about topics of interest, about diving safety and medical problems of diving. We need case reports and opinions. This is not a plea for instant papers of doubtful quality. It is a restatement of a SPUMS point of view. SPUMS needs more members who contribute more to diving medicine than just doing medicals. Sharing ones knowledge or ideas, even if they are a bit unclear, is a great way to contribute to the growth of knowledge. Even if no one else thinks the same way as you do, you may be right and the others wrong ! Every paper submitted to the Journal is peer reviewed. If it is accepted the editorial staff help the writer express his or her meaning clearly and, we hope, concisely. No one doctor will see all the problems of diving, but collectively, if we work together, we can provide case reports which cover everything. Then the information can be co-ordinated by someone as Douglas Walker has done with diving deaths for nearly 20 years and Chris Acott is doing with diving incidents.

The Australian Medical Association (AMA) Federal Secretariat has not, as yet, replied to the Editor's letter of late March. Their secretariat requested an article, about the reasons for having training in underwater medicine before doing diving medicals, for their publication *Australian Doctor*. Dr Wilkins was to present the reasons why training was unnecessary. Although provided two months ago this article has yet to appear. The Editor has been informed, via the grapevine, that the Queensland Branch of the AMA has recently voted to rescind their opposition to the need for training before undertaking diving medicals. We hope that the Federal AMA will soon feel in a position to support SPUMS' efforts to provide better care for trainee divers. After all their Code of Ethics says that doctors should not work outside their field of expertise.

The workshop held at the recent ASM in Palau on Emergency Ascent will be the theme for a later issue. This should generate a number of Letters to the Editor as there are so many views on what is the right way to organise one's rapid return to the surface.

The diver, the Great Barrier Reef and our planet

There would scarcely be a diver who has not heard of "Australia's Wonder of the World", The Great Barrier Reef (GBR). Indeed thousands of Australian (and hundreds of thousands of visiting international recreational) divers have already dived safely on it.[1] Many have come away from this experience awe inspired.

However, fewer divers will be aware of the Australian Institute of Marine Science (AIMS), located at Cape Ferguson, just south of Townsville in North Queensland. This body of internationally renowned scientists, of many different scientific disciplines and nationalities,[2] studies the complex combinations of geological, palaeontological, physical, chemical, oceanographic, climatic, biological, ecological and environmental elements that make up the GBR. These studies have had profound influence, and in a partially unexpected way, even to the scientists themselves, are causing Australians, and the world, to look at the GBR and all world reefs and their environs in a more respectful light. The work of AIMS is bringing us to understand that coral reefs and their environments are important, even crucial, ecological treasure stores for mother earth and its inhabitants. Two examples are Dr John Veron's work on corals,[3] and the AIMS research that is revealing the previously unappreciated and pivotal biological role played by mangroves.

The South Pacific Underwater Medicine Society (SPUMS) believes that divers are sensitive to the gathering momentum of influence which says we must stop destroying our environment like imbecile children and protect our planet, or die. Divers, by selection, tend to be an environmentally conscious group of people anyway, if not before they undertake diving, then very soon afterwards. Apart from the threat to our very existence of our race's destructive behaviour towards the earth's natural resources, what diver would argue against preserving the opportunity for ourselves and our children to witness the exquisite Ming-blue of a pollution-free coral sea, or the almost spiritual, cathedral beauty of an underwater living reef ?

So it is hardly surprising, and indeed perhaps past time, that the 1992 Annual Scientific Meeting (ASM) of SPUMS held at Port Douglas, Far North Queensland, from the 30th May to the 6th June, was devoted to the GBR, and that the scientific program involved the participation of many leading scientists from AIMS, the Great Barrier Reef Marine Park Authority (GBRMPA) and the James Cook University of North Queensland (all located in Townsville). Leading this cohort of some 17 internationally respected researchers was Dr Michel Pichon, DSc., the Deputy Director of AIMS and a leading coral taxonomist and ecologist. Several of the speakers discussed new research findings never before presented, and many showed original slides and films of breathtaking quality. All conveyed their own deep respect for the intricate and beautifully balanced complexity of the GBR, and appealed to us all to preserve and learn from it. To conclude the program there was a short symposium on Diving Safety and Diving Medical Management on the GBR to which both diving doctors and representatives of the diver training organisations contributed. This included a consideration of the difficult area of Queensland's legislative efforts to increase safe diving workplace practices presented by Mr John Hodges, Director of the Division of Workplace Health and Safety, of the Queensland Department of Employment, Vocational Education, Training and Industrial Relations.

This issue of the Journal is a theme issue based upon some of the outstanding presentations at Port Douglas. It provides a feast of information. For example, read the description by Martin Jones, Curator of the Great Barrier Reef Aquarium in Townsville, of the amazing learning curve involved in the creation of that Aquarium's, now internationally renowned, artificial living reef A paper which will excite those interested in venomous marine animals are by Dr Jacquie Rifkin, PhD, on jellyfish nematocyst structure and function. The contribution by Dr Ed Drew, PhD, on *Halimeda* banks is also fascinating. In fact the Port Douglas program featured so many "world authorities" on their respective subjects that they became almost common place at the Meeting, to the delegates!

All who attended Port Douglas were, and all those who read the papers in this issue will be, left with a heightened appreciation for the beauty and delicacy of the interplay of marine life on the GBR. More than that, diving delegates to Port Douglas looked through the different eyes of enhanced understanding, as they dived from MS "Quicksilver" during 3 days of diving on the outer Reef and they clearly showed greater care for the coral and fish life.

What can divers do to help preserve this mightiest and most beautiful of the world's living structures and halt the damage and pollution that still occurs (although decreasingly of late, thanks largely because of the work of GBRMPA, with its development of the marine park concept)? When asked this question at Port Douglas, Dr Joe Barker OBE, PhD, the Director of AIMS replied, "At least three things! First, divers should avoid passing urine while diving on the reef. The chemical composition of human urine is hostile to the delicate coral and fish life. Second, never stand upright on a living coral reef wearing fins. Extensive reef damage can result. Third, if you witness first-hand an unusual or unexpected Reef phenomenon while diving, report it. If possible, and it is safe to do so, photograph the event as well." Both AIMS (077-789 3211) and the Hyperbaric Medicine Unit at the Royal Adelaide Hospital (08-224 5116) would be pleased to receive such notifications. Of course, suitable events could be submitted to the Editor of the Journal (see "Instructions to Authors" on the inside of the back cover of this issue), and if accepted for publication, could reach a wide audience.

It is clear to all who attended Port Douglas, if it was not clear to them before, that divers have an on-going responsibility to use the new knowledge emerging from marine research, to dive more responsibly and to influence all people everywhere to preserve and protect the ocean and reefs of the world. No longer should divers stand idly by while greedy, short-sighted and just plain stupid corporate and political groups and individuals attempt to manipulate and legislate for reef, littoral and adjacent ecological destruction in the name of "progress". It was a real pleasure to have Dr Lesley Clark, MLA, PhD, the Queensland Government Member for Barron, North Queensland, to open the SPUMS 1992 ASM. Dr Clark is not only an "intelligent greenie", with a demonstrated practical support for conservation, but she had to deputise for the task of opening our Meeting at very short notice. SPUMS appreciated her support and her opening address.

The divers' opportunity to play a key role in this drama of world conservation is in some ways unique. The wisdom of doing so needs to be made crystal clear to the diving "blind Freddies" and there are still a few of them around !

John Williamson
Convener, SPUMS ASM 1992

References

1 Wilks J. Scuba diving safety. *Med J Aust* 1992; 156: 580

2 *Australian Institute of Marine Science. Annual Report 1991-1992.* Townsville, Queensland: Australian Institute of Marine Science Publishing, 1992

3 Veron JEN. *Corals of Australia and the Indo-Pacific.* North Ryde, New South Wales: Angus and Robertson, 1986

Dr John Williamson, FANZCA, DipDHM, FACTM, is the Director of Hyperbaric Medicine at the Royal Adelaide Hospital. His address is GPO Box Box 400, Adelaide, South Australia 5001.

ORIGINAL PAPERS

PULMONARY BAROTRAUMA: A POSSIBLE ROLE FOR SURFACTANT IN OPPOSING THE ENTRY OF AIR INTO THE CIRCULATION

Brian Hills

Abstract

The alveolar wall of sheep lungs has been studied by electronmicroscopy, employing vascular fixation, i.e. "fixation from behind", using a formulation designed to preserve any lamellated structure of surface-active phospholipid (surfactant). The electron micrographs (ems)show channels traversing epithelial cells, as reported previously, but the mouths of these channels are very close to the oligolamellar lining of surfactant which follows the alveolar surface, whether this is a fluid "pool" or the epithelium.

These findings are discussed as indicating a model whereby the relatively rigid surfactant "raft" can act as a flap-valve (non-return valve), allowing fluid to exude onto the alveolar surface under conditions which provoke oedema, while sealing the pores to prevent the entry of air if alveolar pressure exceeds capillary blood pressure.

Introduction

Pulmonary barotrauma is not a rare occurrence, and one of particular concern in view of the incidence of death or residual neurologic injury which can result.[1,2] "Burst lung" will occur if the difference between intrapulmonary and environmental pressures exceeds a threshold which has been placed at around 70 mm Hg, approximately 100 cm of sea water.[3] Hence, in the training of divers and submariners undergoing submarine escape training, much emphasis is placed upon keeping the glottis open in order to avoid any significant gradient developing between intra-alveolar and lung tissue pressures. However, even after exhaustive practice of the correct technique, cases of pulmonary barotrauma still occur in fit persons[4] and even in instructors particularly well trained and aware of the potential hazards. Cases have also been recorded[1] during the relatively slow decompression from a simulated dive performed in a pressure chamber, while even a cough or a sneeze under those conditions has been known to precipitate symptoms. In some of these instances it is difficult to believe that the pressure gradient for rupturing lung tissue had been exceeded. Such considerations raise the issue of what other means might be involved or what other pathways might exist by which air could enter the pulmonary circulation under much lower pressure gradients.

Fluid can pass from blood to air and accumulate on the epithelial surface as alveolar oedema, so some channels must exist. Moreover these must be large to enable macromolecular proteins to reach the alveolar surface from blood, the concept of "stretched pores" having been raised as early as 1934 by Landis.[5] A review of current thinking[6] states that, although the exact route by which fluid enters the alveoli from the intersitium remains controversial, there is currently general agreement that fluid enters by "bulk flow" through channels too large to permit any significant "sieving" of proteins. At the more selective capillary endothelial membrane, macromolecules of 255,000 have long been known[7] to escape from blood; while more recent studies[6] of protein transport in the normal lung have estimated that the internal diameter of pores is about 500Å, but "strictures" reduce the effective size to 100-400Å. This applies to normal physiological conditions and much higher values have been indicated pathologically.

Channels of diameter 40 nm (400 Å) should be clearly visible by electronmicroscopy and many ems displaying gaps at intercellular junctions have been published.[8,9] Macromolecular protein markers such as haemoglobin and horseradish peroxidase can be visualized at intercellular clefts in the alveolar epithelium[10,11] While these studies clearly indicate the presence of some system of channels by which fluid and plasma proteins can traverse the blood-air barrier, the vital question is whether air is able to traverse that pathway in the opposite direction. At first sight one might dismiss this possibility on the basis that air would be excluded from entering a pore of the dimensions mentioned on account of capillarity. The penetration pressure ΔP would need to be too high on account of the very low radius of curvature (r) related to Δ by the Laplace equation, viz.

$$\Delta P = 2 g/r \quad (1)$$

where g is the surface tension at the air-liquid interface. However, according to conventional theory[12] g is "near-zero" at maximum compression of the surfactant monolayer corresponding to end-expiration. The fundamental physics have been discussed by Bangham[13] who is highly critical of the concept of near-zero surface tension. He and his co-workers have produced ems of the basic tendency for surfactant to form multi-lamellated structures *in vitro*[14], implying that "rafts" of such material occupy the fluid-air interface and so stabilise the alveoli.[15] Direct morphological evidence for an oligolamellar lining to the alveolus has been clearly demonstrated by Ueda et al.[16], but their ems display no fluid layer separating the surfactant from the epithelium.

These findings raise a number of questions concerning the ability of air to enter a pore on the epithelial surface. If directly adsorbed to the alveolar membrane, the surfactant lining might seal the pore or render it sufficiently hydrophobic to encourage the entry of air. *In vitro*, an adsorbed layer of surfactant has been shown to rupture a supernatant aqueous layer[18] by a process known in the physical sciences as the "de-watering" of a surface. On the other hand, a floating "raft" of surfactant could act as a flap-valve to allow fluid to exude onto the alveolar surface without allowing air to enter if the pressure gradient is reversed. This study has been designed to try to answer some of these questions by attempting to relate the oligolamellar surfactant lining to "pores" and the epithelial topography in general.

Materials and methods

PRINCIPLES

1 All previous studies of alveolar "pores" by electron microscopy have employed the almost universal fixative glutaraldehyde introduced[19] for its ability to fix protein. However aldehydes are well known to destroy hydrophobic surfaces[20] which include other mucosal surfaces on which an adsorbed layer of surfactant has been identified. Hence most of the glutaraldehyde has been replaced in this study by tannic acid which is ideal for visualizing the lamellated structure of any surface-active phospholipid (SAPL) present[21] and has been used successfully for this purpose in the lung[16].

2 In previous studies of alveolar ultrastructure the fixative was applied via the airways, but this could float off any rafts of surfactant or SAPL in any form which has not attached to the epithelium. Hence vascular fixation, or "fixing from behind" has been adopted as introduced and described in detail by Gil and Weibel.[22]

3 Since multi-laminated structures of SAPL have been found on other mucosal surfaces where they are attributed "barrier" properties to water-soluble solutes, long (72 h) fixation times have been employed to ensure penetration by the fixative.

MATERIALS

Lungs were obtained from five healthy adult sheep killed painlessly by stunning with a captive-bolt gun followed by exsanguination, the three for vascular perfusion having been heparinised 15 minutes before death. In those cases the lungs were kept at FRC by clamping the trachea before excision. The fixative was introduced from a large syringe via the pulmonary artery until the blood emerging from the pulmonary vein was largely diluted by fixative. In the other two sheep fixative was introduced via the trachea from a large syringe which was cycled back and forth until no more bubbles could be seen emerging.

FIXATION

The initial fixation (72 hour) employed 2% glutaraldehyde plus 3% tannic acid buffered at a pH of 7.4 with 0.1 M sodium cacodylate at 4°C and rendered isotonic (320 mOs) with sodium chloride. Post-fixation was effected in excised blocks with 1% osmium tetroxide buffered at 7.4 with embedding in resin (Spurr mix "A", Probing and Structure, Kirwan, OLD) polymerized at 60°C. Very thin (<60 nm) sections were cut from each block using a very sharp diamond knife in the microtome in order to resolve any lamellated structure of the surfactant.

METHODS

Sections were cut from the six blocks of the three lungs fixed by vascular perfusion and from another six blocks of the two lungs which underwent airway fixation. Sections from the remaining eighteen blocks were not only observed for major features such as "pores" but for the number of lamellae at the mucosal surface to give the mean number of phospholipid bilayers. This was undertaken for a total linear distance of 18 µm, representing 1,000 nm per block.

Results

Examination of the sections from lungs fixed by vascular perfusion showed essentially the same features as reported previously by other investigators using more conventional fixatives. These included the "pits" and "pools" visualized so clearly by Gil et al[23] but not with quite the definition of cellular detail achieved in their studies. This could be attributed to the higher concentration of glutaraldehyde in their fixative. All the figures in this paper are from lungs fixed by vascular perfusion. However, the osmiophilic surface lining of surfactant was well defined as shown in Figure 1 where it is located at the interface between air and the fluid layer (aqueous hypophase) lining the epithelium. Another view of the air-aqueous interface is shown in Figure 2 in which a myelin figure can be seen, as reported by many previous investigators.[24] Over 70-80% of the epithelial surface, however, the surfactant followed the epithelial surface as shown in Figures 3-6. Channels permeating the epithelium reported by many previous workers[8-10] can be clearly seen in Figures 4-6.

These channels enter and leave the plane of the section, but no single channel could be traced from the alveolar surface to the basement membrane within the one section. This can be attributed to the fact that extremely thin (<60 nm) sections were needed in order to resolve the surfactant layer into an oligolamellar structure. Upon cutting serial sections, however, it was possible to obtain sections of the entrances from both the alveolar side (Figure 5) and vascular side (Figure 6).

The average number of lamellations (ñ) was calculated by weighting the number at any location (n_i) by the length of cross-sectional surface (L_i) over which that number persisted according to the following equation:

$$\tilde{n} = \frac{\Sigma n_i L_i}{\Sigma L_i} \qquad (2)$$

The result was $\tilde{n} = 5.43 \pm 1.02$. This indicates that in addition to the two lines representing the epithelial membrane *per se* there are an average of 5.43 additional bilayers, translating into about 11 additional monolayers of SAPL.

Another very interesting feature seen in all of these oligolamellar structures is the uniformity of spacing of the lines (40-50 Å) and their uniformity of intensity, which has been reported before.[16]

Discussion

An oligolamellar layer of surfactant lining alveolar epithelium has been demonstrated in all sections of the alveolar surface, of which typical examples are shown in Figures 1-6. These layers are very similar in number and overall structure to those previously visualized in human lung tissue by Ueda et al.[16] using a similar fixation procedure based upon tannic acid. The primary difference is that, in all cases, Ueda et al. showed the surfactant layer immediately apposed to the alveolar membrane whereas in this study.no more than 10-20% of these surfaces were apposed The difference might be attributable to our preference for em-

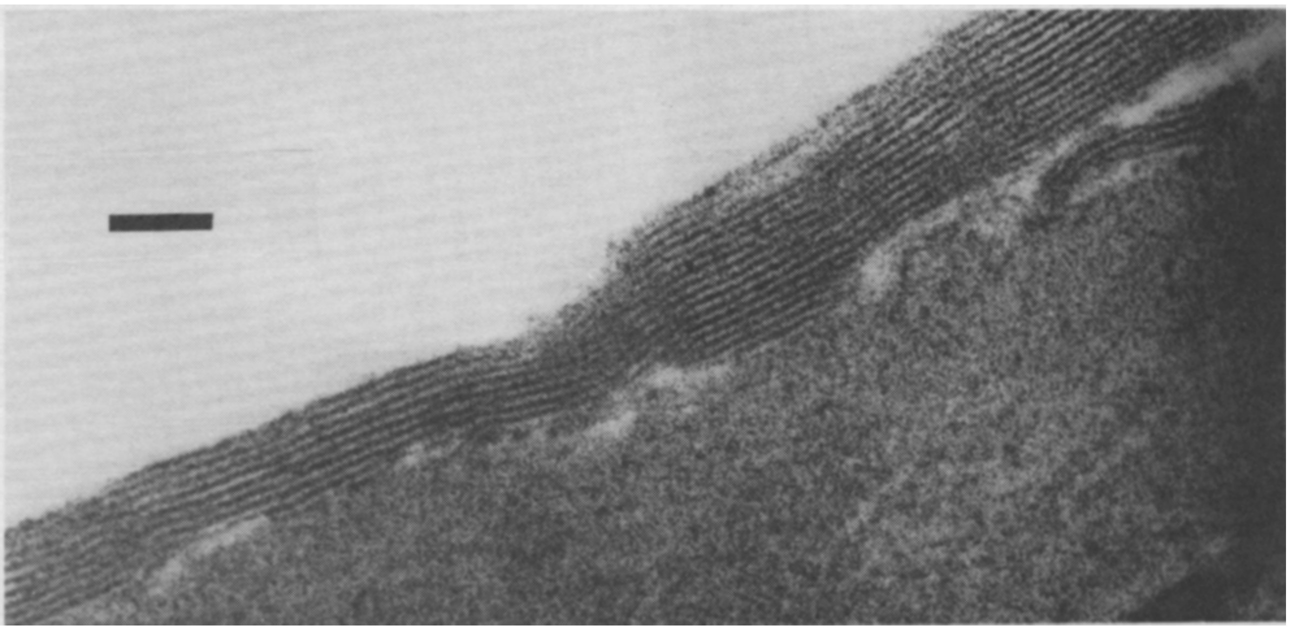

Figure 1. This and all the other figures is an electronmicrograph of the avleolar surface from a sheep lung fixed by vascular perfusion. Note the oligolamellar lining of surfactant appearing to float as a raft separatig air from the aqueous hypophase where the alveolar fluid has accumulated as a surface "pool".[22,23] The bar represents 50 nm.

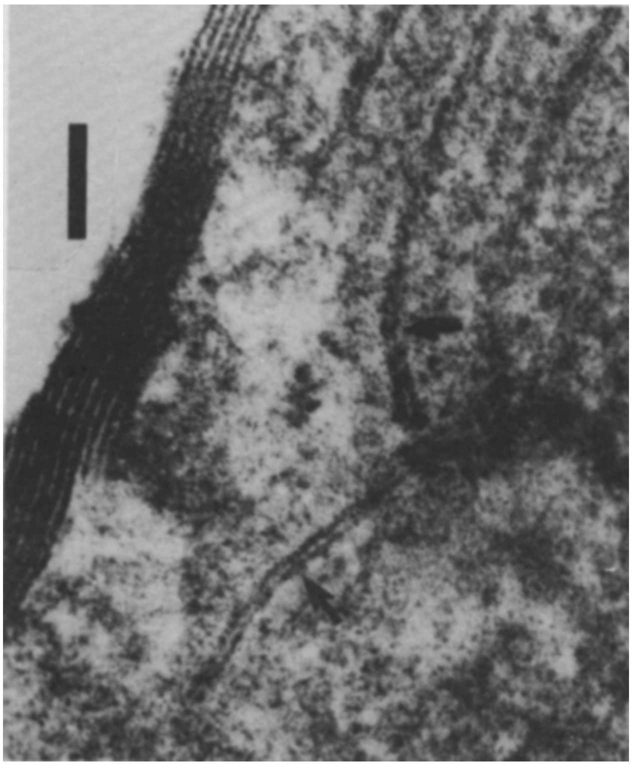

Figure 2. The oligolamellar raft of surfactant can be seen floating on the fluid in a surface "pool". The outline of a myelin figure can be seen within the aqueous hypophase as indicated by arrows. The bar represents 50 nm.

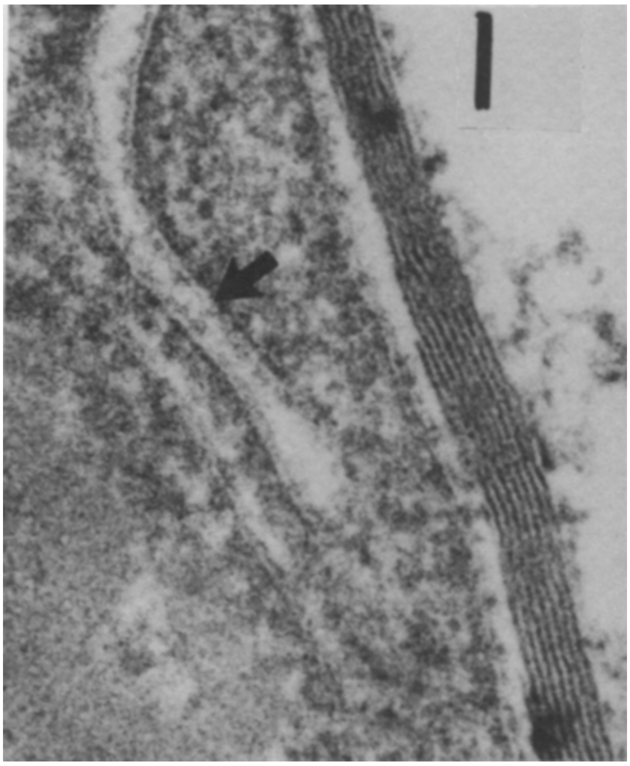

Figure 4. This also displays the oligolamellar lining of surfactant very close to the alveolar surface yet not totally apposed to the underlying epithelial cell, in which a channel is clearly visible (arrowed). The bar represents 50 nm.

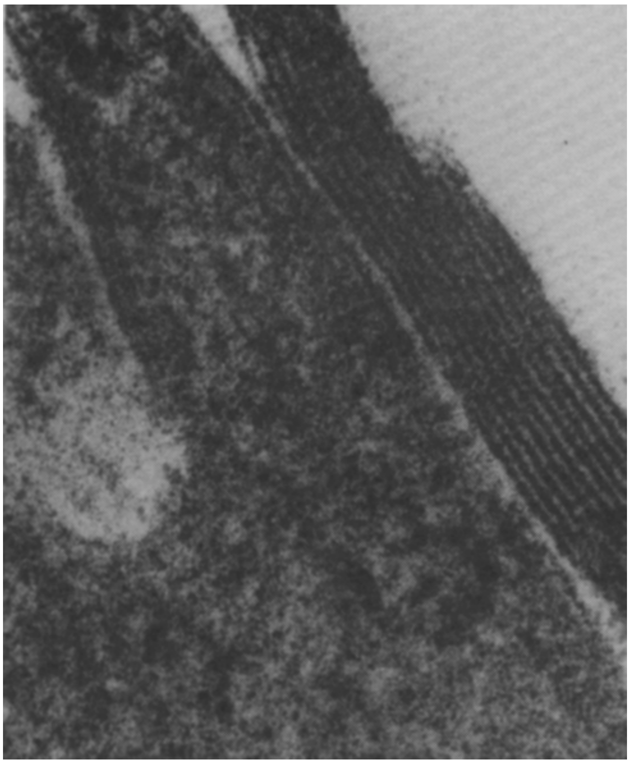

Figure 3. Note the oligolamellar lining of surfactant adjacent to the epithelial surface but still separated from it by a very thin fluid layer of varying thickness.

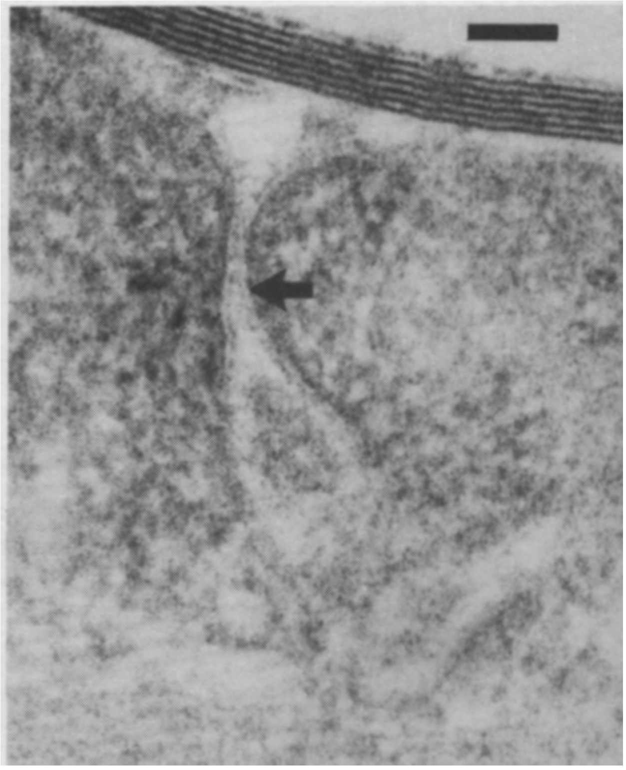

Figure 5. Note the "pore" (arrowed) in the epithelial cell and its location relative to the oligolamellar "raft" of surfactant lining the alveolar surface. The bar represents 50 nm.

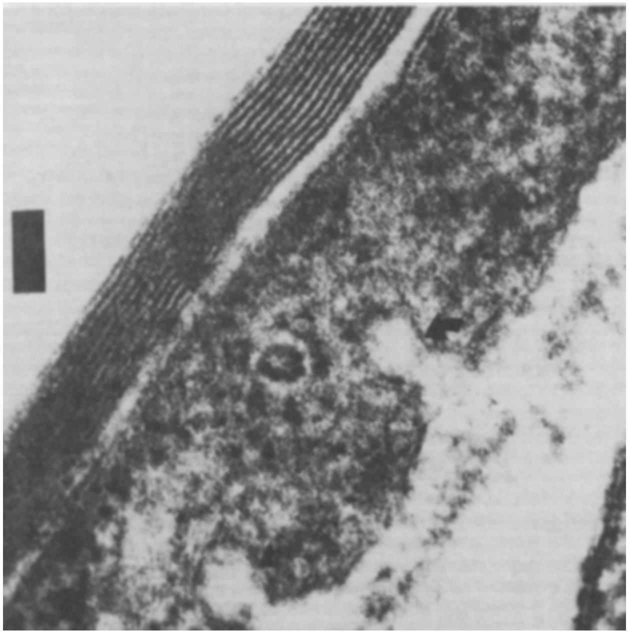

Figure 6. This displays a slight separation of the oligolamellar surfactant lining from the epithelial membrane. Invagniations of the endothelial cell can be seen at its interface with the basement membrane (arrowed).

ploying vascular fixation with an isotonic fixative, although the published information was insufficient to ascertain the tonicity adopted by Ueda et al. The oligolamellar lining covered both the fluid in the "pools" and "pits" (Figures 1 &2) and followed the epithelial membrane as described earlier by Weibel[26] but, even then, a very thin intervening fluid film was apparent (Figures 3-6).

Another feature of the electron micrographs is the system of channels within epithelial cells (Figures 4-6) and their connections to the aqueous hypophase on the alveolar surface (Figure 5) and to the basement membrane (Figure 6); although there is no certainty that they present a direct connection. Such channels have been demonstrated in many previous ultrastructural studies employing aldehyde fixatives.[8-10] The calibre of these channels is just about that predicted for the "bulk flow" of alveolar oedema as described earlier.

The feature of particular interest in Figure 5 is the relation of the mouth of the "pore" to the surfactant lining. On could easily envisage fluid exuding from the "pore" onto the epithelial surface beneath the oligolamellar layers, allowing alveolar oedema to accumulate by enlarging the aqueous hypophase as explained by conventional theory.[12] The question arises to what would occur if the pressure gradient were reversed. A small excess of alveolar over vascular pressure would tend to revers the flow of oedema. This is exploited in the clinical use of positive end-expiratory pressure (PEEP) with ventilators to control alveolar flooding.[27] If the gradient is larger, however, then one could envisage the higher pressure of alveolar air forcing the surfactant lining against the mouth of the pore, effectively sealing it against penetration by air. The surfactant could be playing an important role as a flap-valve, preventing air traversing the blood-air barrier and causing air embolism, in addition to its traditionally accepted role of reducing surface tension.[12]

Unless the pressure gradient is excessive, the floating "raft" of surfactant is unlikely to be deformed sufficiently to admit air to the "pore" it is sealing. Although SAPL in the form of lipid-bilayer membranes is very flexible, this property is generally attributed to cholesterol which occurs in much lesser amounts in lung surfactant. In any case the major component (DPPC) is recognised as a "rigidifying agent".[28]

If this hypothesis of the oligolamellar raft of SAPL acting as a flap-valve (non-return valve) to exclude air is correct, then any agent likely to compromise the surfactant lining is also likely to increase the risk of air embolism. A major deficiency in surfactant, as occurs in premature lambs, can not only greatly increase the permeability of the blood-air barrier to protein but does so bidirecitonally.[29] In humans the adult respiratory distress syndrome (ARDS), associated with SAPL deficiency, is characterised by increased permeability and leakage of macromolecular protein onto the alveolar surface.[30] It is reported that ARDS is often associated with embolism.[28] Leakage of proteins onto the epithelial surface could have an adverse effect upon the integrity of the surfactant lining, the surface activity of which has been shown to be compromised by albumin.[31]

Another factor to consider in maintaining the viability of the surfactant 'flap-valve' is sepsis, since septic or traumatic shock can greatly increase permeability.[32] In acute inflammation, the formation of exudate has been shown to depend upon the presence of gaps of 0.1 to 1 µm in diameter, i.e. 100-1,000 nm, indicating a severe test of the competence of the surfactant flap-valve in excluding air if the pressure gradient were reversed.

This discussion strongly supports the current practice of excluding from submarine escape training anyone with the least indication of respiratory tract infection or lung disease. It should also be borne in mind for considering fitness to dive or participate in any operation involving change of pressure. The concept of a surfactant flap-valve is also relevant to the selection of the pressure range for ventilatory support of patients and the risk of embolisation in ARDS, which can ensue if the wrong choice is made.

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SPUMS NOTICES

MINUTES OF SPUMS EXECUTIVE MEETING (TELECONFERENCE), FEBRUARY 7, 1993 AT 1000 ESDST

Apologies

Drs D Davies and A Slark

Present

Drs D Gorman (President), D Wallner (Secretary), S Paton (Treasurer), J Knight (Editor), C Acott, G Williams, J Williamson with Dr L Barr and Mr S Dent by invitation.

1 Minutes of the previous meeting

These were accepted with the last paragraph of Item 6 to go under Item 7 (Correspondence).

2 Business arising from the Minutes

2.1 PALAU ASM

The breakdown of the registration fee was discussed and also the possible 3% increase in land content costs. Dr Gorman stated that the Gala Dinner costs, although high, had been honed down as much as possible. It was resolved that Dr Gorman ask Allways to review the need for Russell Kitt's presence and Guest Speakers' costs, which appear excessive. He will inform Allways that any increase in costs due to currency fluctuation would not be borne by SPUMS.

The Workshop "Free Ascent" has been entitled "Emergency Ascent" as the agreed definition. Dr G Williams will investigate possible sponsors for the ASM. He has had preliminary discussions with some of the drug detailers. It was suggested that the American company that manufactures "Spare Air" could be interested since the Emergency Ascent Workshop directly impinges on their product. Dr Gorman to investigate.

2.2 PNG ASM PROGRESS

Dr Acott stated that dive escorts will definitely be required.

Dr P Bennett has suggested he show two 30 minute videos made by the Divers Alert Network. It was agreed that they would not be suitable for our meeting.

David Pennefather has been contacted regarding talks on historic wrecks, but has not replied.

Malarial Prophylaxis: The North Americans have enquired regarding the use of Lariam. Dr Acott believes it is unsuitable and will continue to promulgate our recommended regime.

Accommodation : A total of approximately 70 rooms has been booked in 3 hotels.

2.3 FUTURE ASMS (Dr S Paton)

The following sites were discussed and discarded. Ningaloo Reef out of Exmouth, has limited accommodation, about 100. This area is developing rapidly and may be suitable in the future. Also discarded were Heron Island, Madagascar (much malaria), Mauritius (poor diving ten years ago), Kenya (very expensive). Dr Paton was requested to obtain firm tenders from a number of operators, including Allways, for:

1 Solomons (Honiara for Conference)
2 Fiji - particularly Taveuni and Mana
3 Kota Kenabula in Sabah. This is a large town, with good hotels. Dive sites are thirty minutes by boat.

There is total flexibility regarding ASM Dates. The aim is to get the best weather conditions for each venue.

3 North American Chapter

Dr L Barr and Mr S Dent were included in this teleconference to improve communications. This will not be a regular occurrence due to expense. Whenever there are matters of particular concern to the North American Chapter they will be represented.

Dr Barr read Dr Ray Rogers' letter of resignation as Chairman of the North American Chapter and his expression of continued interest and membership of SPUMS was noted. Dr Gorman will write a letter of appreciation to Dr Rogers on his work and enthusiasm in setting up the North American Chapter. Communication has improved and accounts are in order and Journal distribution is proceeding smoothly. The Executive of the North American Chapter is now Chairman Dr Lori Barr and Secretary Steve Dent.

Reimbursement from the Treasurer to the North American Chapter will proceed on a regular quarterly basis.

4 Diving Doctors List

The list is now kept by Dr Paton. Missing details are gradually being completed.

The Fremantle Hospital (Dr H Oxer's) Diving and Hyperbaric Medicine course syllabus has been approved by the censors as suitable training for the Diving Doctors' list. The first course will be held in March.

5 Treasurer's Report

Bank Account has approximately $50,000. Regular quarterly costs are about $11,000.

In June/July, 26% of members had not paid. Reminders were sent and by November 20% were still outstanding.

6 Journal

Journal costs of printing have dropped with the use of a different printer. NASDS has had 310 Journals of each issue of 1992 in bulk at $3.30 per copy which only pays for printing. It was agreed that Dr Paton inform them that the price will be $7.50 in future.

7 Correspondence

7.1 AMA

Dr Knight will reply to the letter of Dr Wilkins, giving details of Diving Medicine Courses and a total figure of graduates from these courses. He will also enlighten the AMA about the dangers of incompetently conducted medicals. It has been brought to the Committee's attention that Doctors performing Aviation Medicals are now required to do a course in Aviation Medicine.

7.2 WORKSAFE AUSTRALIA

Dr I Miller has supplied for comment a draft protocol for Decompression Chamber requirements at dive sites produced for Worksafe Australia. Dr Gorman has replied expressing the Society's disapproval and enclosing our recommended protocol.

7.3 DIVING DOCTORS LIST

Dr Darling's letter : The Secretary to reply stating that to be included on the SPUMS Diving Doctors' list a member must have completed an approved Diving Medicine course.

7.4 MEMBERSHIP

Mr R Ramsay's letter : Dr Gorman to reply reiterating the Constitutional position regarding non-medicos being full members.

8 Other Business

The early notification of overseas members of time and place of future ASM's should be adequately dealt with by early publication in the SPUMS Journal, and by the Travel Agent air-mailing the preliminary "flyers" to overseas' members.

Nominations for 1993 Executive are coming in slowly.

The next teleconference will be held on Sunday, April 18th at 10 am EST.

Darrell Wallner
Secretary, SPUMS

SPUMS DIPLOMA OF DIVING AND HYPERBARIC MEDICINE

Requirements for candidates

In order for the Diploma of Diving and Hyperbaric Medicine to be awarded by the Society, the candidate must comply with the following conditions:

1 The candidate must be a financial member of the Society.

2 The candidate must supply documentary evidence of satisfactory completion of examined courses in both Basic and Advanced Hyperbaric and Diving Medicine at an institution approved by the Board of Censors of the Society.

3 The candidate must have completed at least six months full time, or equivalent part time, training in an approved Hyperbaric Medicine Unit.

4 All candidates will be required to advise the Board of Censors of their intended candidacy and to discuss the proposed subject matter of their thesis.

5 Having received prior approval of the subject matter by the Board of Censors, the candidate must submit a thesis, treatise or paper, in a form suitable for publication, for consideration by the Board of Censors.

Candidates are advised that preference will be given to papers reporting original basic or clinical research work. All clinical research material must be accompanied by documentary evidence of approval by an appropriate Ethics Committee.

Case reports may be acceptable provided they are thoroughly documented, the subject is extensively researched and is then discussed in depth. Reports of a single case will be deemed insufficient.

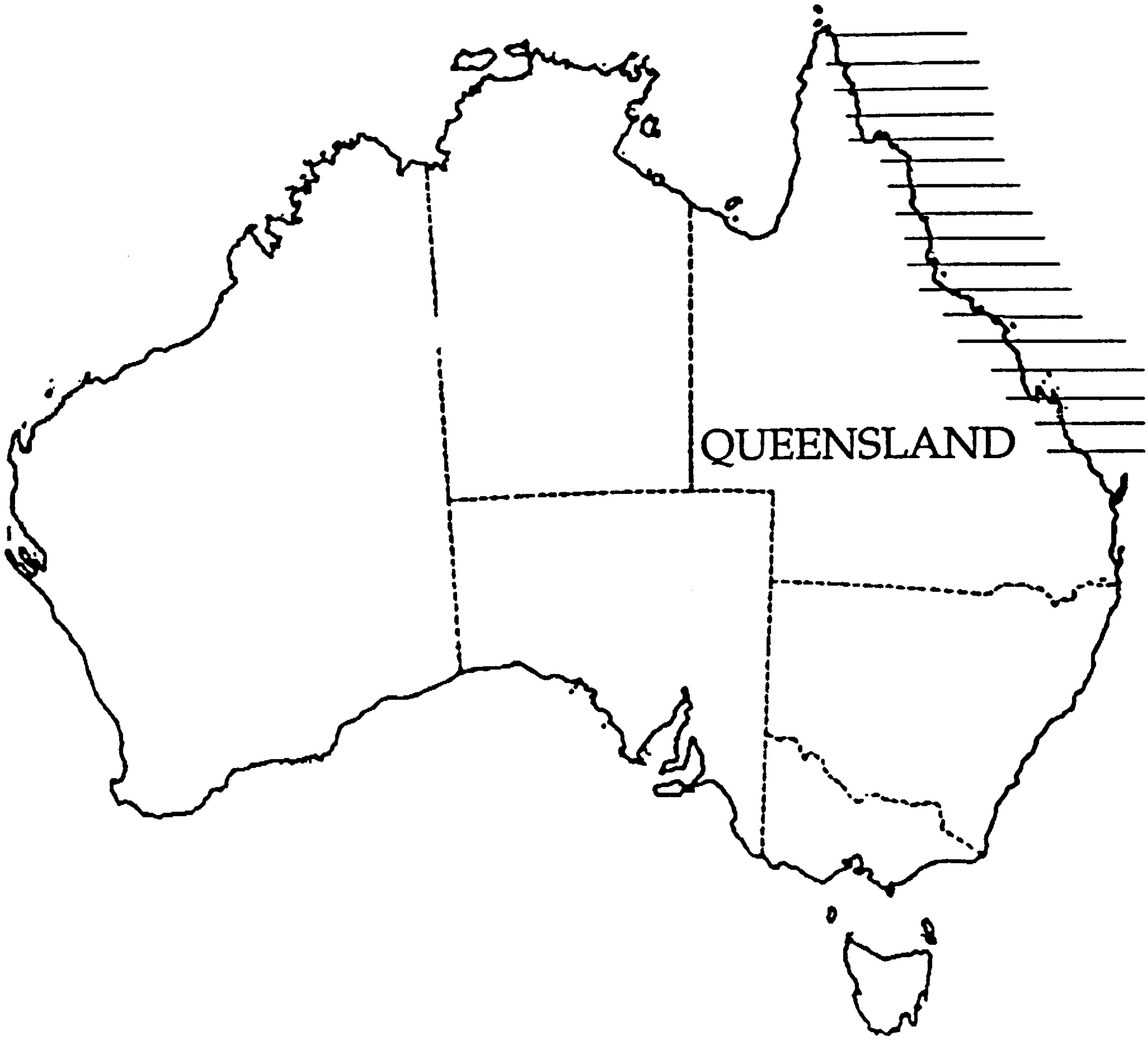
Review articles may be acceptable only if the review is of the world literature, it is thoroughly analysed and discussed and the subject matter has not received a similar review in recent times.

6 All successful thesis material becomes the property of the Society to be published as it deems fit.

7 The Board of Censors reserves the right to modify any of these requirements from time to time.

SPUMS ANNUAL SCIENTIFIC MEETING 1992

THE GREAT BARRIER REEF SYMPOSIUM



THE SIGNIFICANCE OF THE GREAT BARRIER REEF

Joe Baker

I am most grateful to Dr John Williamson and to SPUMS in general for the opportunity to present this opening address to the 1992 SPUMS Scientific Meeting.

The lectures that follow are to be given by specialists in their respective fields. I am going to analyse what are regarded as the truly significant aspects of the Great Barrier Reef (GBR). I have structured this talk to analyse how the world views the significance of the reef through international conventions and how our nation has acted to protect this natural feature from adverse human impacts as far as it is practicable. Ultimately the individual must judge what is "significant". Depending on the significance in their own minds more and more people in this society will regard the conservation of the Great Barrier Reef region as essential to our national heritage.

We have come a long was since 1972. Most of us at AIMS were starting our professional careers at that time. Some of us had not yet determined where our specialisation would lie. But 1972 is a great year in the history of world recognition of the significance of natural and built features of distinction. In 1972 the United Nations Educational Science and Cultural Organisation (UNESCO) established a Convention which we refer to as the "World Heritage Convention".

The accurate name for the Convention is "The Convention Concerning the Protection of the World Culture and Natural Heritage' which was adopted by the General Conference of UNESCO in 1972.

A World Heritage Committee was established to "oversee the development of a 'World Heritage List', a list of properties forming part of the cultural and natural heritage which the Committee considers as having outstanding universal value in terms of such criteria as the Committee will have established".

To register the Great Barrier Reef site on the World Heritage List is was first of all necessary to prepare a very detailed submission which would be presented to the Executive Committee of the World Heritage Committee. This Committee would assess the presentation, and the evidence produced, to determine if the submission in fact did represent a unique world feature worthy of inscription on the World Heritage List.

Fundamentally one can apply for World Heritage Listing on the basis of either cultural sites or natural sites. If it is a cultural site it must be first considered by the International Committee on Monuments and Sites (ICOMOS) and if it is a natural feature it must be considered by the International Union for Conservation of Nature and Natural Resources (IUCN).

It was my great honour in 1981 to be a member of the Australian Delegation presenting cases for sites for inscription on the World Heritage List and my responsibility was to speak to the nomination of the Great Barrier Reef. I have with me today the documentation that I had for that presentation and it will remain one of my treasured possession. Australia should be proud to have the responsibility of caring for a site such as the Great Barrier Reef which, in its inscription on the World Heritage List, was evaluated as satisfying both the cultural and the natural characteristics.

The area within the Great Barrier Reef Region contains many middens and other archaeological sits of aboriginal and/or Torres Strait Islander origin. Additionally there are over 30 historic ship wrecks in the area, and on the islands within the reef region there are ruins, and also operating lighthouses, which are of cultural and historical significance. In the series of colour slides that follow I have chosen a number of ways to represent significance.

The Great Barrier Reef was seen to meet all four criteria set out in article (ii) of the World Heritage Convention viz:

1. "being an outstanding example representing a major stage of the earth's evolutionary history";
2. "being an outstanding example representing significant ongoing geological processes, biological evolution, and man's interaction with his natural environment";
3. "containing unique, rare and superlative natural phenomena, formations and features and areas of exceptional natural beauty"; and
4. "providing habitats where populations and endangered species of plants and animals still survive".

The Great Barrier Reef of course is not the only Australian site registered on the World Heritage List. The Willandra Lakes area of south-western New South Wales and into Victoria, the south-west Tasmanian forests, the Lord Howe Islands group and Kakadu National Park were amongst the early sites inscribed. Subsequently we have seen submissions for the tropical rain forests of Queensland, for the forest of northern New South Wales and other sites such as Shark Bay which have been subject to detailed analysis. One site long favoured by Australian conservationists as worthy of inscription on the World Heritage List is the Great Sandy Region incorporating Fraser Island in the south-central Coastal Queensland and this site will continue to receive most careful consideration.

It is interesting to note that the Fraser Island region was the first site inscribed on the list of the Register of the National Estate as established by the Australian Heritage Commission. It was my honour to be Chairman of the Australian Heritage Commission prior to becoming Director at the Australian Institute of Marine Science and, although I did not realise it at the time, the good fortune that I also had in being Vice-President of the Australian National Commission for UNESCO, Chairman of the Special Program Committee for the World Heritage Convention, Foundation member of the Great Barrier Reef Marine Park Authority and member for some 13 years, and Chairman of the Scientific Committee for World Wildlife Fund Australia and Vice-President of World Wildlife Fund Australia at a time when Australia was establishing its practices and procedures to give greater recognition to the conservation value of its natural resources, and important cultural resources, were indeed hallmarks of significance in my professional career.

The Great Barrier Reef is of course the jewel of Australia's natural resources. It lies off the north-east coast and in this large island of Australia we tend to take for granted the extent of the reef. Once again I seek your evaluation of significance as the determining factor. Is its significance due to its size ? Compare it with Europe and recognise that the Great Barrier Reef covers an area greater than that of all the British Isles, including Ireland. Size itself is not enough: there are many other features which may be significant! The unique feature of the shelf of the north-east coast of Australia gave the foundation for this natural structure. The harmony of collaboration between the Federal Government and the Queensland Government established the Great Barrier Reef Marine Park Authority and the Great Barrier Reef Marine Park Act. All of are enormous significance. This structure, built by living organisms, extending for more than 2,000 km down our eastern coast and containing more than 2,900 reefs and more than 600 islands impresses on us the physical dimension of this unique feature. The significance of beauty associated with the barrier reefs of the far north, the patch reefs off Townsville and the spectacular reefs of the Swain and Pompeys group in the south, all draw attention to the enormous variety and the significance of the formations which represent the Great Barrier Reef. The surface significance can often be best appreciated by viewing from a low flying aeroplane.

As a scuba diver, one participates in a new world, a world where the human body is effectively weightless. We can glide through the water taking in the immense beauty and the significance of the diversity of life forms, whether it be the myriad of schools of fish, the unusual shapes and colours of sponges, hard corals, soft corals, fish, seaweed, sea anemones or the spectacular harshness of the Crown-of-Thorn starfish (*Acanthaster planci*). Perhaps some see significance in the rich colours and diverse forms of nudibranchs or spectacular reef fish, the gorgonians, the crinoids, or the tube worms.

But surely one of the most significant features to strike us all is the myriad of life forms which coexist in this wonderful feature of the Great Barrier Reef. The exposed Myrmidon Reef of the outer Barrier Reef in the central section highlights this enormous diversity of species and diversity of of form which has been maintained through the ages by the spectacular and synchronous spawning of corals at predictable times throughout the year. This discovery, made a by a group of young PhD scientists at James Cook University, is of world significance and brought even more attention to the Great Barrier Reef than might otherwise have been the case.

Whereas the diversity of form and the smaller corals and their inhabitants are always of interest, one should also observe the massive corals such as the *Porites* species which have given us so much information on past climatic conditions in the Great Barrier Reef region. These records themselves are of enormous significance, a significance that could not be interpreted by humans if it were not for the way in which corals grow and the way in which they entrap in their skeletons historical records of past characteristics of waters of the Great Barrier Reef.

The significance of the reef as a place for game fish is now well known and large sailfish and marlin are caught on the outer edges and sometimes in the inner regions of the Great Barrier Reef. On the Reef fishermen are more likely to catch the coral trout, the red emperor, the spangled emperor or similar beautiful attractive fish. Some of these fish have their own peculiar characteristics.

One of the best known of course, and of medical interest, is ciguateric fish poisoning . This is often associated with very large coral trout but in fact the toxin is more common in the mackerel that are caught to the south of the Great Barrier Reef, than in any single reef fish. However we are cautious about eating very large coral trout, say over 10 kilos, and should ensure that they are not carrying the ciguateric toxin. Ciguateric fish poisoning is not something that is confined to the Great Barrier Reef but in Australia it has been associated, perhaps unfairly, with Great Barrier Reef fish. We now know that it is associated with fish from other tropical regions and certainly from the Hervey Bay region where most case of ciguateric fish poisoning have been reported.

Emerging now from the submarine environment where so many scuba divers have enjoyed so much time, we can also look to the reef as a playground for young families at low tide where tour boats enable an increasing number of people to enjoy the spectacle of the Great Barrier Reef.

Another significant aspect of the Great Barrier Reef is the management structure in place through the Great Barrier Reef Marine Park Authority, undoubtedly the world's most effective and efficient management system of any marine feature. We have been fortunate in the time that the Great Barrier Reef Marine Park Authority has been in place that we have had politicians in power generally concerned for the well being of the reef. Through the dedication, commitment and ability of the current Chairman, Mr Graeme Kelleher, we have been very fortunate in having outstanding leadership and concern for the well being of the reef. The type of zoning that has been put in place allows for progressive revision of zoning plans. This allows user groups and individuals to express their opinions on the effectiveness of the zoning and on any changes that may be necessary. These can be due to changing recreational patterns, to changing fishing patterns and, hopefully, to greater and expanding knowledge of the marine ecosystem of the Great Barrier Reef.

The significance of the Great Barrier Reef as a tourist attraction must not be lost to Australia because it is one of our principal income earners.

One hopes that although we, the scientists, and we, the humans, having enjoyed the pleasures of the reef, may return from the excitement and adventure of a day on the Great Barrier Reef truly exhausted but fully satisfied, we will leave the animals and plants of the Great Reef undisturbed by human activity. To achieve this the management challenges are great. The reef must be able to regenerate.

The spawning of hard corals as a synchronous activity effectively results in all reproductive activity of the majority of hard corals of the Great Barrier Reef occurring on only a few predictable days of the year.

My objective in this talk has been to draw to your attention the different aspects of the Great Barrier Reef which may represent significance in your individual opinions.

Only the individual can express the particular sentiment which represents their own interpretation of "significance" but one would hope that in the variety of life forms, in the variety of aesthetic pleasures, in the variety of food resources, and in the variety of chemical products that can be obtained from the different marine organisms, we will, together, communicate a sense of significance which will result in the long term protection of the Great Barrier Reef and in the conservation of its diversity and form, undisturbed by human activities, so that it can be enjoyed by future generations in the same way that you and I have been able to enjoy it in our lifetime.

Dr J T Baker OBE, DSc, is Director of the Australian Institute of Marine Science. The Institute's address is PMB No. 3, Townsville Mail Centre, Queensland, 4810, Australia.

This paper, illustrated by 76 slides, was the keynote address of the 1992 SPUMS Annual Scientific Meeting at Port Douglas, Queensland, Australia.

CONSERVATION AND ZONING OF AUSTRALIA'S GREAT BARRIER REEF

Peter McGinnity

Introduction

Australia's Great Barrier Reef was declared a Marine Park in 1975 and was listed as a World Heritage Area in 1982. This paper provides a brief description of the Marine Park and the strategies being implemented to ensure protection of the Reef and carefully balance human use.

Great Barrier Reef Marine Park

The Great Barrier Reef extends for 2,000 kilometres along the north eastern coastline of Australia. Its 2,900 reefs and almost 1,000 islands compose one of the most divers ecosystems on earth, being home to 1,500 species of fish, 4,000 species of mollusc, 215 types of birds, 22 different types of whales, 500 types of seaweed, six breeding species of turtle, and 400 species of coral. The Reef may be the last place on earth in which the Dugong are not in jeopardy.

The Great Barrier Reef Marine Park has been established to encompass the entire Reef ecosystem. Maps on pages 65 and 75 show the location of the Park.

Use of the Reef

Australian Aboriginal people have used the near shore areas of the Reef for at least twenty thousand years, and continue to do so as an important part of their subsistence, culture and lifestyle.

Intensive European use of the reef commenced in the latter part of last century with the beche de mere (sea cucumber), trochus (snail shell) and pearl shell fisheries, but has increased dramatically since World War II with tourism, prawn (shrimp) trawling and reef-line fishing being the dominant activities. Today Reef-related commercial activities have extended human use to all parts of the Reef and have an estimated value in excess of $1,000 million per annum.

Tourism is the largest commercial activity in economic terms with parts of the coastline in the southern half of the reef and twenty four islands currently wholly or partly developed for tourism purposes. Reef based activities associated with tourism include diving, fishing and boating. Because the major and most spectacular reefs and clearest waters lie well offshore across an exposed channel, historically vessel capabilities were a major limitation with most activities being confined to a dozen reefs within 20 miles of island resorts and major ports. This changed in 1982 with the introduction of high-speed catamarans capable of carrying 150 passengers at speeds in excess of 20 knots. Largely as a consequence of the access provided by these catamarans, tourism has increased to the extent thatmore than 5 million people now visit the Reef region each year.

Modern day fishing activities include recreational line and spear fishing, shell and ornamental fish collection, and commercial trawl, line and net fishing. The commercial fishing industry alone annually generates $250 million a year and directly employs nearly 4,000 people.

Activities that have been totally excluded from the Park are mining (limestone etc.) oil drilling and fishing using large scale, non discriminatory techniques such as longlining, purse seining and large scale drift-nets. All other activities are managed to ensure that they are ecologically sustainable.

Park Management

Responsibility for management of the Marine Park is vested with a three person independent Authority, composing a permanent Chairman, a representative of the State of Queensland, and a third appointed member who to date has been from a scientific background.

Zoning plans provide the flesh to the skeleton established by the Act. They are developed using the most up-to-date management techniques and scientific principles, including :

establishment of "representative areas" of protected habitats as flora and fauna refuges and scientific reference areas;
protection of sensitive habitats and species from activities that might threaten them (e.g. trawl fishing is precluded from coral reef and sea grass communities, and dugong are protected from all but traditional hunting); and
provision for detailed management plans and strategies to be developed for high use and sensitive sites.

Zoning plans for the Park are thoroughly reviewed every five years or so and may be amended to take into account changing use patterns and more recent scientific information.

Where necessary other methods are also used to protect the Reef, for example, the waters between the Reef and the mainland are a major shipping lane for eastern Australia. International agreement has been reached to declare parts of the Reef as "areas to be avoided by shipping", and to require approved pilots to be carried to guide ships through other parts of the Reef where particular care is required.

Perhaps a measure of the success of the management practices adopted by Great Barrier Reef Marine Park Authority (GBRMPA) is the extent to which GBRMPA as a Federal agency is now supported by the State of Queensland. The Queensland Government has established marine parks to cover the State's inter-tidal waters, and has included these and the island State Parks under a management agreement. Funding for the management of these State parks and the Great Barrier Reef Marine Park is provided on a 50/50 basis by the Federal and Queensland governments.

Many of the problems affecting the Park are generated outside its boundaries; nutrient run-off and siltation form coastal areas is of considerable concern. Integrated catchment management and coastal development strategies are currently being developed by the Queensland Government and GBRMPA is actively working with the State agencies developing these strategies.

In order to strengthen these complementary management arrangements GBRMPA has recently initiated the development of a 25 year strategic plan for the Great Barrier Reef World Heritage Area (including the Marine Park, all of the islands and the inter-tidal areas). This plan has involved all other key agencies, local government authorities, Aboriginal and Torres Strait Islander groups, and other stake holders. The plan establishes five year and one year objectives to be achieved jointly by all groups and agencies. Priorities in the Plan include more appropriate recognition of the traditional relationships of Aboriginal and Torres Strait people to parts of the Reef, prevention of pollution to ensure water quality is not degraded, and careful examination of fishing practices to make sure they are ecologically sustainable.

A presentation about the Marine Park would not be complete unless some mention was made about public involvement. Public involvement is the cornerstone of the Marine Park. A formally constituted Consultative Committee was established by the Act and advises GBRMPA and the responsible Federal and State ministers The Act also requires GBRMPA to seek public input into the development of zoning plans. Specialist advisory committees are established where appropriate, for example, to advise on monitoring and research programs or to develop more detailed plans for management of intensively used areas. In these days of tightening budgets and ever increasing management demands, reef users and volunteers are an increasingly important resource, providing not only assistance in the form of transportation and human labour, but highly developed knowledge and skills to assist in areas such as research and public education.

Conclusions

Management of the Great Barrier Reef Marine Park has been successful because :

a holistic, or whole ecosystem, approach has been adopted to management of the Reef Region;
GBRMPA has been established as an independent Authority with a very strong legislative mandate to focus solely on management of the Region;
complementary management arrangements have been established between the Federal and Queensland State government agencies;
a system of multiple use management has been established using the best available information, but ensuring that where there is an absence of perfect information, the Reef and its natural resources are given priority (the precautionary principle);
the Park is supported by the community, who are involved in the processes of establishing management; and to date the Park has been reasonably funded through an agreement reached between the Commonwealth and State governments.

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CORAL REEFS

J.E.N.Veron

Introducing coral reefs

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

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

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

The world-wide distribution of coral reefs (and reef-building corals) is controlled primarily by bathymetry and temperature, for reefs can only develop in shallow, sun-lit waters where the temperature seldom falls below 18°C (Figure 1). Secondary constraints are related to Cenozoic geological history (e.g. the complete absence of reef building corals in the Mediterranean Ocean), surface circulation patterns (e.g. their paucity in the far eastern Pacific) and regional environments of which salinity (the absence of reefs in areas influenced by major rivers), substrate type (the paucity of reefs in extensive areas of soft terrigenous substrates) and nutrients are the most important. Clearly, surface circulation patterns and temperature are interlinked, as is bathymetry and the existence of extensive rive deltas, soft terrigenous substrates, and light availability. Nutrients, or rather lack of them, are critical to reef development: reefs obviously thrive around islands in the "nutrient deserts" of the remote oceans; they also thrive around the more nutrient-rich waters of continental margins, but they appear to do so only where natural ecological checks and balances between corals and other organisms (e.g. herbivores and macro-algae) are preserved.

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

Approximately one-third of the world's coral reefs, covering an area of about 200,000 km^2, occur in the central Indo-Pacific. This region is the world's centre of reef coral diversity, and a similar pattern applies to most other major groups of reefal organisms. The reasons involve a complex mixture of geological history, oceanography and biology, but the principal reason concerns past and present sea surface circulation patterns for they provide the means of long-distance dispersal for all groups of organisms capable of maintaining a planktonic existence. Virtually all major groups of reef builders have that capability, usually in a larval phase of their life-cycle.

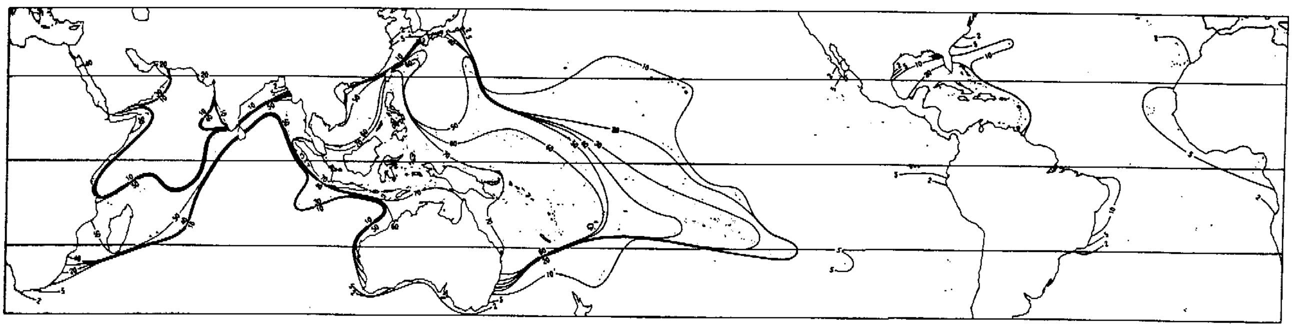

Figure 1. World wide distribution of coral reefs with contours of genetic diversity.

Australia's geographic position within the world's centre of marine diversity is critical to conservation. Coral reefs mostly occur around the developing, over-populated countries of the world's tropics. Within major regions of the central Indo-Pacific Centre of Diversity, only western Micronesia, northern Papua New Guinea, Australia and (perhaps) Japan, have a low population pressure and/or the capacity to permanently regulate human impacts. These impacts are , as yet, poorly known: my own subjective estimate is that 70% of all central Indo-Pacific reefs have been significantly degraded. This is due primarily to over fishing (which has effectively removed the top of the food pyramid of most of south-east Asian and Japanese reefs), eutrophication and increased sedimentation (from urban outfall, deforestation, agricultural run-off and coastal zone development) and direct intrusive activities (principally through subsistence food gathering, particular mining practices, shell collecting and unregulated tourism).

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

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

Australian coral reefs

HIGH-LATITUDE REEFS OF EASTERN AUSTRALIA

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

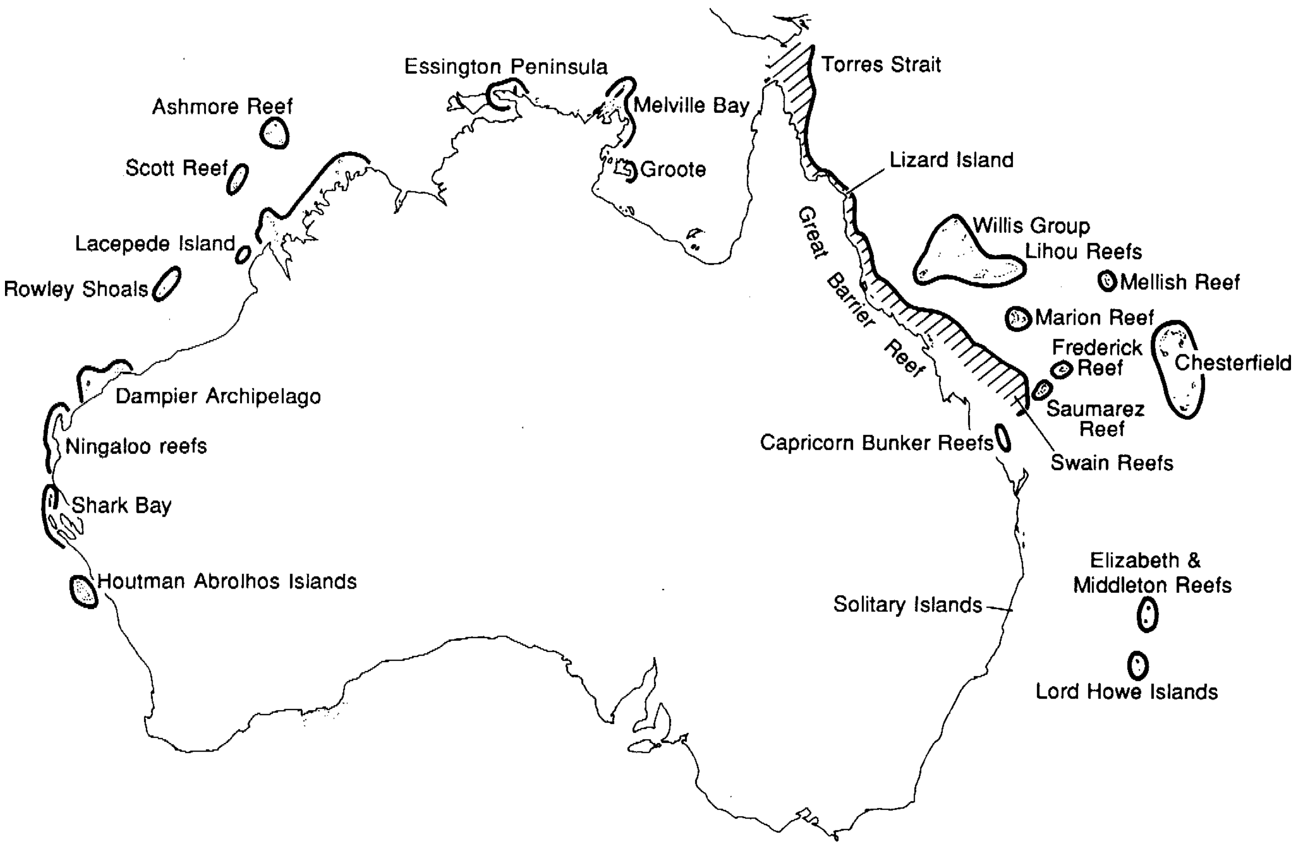

Figure 2. Distribution of Australian coral reefs.

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

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

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

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

THE GREAT BARRIER REEF

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

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

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

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

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

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

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

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

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

REEFS OF THE CORAL SEA

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

REEFS OF NORTHERN AUSTRALIA

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

COCOS (KEELING) ATOLL AND CHRISTMAS ISLAND

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

REEFS OF THE NORTH-WEST SHELF

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

REEFS OF COASTAL WESTERN AUSTRALIA

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

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

The 230 km long Ningaloo Reefs, by far Australia's biggest fringing reef, are situated at the barren far western extremity of the country where the continental slope comes closest to the coast. They are readily accessible to visitors from Perth and until recently have been heavily fished.

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

The value of the Great Barrier Reef

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

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

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

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

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

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CREATING A CAPTIVE CORAL REEF ECOSYSTEM

Martin S Jones

Introduction

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

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

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

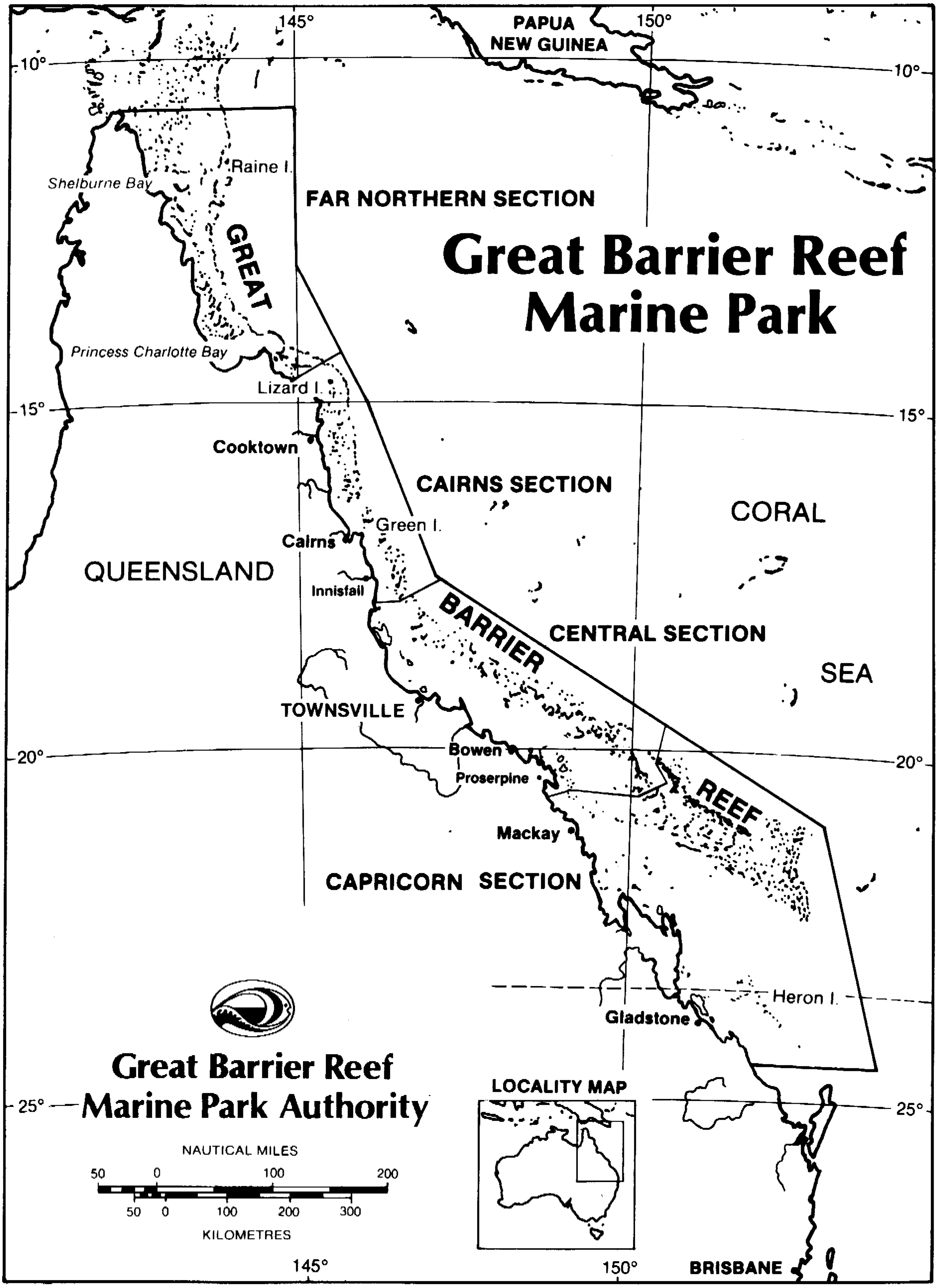

Figure 1 Map of the Great Barrier Reef Marine Park

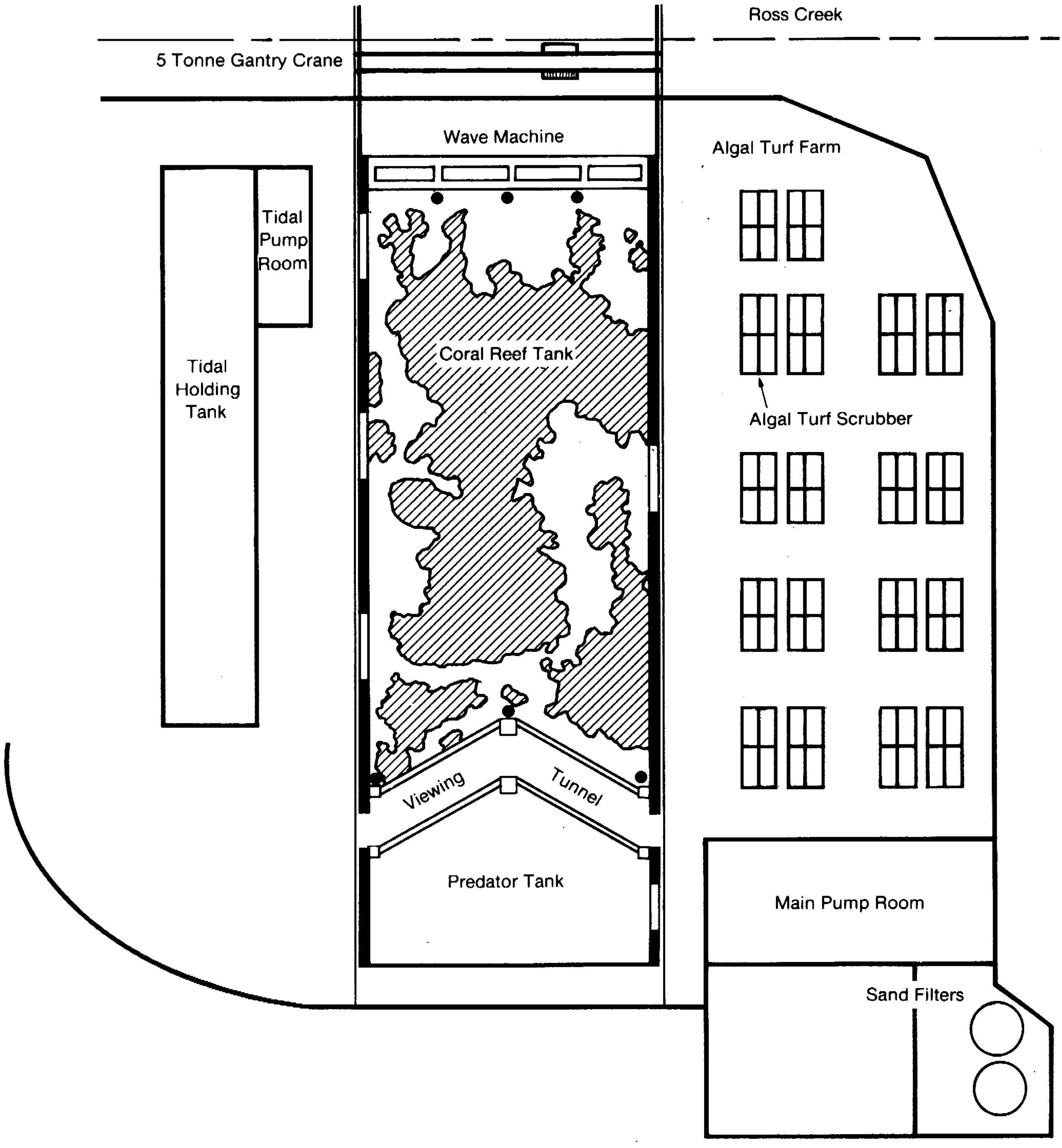

Figure 2 Plan of the Aquarium

tute of Marine Science, the GBRMPA and the Department of Marine Biology, James Cook University, are all located in the region.

The aquarium

As the quality of the water in nearby Cleveland Bay was considered unsuitable the Aquarium Coral Reef Exhibit is run on a closed circuit process with all seawater recycled through a purification process based on marine plants.

The 2,50,000 litre Coral Reef Exhibit tank is 17 m wide, 38 m long and 5 m deep with a four chambered wave machine at one end. At the opposite end a 20 m walk-through acrylic tunnel separates the reef exhibit from the 750,000 litre predator exhibit tank (17 m wide,10 m long and 5 m deep). Next to the coral reef, and under the observation area, there is a tidal holding tank with a capacity of approximately 750,000 litres. The unique algal turf farm, where the water purification occurs[1], occupies the roof of the interpretive area on the opposite side of the reef exhibit (Figure 2).

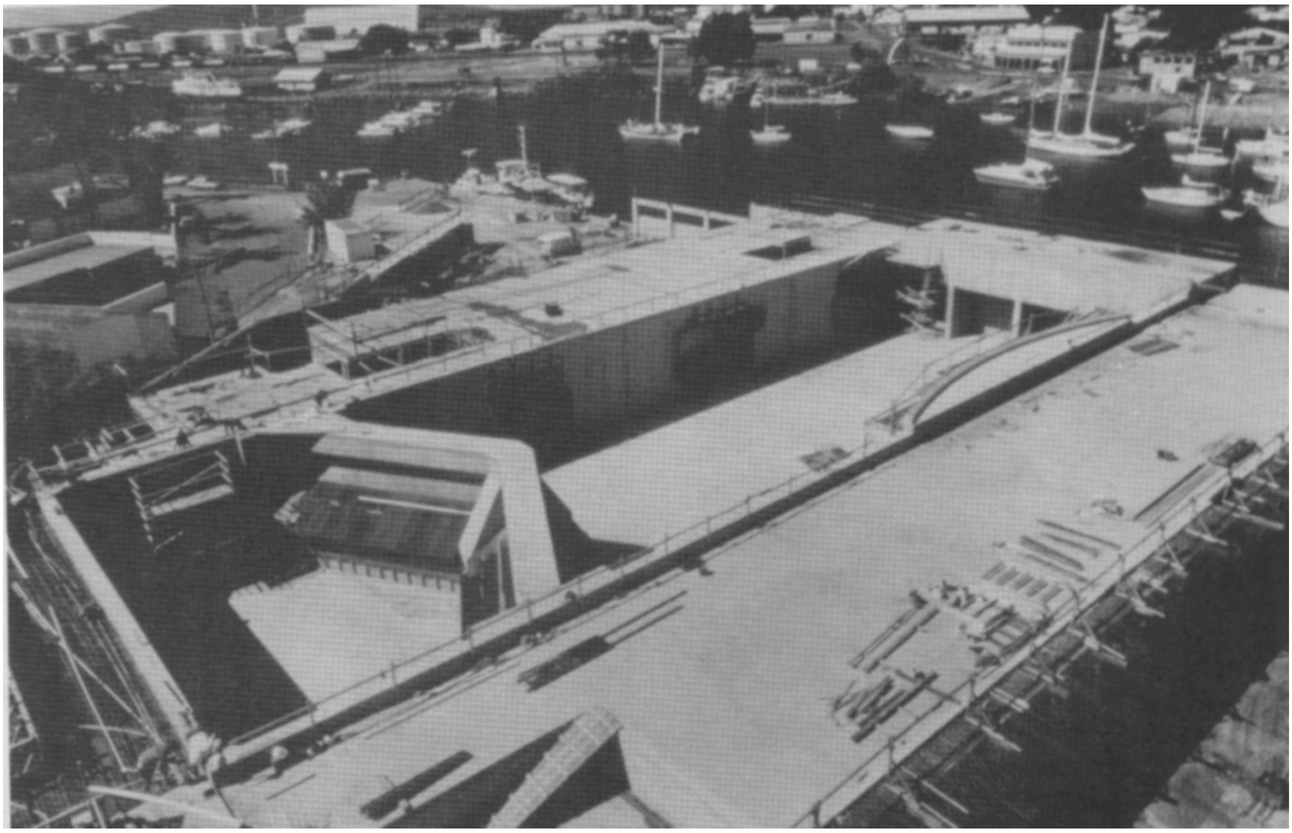

Figure 3 The Aquarium under construction

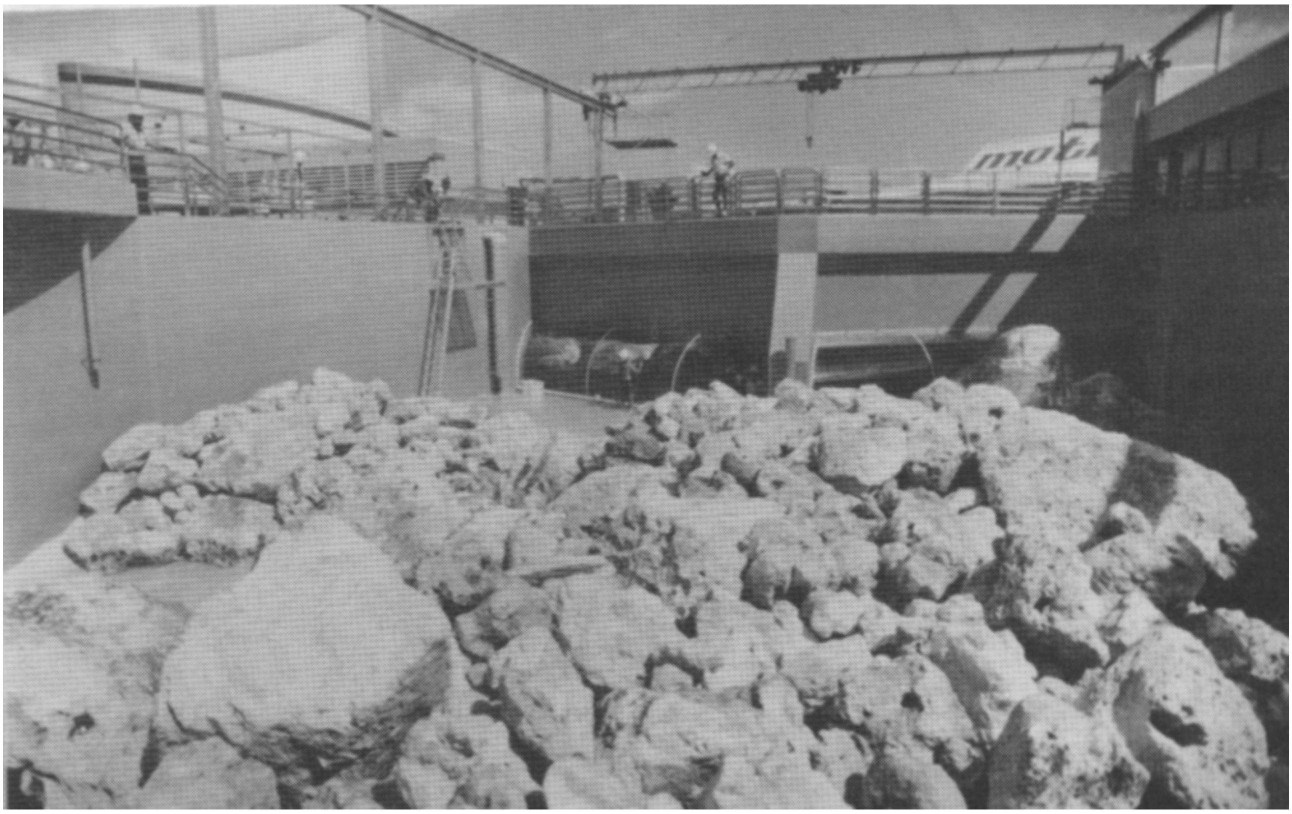

Figure 4 The Aquarium reef under construction

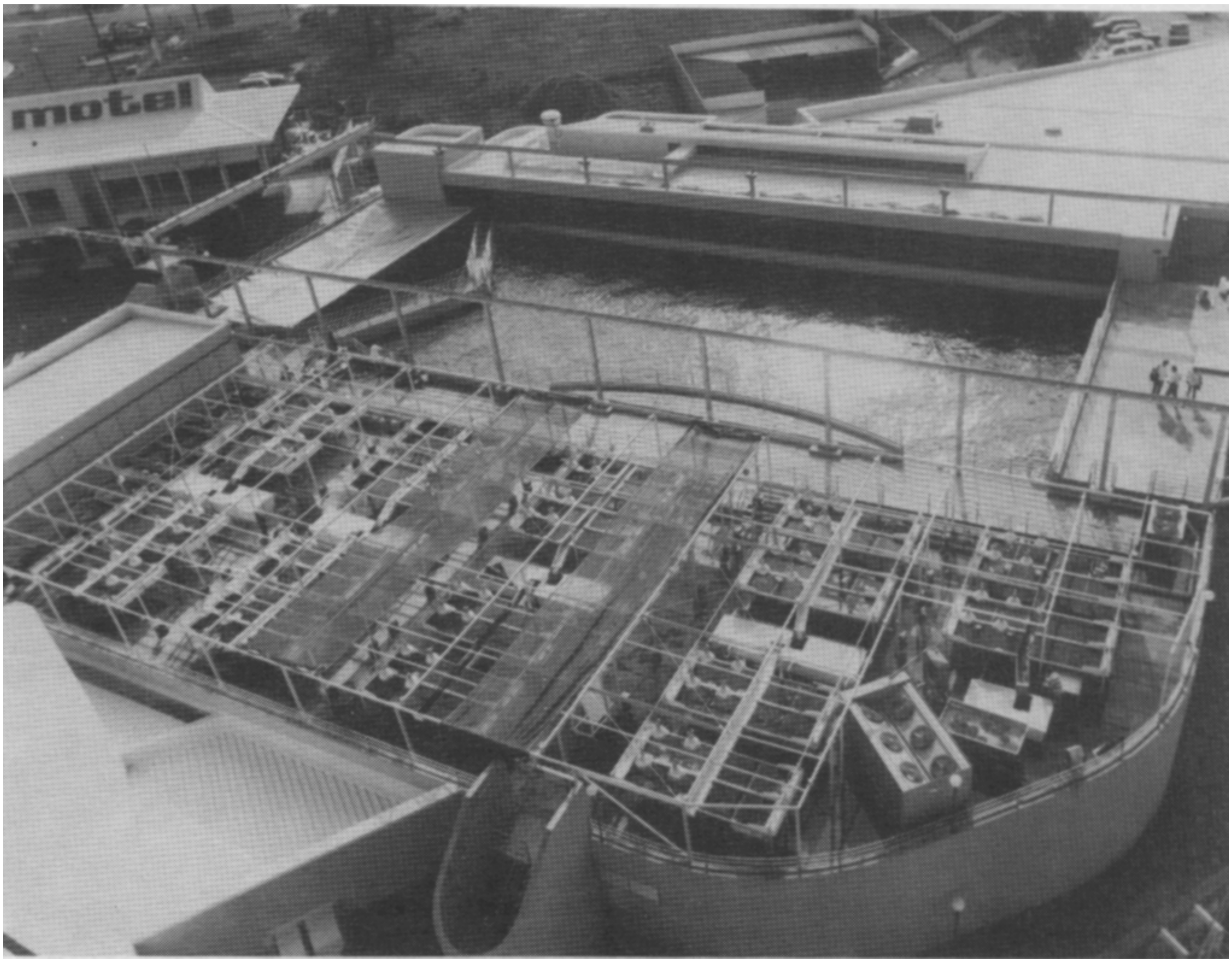

Figure 5 An aerial view of the completed Aquarium

The main interpretive area contains 15 smaller aquaria, a shop, a 200 seat theatre and static and video displays. A classroom and laboratory for school and other groups, a large Touch Pool and other exhibits are located on an enclosed observation deck overlooking the main tanks. Exhibit preparation areas, staff offices and a mechanical workshop are on the ground floor beside the Tidal Holding Tank.

Adjacent to the predator tank, is the main pump room. This houses the main circulation and filtration pumps for the coral reef and predator exhibits, together with the deionised water supply system and the scuba compressor. Two large sand filters and two freshwater reservoirs for filter backwashing are housed behind the pump room at street level. A 5 tonne gantry crane traverses the width and length of the coral reef and predator tanks and reaches over Ross Creek to allow servicing and stocking the main tanks.

The aquarium coral reef

Our understanding of how a reef functions has been largely derived by studying whole reefs or by taking reefs apart and investigating the various components. The job of trying to put a functioning coral reef together is a little different. It is rather like trying to put a jigsaw together with several important pieces missing.

The site for the Aquarium on the banks of Ross Creek was a former mangrove forest. To support the 4,000 tonnes of seawater and the weight of the concrete structures approximately 200 piles, each with a design load of 125 tonnes, were driven through more than 10 metres of soft mud to reach a hard foundation of clay and rock.

As draining the tank would kill much of the resident plant and animal life the tank housing the unique closed-cycle coral reef had to be designed to withstand the effects of seawater for 50 years.

A special high strength, low water/cement ratio mix of concrete was used. This concrete was pre-cooled with liquid nitrogen, to minimise cracking during curing, before pouring the foundations and tank walls. Conventional reinforcing steel was used, covered with twice the normal

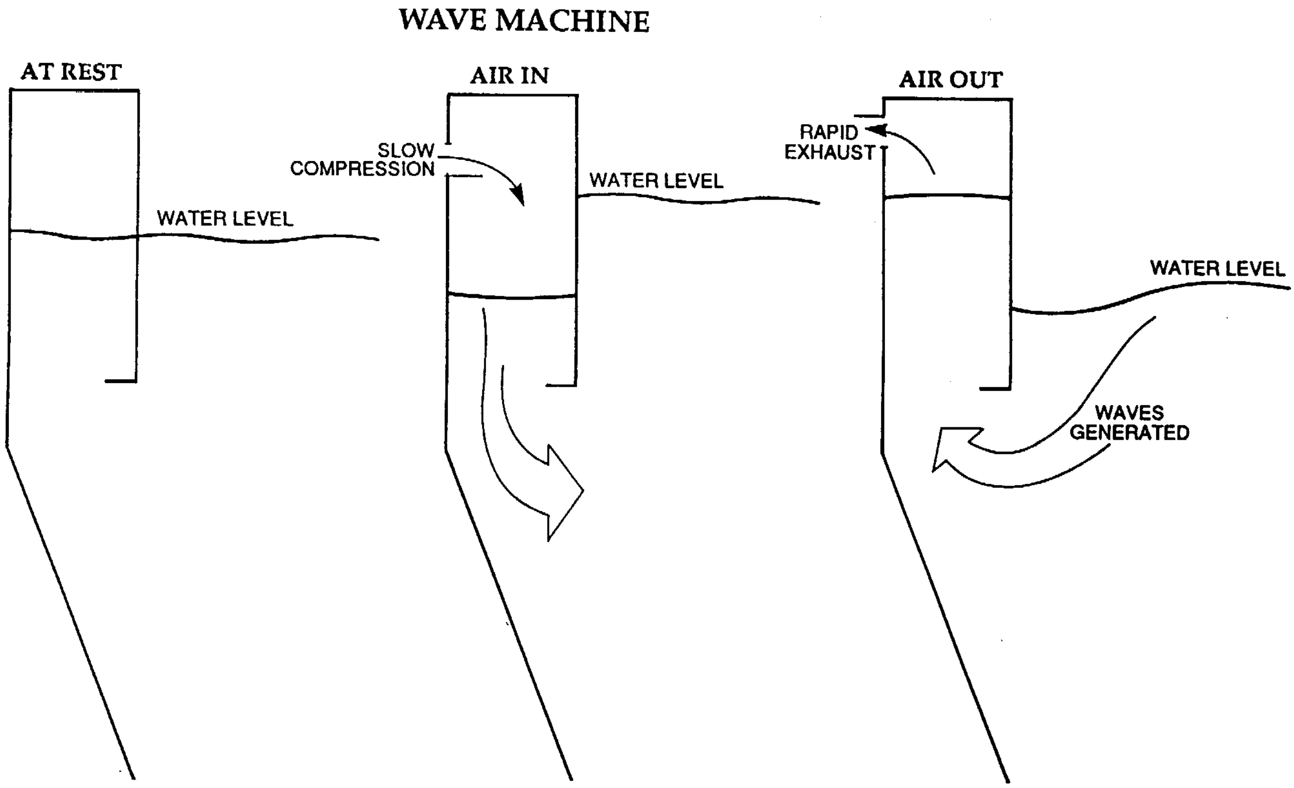

Figure 6 Diagram of the wave machine

depth of concrete, with stainless steel plates at the main tank joints. The internal tank walls were coated with non-toxic epoxy paint to give a smooth finish, reduce leaching of lime from the concrete and to ensure waterproofing.[2]

The principal feature of the Aquarium is a 20 m long acrylic viewing tunnel. In addition there are 5 flat viewing windows, each approximately 3.5 x 4 m, which provide a good view to the remainder of the coral reef exhibit. Construction of the Aquarium was completed on schedule in December 1986 leaving 6 months for stocking and fitting out before opening.

Building the coral reef exhibit started with dredging some 200 tonnes of coral sand, under permit, from the lagoon of Flinders Reef. A sand layer about 0.5 m thick was laid as the foundation. The basic reef shape was then constructed from 700 tonnes of coral boulders obtained from an excavation for a harbour development at Hayman Island in the Whitsunday Islands group (Figure 4). The tank was then filled with seawater, collected well offshore to ensure starting with unpolluted seawater and transported by barge to the Aquarium.

Waves and currents

The structure and biological activity of coral reefs are largely determined by the water motion due to waves, tides and currents and the chemical composition, temperature and salinity of seawater. As far as possible the physical and chemical environment of the Great Barrier Reef have been replicated in the Aquarium coral reef exhibit.

Waves are created by a pneumatic wave machine (Figure 6). For generating waves, producing a trough is just as good as producing a crest. At rest the water level in the wave machine chambers is the same as the water level in the coral reef exhibit. In the first stage of the wave generation cycle, compressed air is blown into the chamber and depresses the water level. At the end of the compression cycle a large valve opens allowing the compressed air to escape rapidly. The water level in the chamber rises swiftly drawing in water from the reef tank effectively generating a trough. This trough is propagated along the tank and reinforced by the next wave generation cycle depending on the timing and volume of air delivered to the 4 wave chambers.

The wave machine is capable of generating a 2 m wave, which gives spectacular results at the tunnel end of the tank! The wave height used is typically 0.25 to 0.75 m in contrast to the Great Barrier Reef itself where wave heights are 1 to 4 m and considerably larger during cyclones. The great advantage of the wave machine is that there are no moving parts in contact with seawater so corrosion, maintenance and contamination of the tank are kept to a minimum. Fish, soft corals and the larger marine plants sway back and forth in the realistic surge generated by the wave machine.

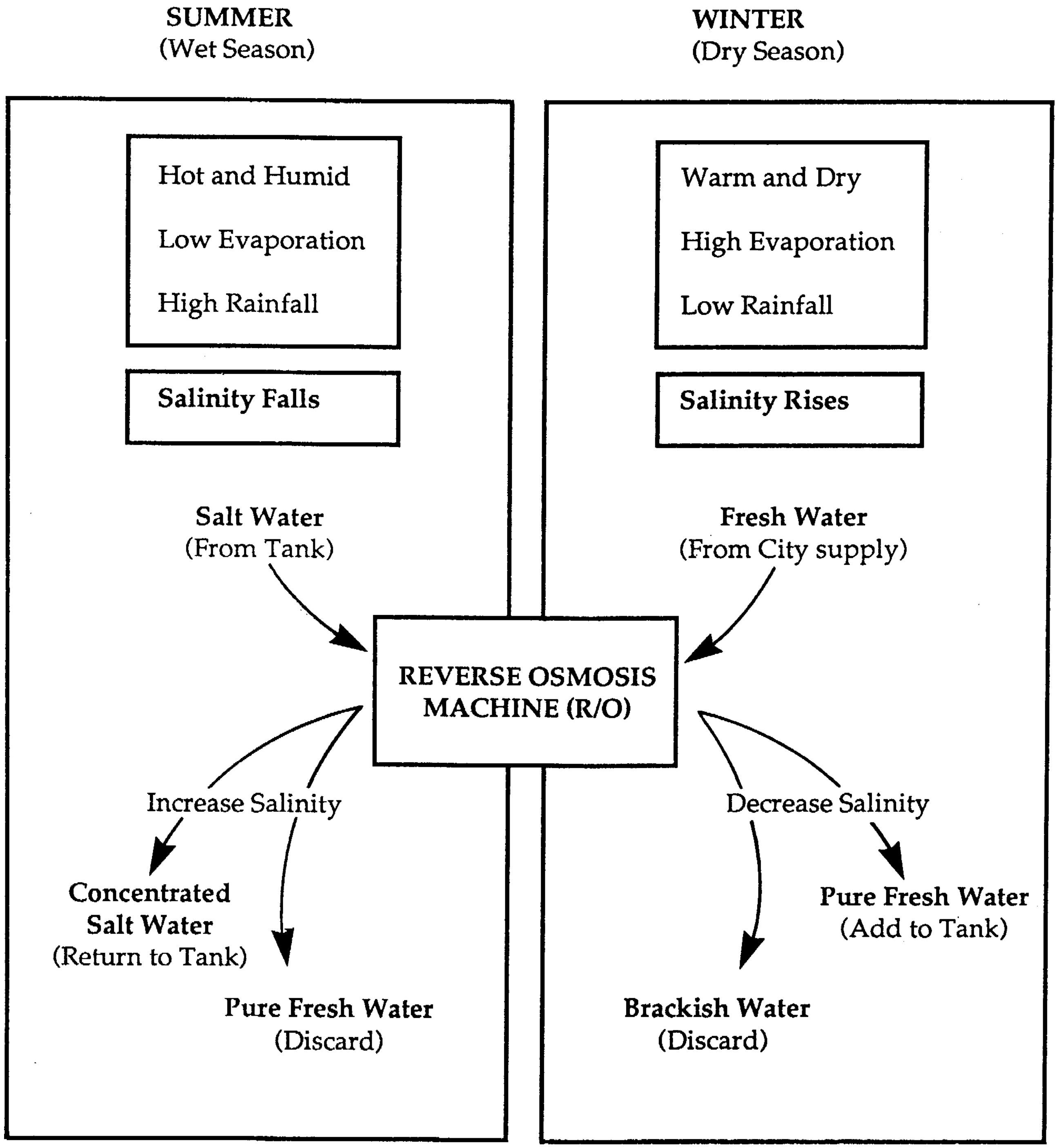

Figure 7 Diagram of salinity control using reverse osmosis

Sediments

As on the GBR, fine sediments are generated by physical and biological processes in the coral reef exhibit. Wave action suspends these sediments and prevents the undesirable effects of them accumulating on the corals and other substrate. Suspended sediments produced on the Great Barrier Reef are normally transported away from the reef by tidal and wind generated currents to settle in the deeper parts of the ocean. In combination with wave action, currents ensure good mixing and facilitate gas and nutrient exchange. A constant current is maintained across the reef in the tank by drawing water from the tunnel end, pumping it through a sand filter to remove suspended material and returning it to the wave machine end of the tank at 90 l sec^{-1}. The sand filter substitutes for the deep ocean in removing the sediments generated in the Aquarium reef.

Life processes in the sea and on reefs generate materials that gather on the water surface as films, scum or slicks. In the ocean these materials are dispersed they but will accumulate in any contained situation. Water constantly overflows from the Aquarium reef exhibit to the tidal holding tank taking these materials with it and dispersing them in the water, leaving a clean surface to facilitate gas exchange. The facility for generating tides to 0.5 m in the Coral Reef Tank has not been routinely used as the change in wave pattern with different water levels reduces visibility in the tank.

Temperature and salinity

Townsville has a climate with warm dry winters and humid hot summers, often involving torrential rains associated with cyclones. The great volume of the sea surrounding the Great Barrier Reef greatly reduces the effect of these sudden changes in air temperature and rainfall. It is generally considered that 30° C is the upper limit for Pacific corals and the phenomenon of "coral bleaching" throughout the Pacific, during high surface water temperature events, is attributed to this.[3] The Aquarium reef has a relatively small water volume and responds rapidly to changes in air temperature, humidity and rainfall. The summer maximum water temperature in the Aquarium reef, is controlled by a combination of refrigeration, shading and evaporative cooling.

Evaporative water losses are highest during the dry winter months and the salinity of the tank rises. During the humid summer periodic heavy rain dilutes the tank seawater and the salinity falls. Both of these conditions are compensated for by using a reverse osmosis machine. During winter the city water supply is purified to the exacting Aquarium standards required (removal of tannin based discolouring compounds, residual chlorine, iron and trace nitrogen and phosphorus nutrients) by passing it through the reverse osmosis treatment. During the summer the tank seawater is passed through the same reverse osmosis machine with the pure extracted fresh water being discarded and the concentrated brine returned to the tank to increase the salinity (Figure 7).

Metabolism of the aquarium reef

Scaling down the Great Barrier Reef to recreate a representative portion in the middle of a city requires close attention to more than replicating the natural physical conditions where coral reefs grow. The maintenance of water quality is critical.

The normal life processes on a reef, as in any living system, start with plants (primary producers) converting inorganic material to living matter by photosynthesis. Animals eat the plants in one form or another and produce organic wastes. These are reduced to inorganic materials by bacteria and are again available for plants. On a global scale this all balances out with sunlight providing the energy at the plant level to maintain a continuous cycle. The differential between primary production at any 2 points in the ocean is dependent on the availability of sunlight and inorganic nutrients. Tropical seas are usually almost devoid of nitrogen and phosphorus nutrients compared to the generally richer temperate and polar waters.

Paradoxically coral reefs, with their great variety and abundance of life forms, thrive in the low fertility tropical oceans. Low dissolved nutrient levels limit the growth of phytoplankton in the water column resulting in very clear water. The great transparency of reef water allows plenty of light to reach the bottom dwelling community. Tightly associated animal and plants such as corals with their symbiotic microscopic plants (zooxanthellae) facilitate direct relocation of basic nutrients and food without the inefficient step of transfer through the ocean.

Scaling down such a system inevitably results in distortion. In the case of the Great Barrier Reef Aquarium, distortion results from the requirement to present as large an area of reef as possible within the tank. In such a closed system the plant/animal ratio is weighted in favour of the animals and more wastes are being produced by the animals than are able to be converted by the plants and ultimately the level of nitrogen and phosphorus nutrients in the water increase.

Apart from adding small amounts of plankton or plankton substitutes, no animals are artificially fed. The Coral Reef Exhibit is a closed system and little water is exchanged with the adjacent ocean. Most closed system aquaria are based on bacterial degradation of metabolic wastes, similar to a basic sewage system. Ammonium compounds are degraded first to nitrites and finally nitrates. The nitrate level is then controlled by regular water changes.

To keep corals in captivity one needs water with a very low nutrient level, less than 50 ppb (parts per billion) nitrate.[4] In the Aquarium coral reef nutrients are generally between 5 and 60 ppb nitrate.[5] Increases exceeding 100 ppb can follow perturbations such as substantial specimen additions or extensive cloudy periods, particularly if accompanied by heavy rain. Higher than normal levels of some nutrients appear to be toxic to some species of corals (particularly *Acropora* species) and also promote the growth of macro-algae that out-compete corals for living space. The solution is to increase the area of plants, not make them available as food to the animals in the system, and harvest them, thereby removing the surplus inorganic nutrients. This is what the algal turf system does.[1]

Algal Turf Scrubbers

Although Townsville is an area of very low level pollution, the aerial addition of nutrients is significantly higher than on the reef, particularly as the Aquarium is in the lee of the main loading facilities for for a relatively large port. The effect of aerial nutrient additions from rain and dust is enhanced by the relatively high surface area of the

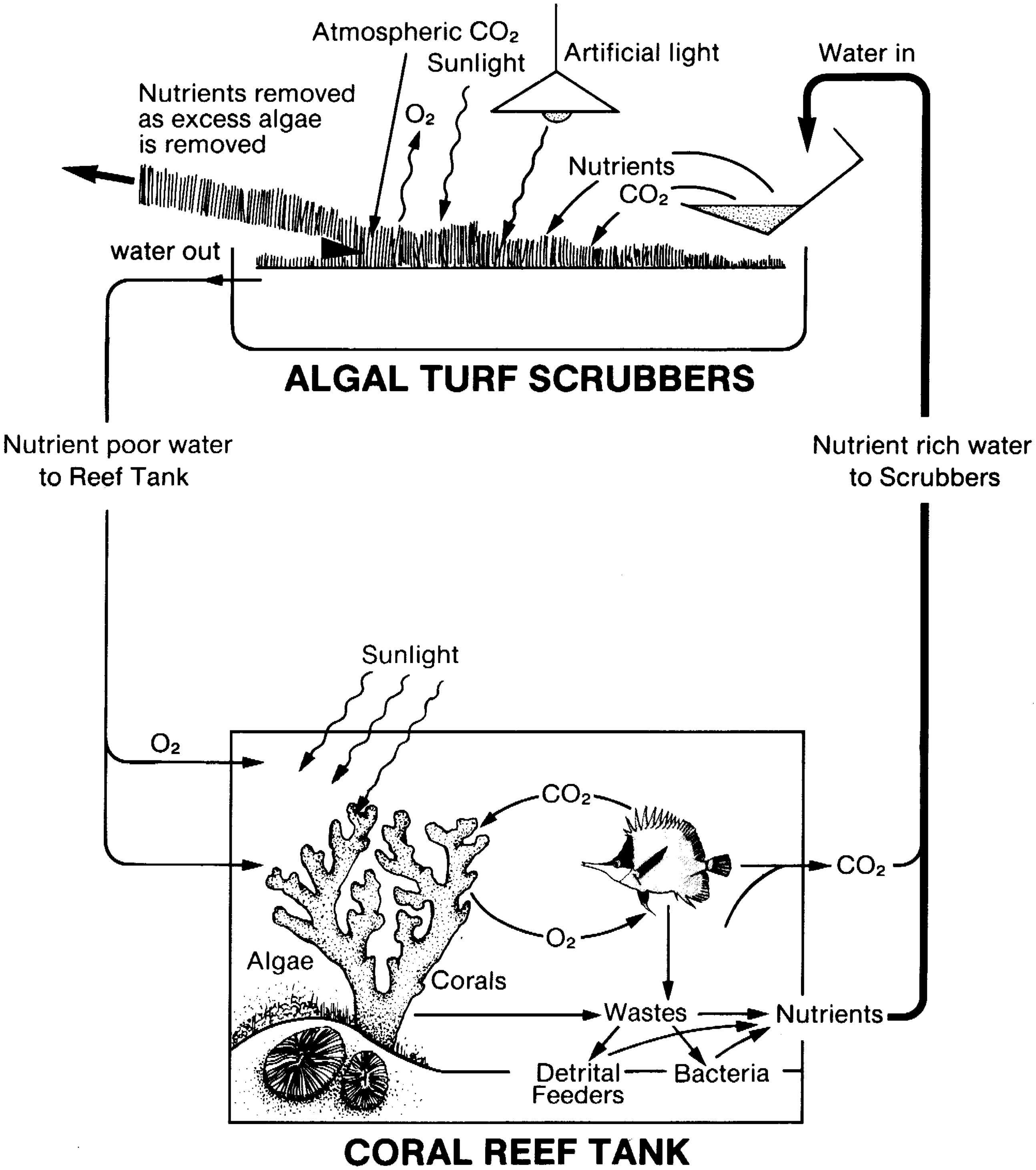

Figure 8 Diagram of the algal turf scrubber

aquarium reef and associated turf farm to the volume of the tank. There is also the, as yet undetermined, contribution of bacterial nitrogen fixation.

The algal turf system simulates the process that occurs on the weather side of coral reefs as the waves break against the reef and cross the reef top. In this area of turbulent mixing behind the breakers, a zone of short dense actively growing algae normally develops.

The system used by the Aquarium, is quite simple and consists of a shallow tray with two removable coarse mesh screens and a tip bucket at one end. Seawater is delivered to the tip bucket, which tips several times per

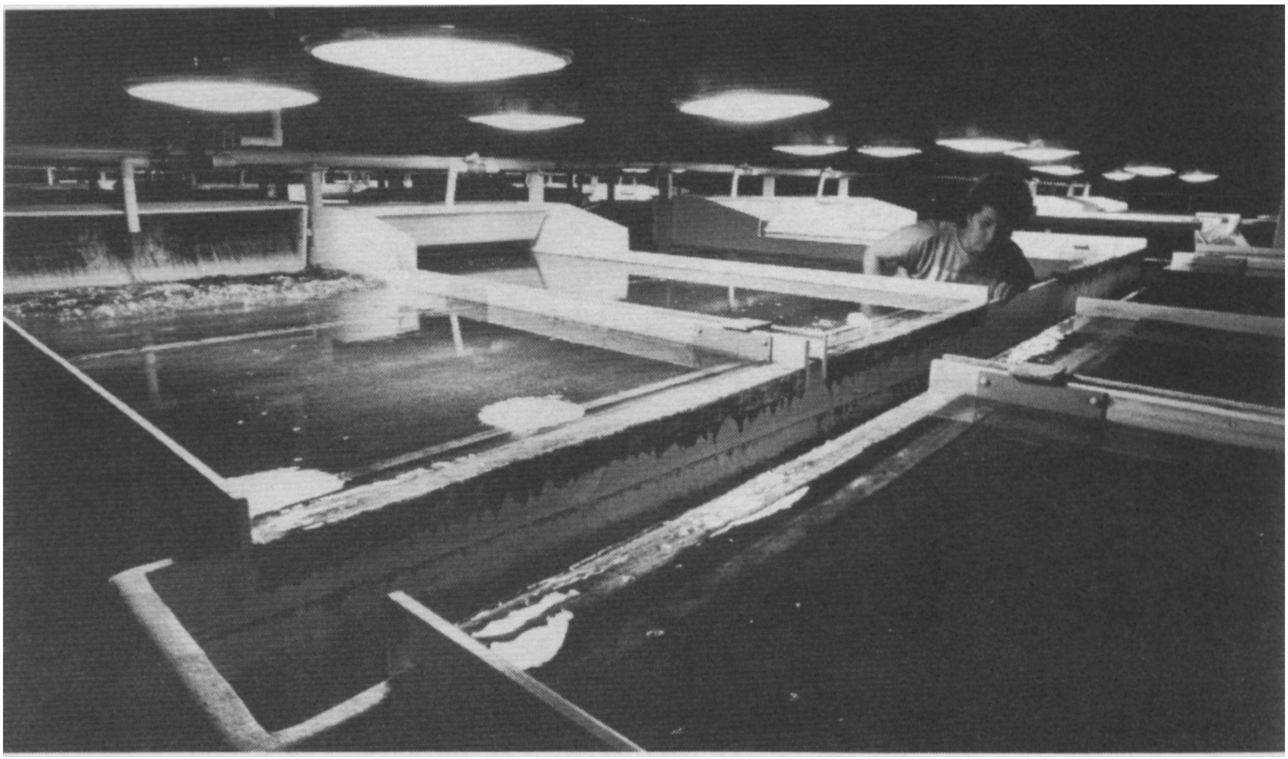

Figure 9 The algal turf scrubber at night

minute, causing a series of waves to rush across the screens. This water turbulence provides good mixing and facilitates gas exchange and nutrient uptake.

Algae in the process of growing on these screens take up nutrients. The algae, with the incorporated nutrients, are regularly scraped from the screens and discarded, effectively removing the inorganic waste from the tank as plant tissue. After passing over the screens the water runs into a settling bin and back to the tank. Artificial light, at an intensity of about half noon summer sunlight, supplied by forty 1 kw metal halide lamps is used at night and on cloudy days. Each algal turf screen has 18 hours illumination per day which increases the growing period and the rate of nutrient removal from the coral reef exhibit seawater (Figure. 9).

The distinguishing feature of the Great Barrier Reef Aquarium is the ability of the algal turf system to maintain water with a much lower nutrient level than conventional systems, some 1,000 fold lower for nitrate. This brings the nutrient concentration close to natural conditions.

The algal turf system provides other benefits. The process of photosynthesis removes carbon dioxide from the seawater thus maintaining the pH (Figure 10). Similarly the seawater oxygen levels are maintained without the need for supplementary aeration. Algae require trace amounts of various metals for compounds such as their photosynthetic pigments, these include heavy metals which may be toxic for reef organisms if allowed to accumulate in the water. Thus the algal turf system controls some trace metals[6] as well an inorganic nutrients.

Evolution of the aquarium reef

The tank was gradually stocked, over a 6 month period, beginning with establishing a diverse plant community. Large quantities of algal covered coral rock, most containing sponges, crabs, worms, sea urchins and other invertebrates, were carefully collected from the Great Barrier Reef and introduced to the tank. As the marine plants became established, herbivorous fish (mainly parrot fish and surgeon fish) were added, followed by herbivorous invertebrates (trochus and sea urchins). After about 3 months some omnivorous fish, hard and soft corals, giant clams, starfish and molluscs were added. Finally a small number of carnivorous fish and detritus feeding organisms such as holothurians and stromb shells were added.

Coral Reproduction

In the first year of operation, the corals spawned in the tank. This was significant as the generally accepted view is that if animals reproduce in captivity the environment must be right.

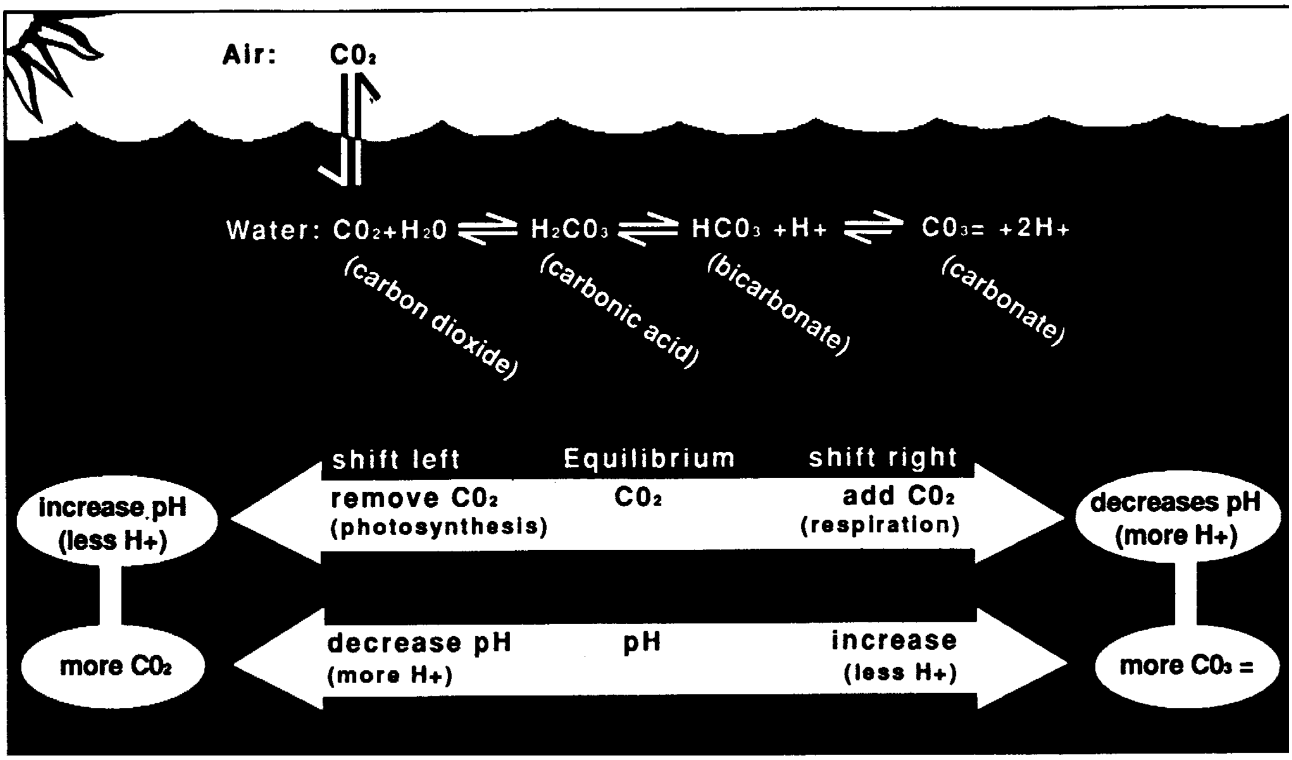

Figure 10 Diagram of the photosynthesis cycle. The pH and CO_2 content of sea water are linked by this reaction system. A change in pH or CO_2 will shift the equilibrium of these reactions. This buffering system helps maintain a relatively constant pH in the ocean.

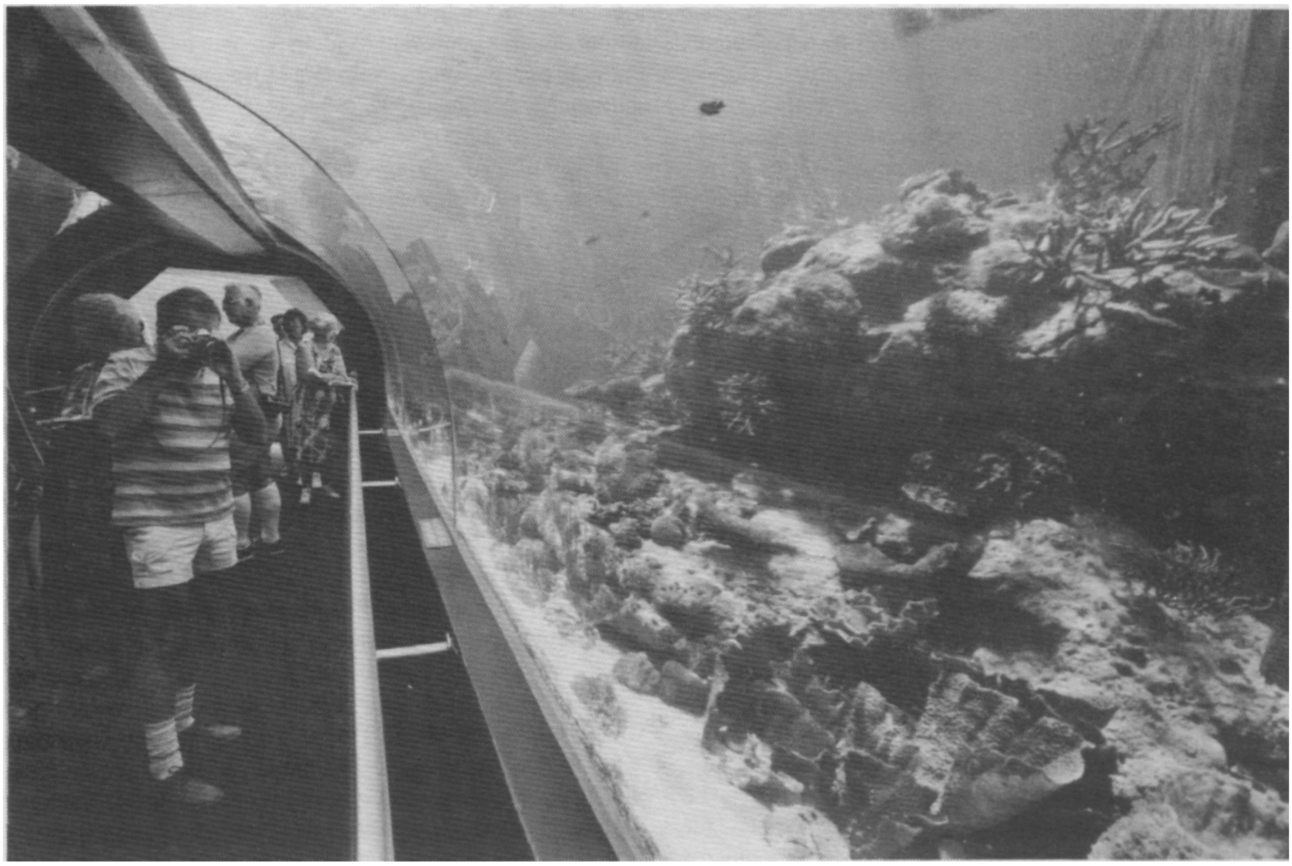

Figure 11 The Aquarium reef from the acrylic tunnel

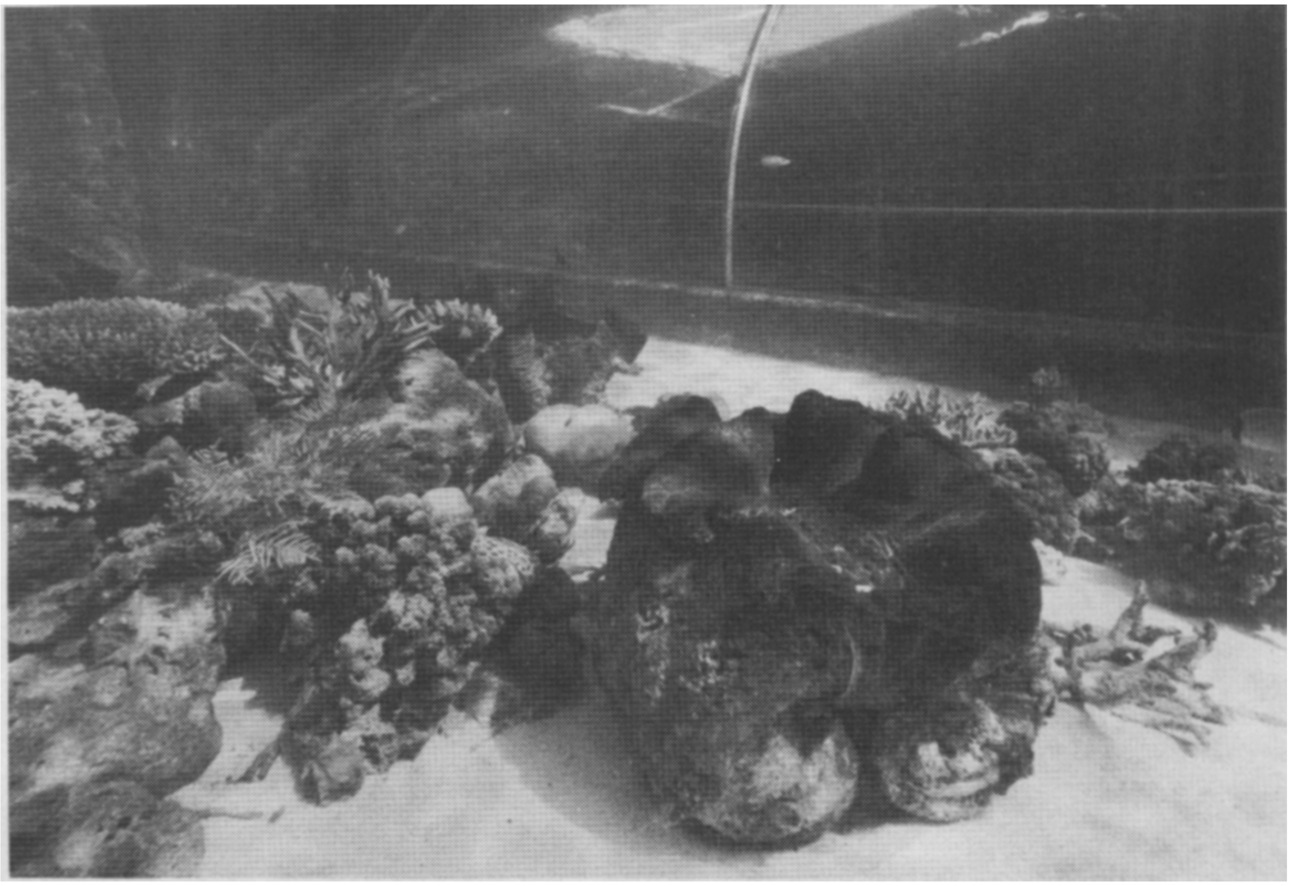

Figure 12 The finished Aquarium reef

Recruitment of corals, that is survival and growth from a successful spawning, is another matter. Coral larvae spend periods varying from 1 day to several months, depending on the species, drifting with the plankton. In the Coral Reef Exhibit young coral larvae are likely to be consumed by the pumps, trapped in the filters or plunged into the darkness of the tidal holding tank. Only one juvenile *Pocillopora* sp coral has, so far, successfully recruited. It had only a brief life before being consumed whole, probably by a coral eating parrot fish.

The tank now contains some 1,500 colonies of hard coral of 100 species, 700 soft coral colonies, 300 sea urchins, 400 molluscs and several thousand fish. No disease problems have developed, possibly as a result of the natural diet and environment. Many species of fish display courtship behaviour (parrot fish, *Chromis sp, Abudufduf sp*, anemone fish) and so far the catfish, *Plotosus anguillaris*, have reproduced in the tank. Other animals, giant clams, sea urchins, holothurians, trochus and spider shells, also spawn regularly in the tank.

Natural Disasters

Few projects go according to plan; and stocking the Aquarium has been no exception. A massive bloom of microscopic algae, turned the seawater a bright green immediately after the initial filling of the Coral Reef Exhibit tank. This was a comparable phenomena to the phytoplankton bloom that occurred in that section of the GBR lagoon affected by Cyclone Winifred.[7] The cyclone resuspended the sea floor sediments and liberated the stored nutrients. Filling the tank with sea water had dissolved and released the nutrients in the layer of dry coral sand. In both cases the abnormally high nutrient situation was taken advantage of by the rapidly growing phytoplankton. The solution was to pump out the phytoplankton (and nutrient) laden water and start again.

One thing was immediately apparent after successfully filling the tank. The reef structure that had looked so impressive through the curved tunnel windows in air, was not nearly as majestic in water. The curved tunnel windows, combined with the different refractive indices of water and acrylic, caused a foreshortening effect on the seascape. Rock moving, now more difficult under water, was continued until an appropriate seascape was produced.

At 6 months, as the tank was approaching full stocking level, a bloom of macro-algae covered the walls and all bare rock surfaces threatening to choke out the corals and filling the tank with unsightly floating algal fragments. Just as weeds initially flourish in freshly tilled earth the availabil-

Figure 13 A diver working in the Aquarium reef

ity of the fresh clean rock and wall surfaces provided opportunities for colonising macro-algae. This growth on the walls was probably encouraged by phosphate compounds (used in all paints) leaching out of the epoxy coating on the walls. For several weeks, teams of divers worked all day mechanically removing the profuse growth. Providing the right mix of herbivorous fish and invertebrates has ameliorated but not entirely resolved the situation. Unfortunately, sea urchins can not be trained to climb the walls to where they are needed to control the algal growth.

The reality of the need for careful management of coral reef systems can best be demonstrated by a simple calculation of the consequences of a diver succumbing to the temptation to urinate in the tank. Under normal circumstances one would expect these minor lapses in etiquette would not matter! At the normal parts per billion level operational level for nutrients in reef systems, this may not be so. The average human excretes 30 g of urea day^{-1}. Urea converts rapidly to ammonia and then to nitrate in the marine environment. One excretory event of say 5 g of urea would be sufficient to raise the nitrogen concentration of 200 m^3 of ocean water to over 10 ppb. This is well above normal ocean water levels.[8]

Fine Tuning

Fine tuning of the community structure of the Aquarium coral reef continues today, 5 years after its inception. Callianassid shrimps and goat fish are added to turn over and clean the sand. Predatory fish are collected to correct the behaviour of anemone and other damsel fish straying too high in the water column. We add territorial herbivorous fish to inhibit overgrazing by other animals and make regular small additions of plant and animal material to maintain diversity and make up for the depredations of the carnivores. No animals in the Aquarium reef are artificially fed, however zooplankton are routinely collected from Cleveland Bay adjacent to Townsville and added to the Coral Reef Exhibit as a substitute for the natural planktonic food available to a coral reef but removed by the sand filtration system in the Aquarium. When we are unable to collect zooplankton brine shrimps or other substitutes are used.

Figure 14 A diver vacuuming surplus algae in the Aquarium coral reef exhibit

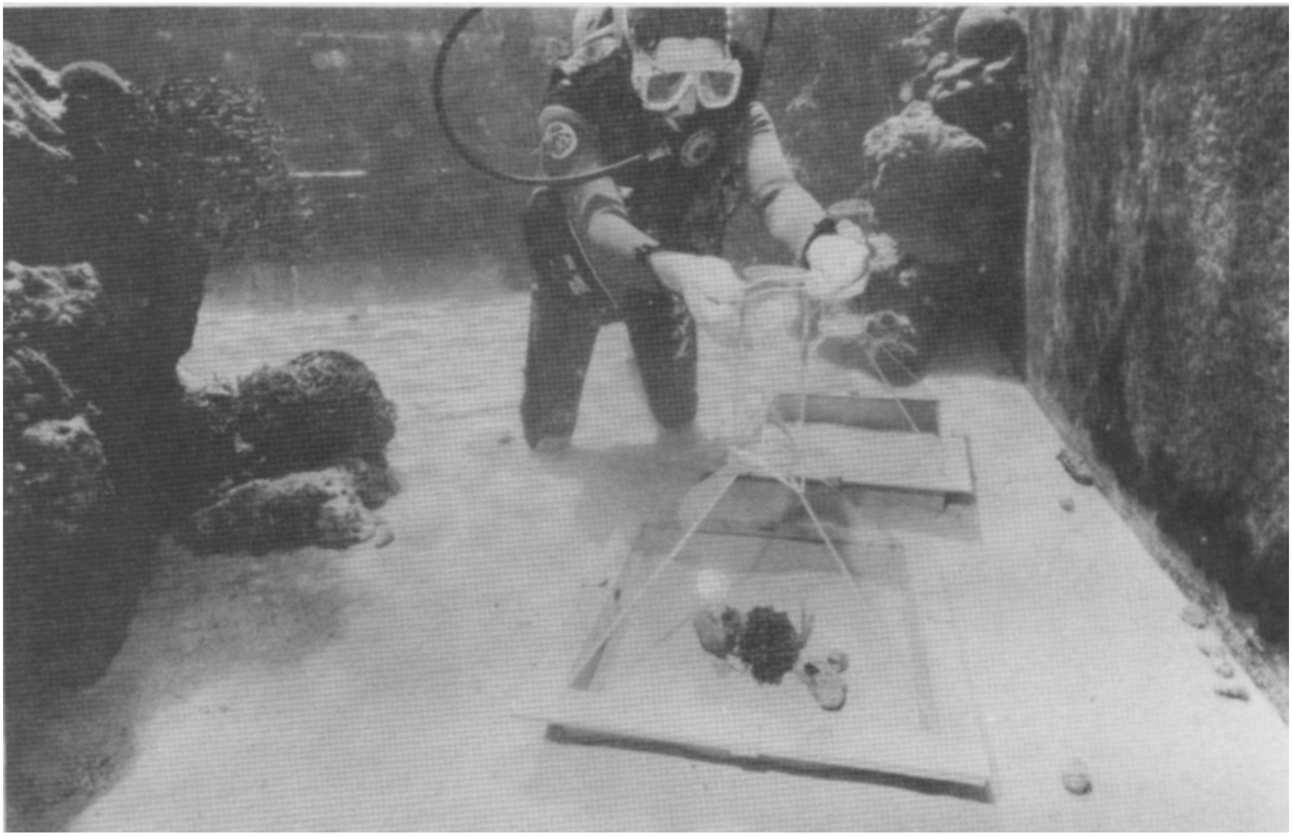

Figure 15 A diver sampling the new benthic zooplankton community of the Aquarium reef.

Reef research

The coral reef exhibit is a ideal research tool. Our research effort at the Aquarium is applied to determining the optimum conditions for the growth of our captive coral reef. The reputation of corals as difficult animals to keep in the home aquarium are well deserved. They are fussy about their surroundings compared to reef fish which have wider environmental tolerances. Corals are the focus of our research activities as we learn about ways to improve coral survival in our tank. Investigations completed or underway at the Aquarium have examined: development of a test for nutritional state of corals, the effects of oil on corals, the light regime in the tank[9] and a comparison of the benthic plankton community of the Great Barrier Reef with the Aquarium coral reef (Figure 15).

Conclusions

Ultimately education is the key to public support for the conservation and wise use of natural resources. The Great Barrier Reef Aquarium provides a readily accessible window on the reef and a wide range of educational experiences and interpretive services. Reproducing a section of the Great Barrier Reef on land, as a self supporting natural ecosystem, was a difficult and exacting task. Our Coral Reef Exhibit is unique in but costly to maintain in terms of skilled labour for operation, maintenance, collecting and monitoring and electricity costs. A captive coral reef ecosystem, for demonstrating and interpreting processes and issues affecting the Great Barrier Reef, is a powerful public education facility for assisting the work of the GBRMPA.

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MANGROVES IN TROPICAL REGIONS ADJACENT TO THE GREAT BARRIER REEF

Joe Baker

I speak on behalf of Alistar Robertson and his colleagues of Program 1 (Coastal Processes and Resources) of the Australian Institute of Marine Science (AIMS). They have established world leadership in understanding of the ecology of tropical mangrove ecosystems. I hope to communicate some of the excitement of this research.

Mangroves are often regarded as small and insignificant trees growing on the coastal fringe. Many people believe they are confined to the tropics. However, there are mangroves in the gulf systems of South Australia. In Western Port and other sections of southern Australia mangroves are common. As one moves up the New South Wales coast, mangroves become more plentiful and more diverse in form until we come to the North Queensland region. At our study site on Hinchinbrook Island there are more than 35 different species of mangrove trees. Mangroves are not confined to the tropical regions but the greatest diversity of mangrove species does occur in the tropics.

What are mangroves? The origin of the word "Mangroves" has been analysed by one of the leaders of mangrove research, Dr Marta Vannucci, in work conducted for UNESCO and with the International Society for Mangrove Ecology. She says:

"I finally concluded that the word mangrove would be African. The word was learned by the Portuguese on the west African coast by the early XV century. In fact, in discussing the fortifications to be made at Cacheu, which is present day Guinea-Bissao ,(Anon. Fortificacao de Cacheu, c. 1600, courtesy M.E. Bandeira Santos, C.E.H.C.A. Lisbon, pers. comm.) on the Guinea coast, "mangue sticks" (paus de mangue) are mentioned as being normally used to fence in the lands of the Portuguese to "protect them from continuous harassment by the natives". The "alagados" (flooded low lying or coastal areas or mangroves) shown on ancient Portuguese charts are marked with symbols still in use on nautical charts.

The mystery was finally solved by Dr E.S. Diop (pers. comm. 1988) who told me that in his mother language, Wolof, which is the national language of Senegal, the name for mangroves in mangue, with exactly the same pronunciations in Portuguese. The people from the "rivers of the south" (down to Guinea-Bissao, e.g. R. Geba) use the word mangle or mangli, which explains the origin of the Spanish word for the mangroves - mangle. The word mangue, therefore appears commonly in Senegal, Gambia, Casamance and Guinea; this name the Portuguese had already adopted in the XV century and spread throughout the world. Later the Spaniards learnt and adopted the words mangle and manglar that are used in all Spanish speaking cultures.

Later the words mangue and mangroves became a synonym for danger, confusion, wastelands. Mangrove swamps were in fact ill reputed areas and neither their intrinsic value nor the service they render to human kind or the role they play in the great drama of nature, were recognised. In the late 1870's a "Manual for the conversion of Wastelands" was published, where the "wastelands" were the Sunderbans, perhaps the largest single unfragmented area of mangroves in the world, on the delta of the Ganga-Brahmaputra river system. The Sunderbans (the word means "beautiful forests") are not only among the most beautiful mangroves, but are also among the most productive. Under the pretext of converting to "better use" such "bad" areas, much damage was done to an important ecosystem. All this happened because no outsider had tried to really understand the mangrove ecosystem and there had not been a local Chief Seattle to tell the invader that man is part of the ecosystem and should live in harmony with it."

Fundamentally mangroves may be regarded as plants that grow in salt water. One can have mangrove ferns, mangrove weeds, mangrove palms and mangrove trees of many different varieties. As one moves from the sea-shore environment one observes different species of mangroves which appear to have adapted to different levels of salinity of the water. The key feature of mangroves is that they can live in salt water. In this simple statement there is perhaps the potential for Australian researchers to study and develop tissue culture techniques to find the way in which other plants may be modified to grow successfully in our inland waters where we are plagued by the problems of increasing salinity. If we could develop such trees we may in the long term assist in the revitalising of the fresh water systems of our continent. Such a development could perhaps lead to allowing replanting of native trees in our inland areas as the water salinity decreases as a result of good management practices.

The mangroves of our coastal areas represent an enormous resource not only for the biological productivity (which I will explain) but also for the physical protection that they afford to our coastline. I would also like you to keep in mind that, in many countries, mangrove trees are already used as sources of energy, and as sources of timber for construction. We believe that within the next 30 years mangrove forests can be grown in Australia to produce timbers that will be suitable for cabinet making and for other domestic use. Some of the timbers on display at the Australian Institute of Marine Science, and notably the mangrove cedar, have attracted significant attention. Alistar Roberston's group has trial plantations in place for different mangrove species.

One of the coastal features of Queensland between Townsville and Port Douglas is Hinchinbrook Island, the world's largest island national park and one the richest areas of mangrove growth. Here we have a 60 square kilometre mangrove study site largely undisturbed by humans, where excellent work has been conducted by AIMS scientists over the past 14 years. The mangrove streams in the Hinchinbrook Island complex have waterways, not with distinctive visible earth banks, but with areas between the water and the land thick with trees featuring complex systems of roots. Around Townsville the mangroves become sparser but they are still of enormous significance with respect to their biological productivity. Mangroves of course are not confined to the coastal fringe. On day trips from Port Douglas to the Low Isles you will observe that one of the islands is a true coral cay and the adjacent island is a mangrove island. That itself is a distinctive feature. If one dives to inspect the coral cay it is well worthwhile moving over to the mangrove island to observe the enormous diversity of life that spawns in a mangrove ecosystem.

Looking at mangrove trees one is impressed by the rich foliage. One can also observe a certain number of dying leaves, identified by their yellow colour, and the propagules (runners) of different species.

At our study site on Hinchinbrook Island, our scientists were very fortunate that the Army built them a walkway so they did not have to struggle through the mud and root system every time they wished to conduct their research. Our scientists observed that the walkway was always covered with leaves whereas the mud around the walkway had effectively no leaves on it. At first it was thought that perhaps the leaves falling on the mud were carried out immediately by the tide but this could not always have been the case. When our scientists sat on the walkway to observe what happened they noted that if a leaf fell on the mud it was quickly taken away by a small crab, one of the sesarmid crabs which lives in the area. This feature was studied in detail by a series of AIMS scientists who observed that, in the study site of 60 square kilometres, each year up to 60,000 tonnes of leaf and litter fall from the mangroves. Of the leaf fall, some 40% is consumed by these small sesarmid crabs.

That equates to approximately 24,000 tonnes per year. Obviously there must be millions of these crabs and they, being well fed, reproduce actively. The larvae of the crabs become food for the small baitfish which accumulate in schools and move to the mouths of the rivers. On different occasions they are then moved by coastal currents to predictable areas where we subsequently observe very large fish taking advantage of this ready food supply.

Near AIMS we face from Cape Ferguson to Bowling Green Bay and thence some 50 kilometres away to Cape Bowling Green. The river systems which feed into Bowling Green Bay are principally the Haughton River and the Barratas. These rivers are mangrove lined. In one of the small mangrove creeks Alistar Robertson and his colleagues netted the mouth of the creek on an outgoing tide. They observed coming from that creek 145 different species of juvenile fish and 28 different species of juvenile crustaceans. That is not the total number of fish nor the total number of crustaceans, but the number of different species. The richness of these mangrove areas for juveniles of different species was up to ten times as great as for the offshore seagrass beds and the mudflats around. However, the numbers of adult fish in the mangroves and adult fish in the seagrass beds were about the same. This suggests that the mangroves are essential nursery areas.

One of the beauties of working at AIMS is that we do not have a departmental structure. There is no Department of Chemistry, no Department of Physics or Department of Mathematics or Department of Oceanography. The scientists work together in multi-disciplinary teams to explain how systems and processes work. If it were not for this harmony of marine research it is unlikely that we would have made the advances that the Institute has achieved in recent years. It was the biologists who observed the litter fall and the interaction with the mud crabs. They also observed that the larvae of these crabs were important as food for the baitfish and other fish. The fish, as they mature move out to the mouths of the creeks, and here the knowledge of Eric Wolanski and his colleagues on the way that waters move under different conditions, was an important factor in being able to predict where schools of baitfish would accumulate under different wind conditions.

For example, off Cape Bowling Green under the prevailing south-easters, which blow generally from March to September or October each year, we do find, (and Dr Wolanski and his colleagues can explain why), schools of baitfish up to 1.5 kilometres in diameter and 30 m deep. The larger fish such as certain, reef fish, the mangrove jack, the red emperor, the fingermark, all realise that there is good food to be obtained here with a minimum of effort. So do the sailfish and the marlin. Our scientists work together. The oceanographers explaining the way in which the living forms are carried in the currents and the biologists explaining how and why the baitfish are produced in the first place. Their combined efforts have led to a better understanding of the way the processes and systems work in the mangroves and adjacent waters. This type of study can be extended to any coastal region.

Partly as a result of the work of AIMS, the Queensland Government has declared the whole of Bowling Green Bay as a fish habitat reserve. Certainly as a result of the AIMS research and , more importantly, the communication of the results of that research to Local Government, and to potential developers, we have, to this time, been able to retain the natural vegetation of the coastal streams into Bowling Green Bay because they are the essential starting points.

The mangroves are the source. The simple facts of the leaf fall, of the crab acquiring this as good food, the reproduction of the crabs, that the crabs aerate the mud and the larvae of the crabs being the feed for the baitfish lead to the accumulation of baitfish. With their transport under different weather conditions to predictable sites it all adds up to an understanding which is essential if we are to successfully manage our marine coastal resources.

Mangroves, the trees which so few appreciate, are in fact one of the richest resources of our coastline.

When the tide comes in through unchanged mangroves it goes throughout the mangrove system. The water traverses between the complex root systems. Those who are good at mathematics could possibly make an estimate of the surface area that is there for different living forms to settle upon when their larvae have finished their free swimming stage and are ready for settlement. Contrast that with the harsh rectangular symmetry of the marina, the absolute interface of concrete with water and we can easily understand how the amount of surface for settlement of future generations of larvae is so dramatically and horrifically modified when we change from mangrove to concrete. Marina development in Florida is an extreme case. We hope that such events never occur in Queensland. But we cannot be complacent. There are many applications before the Queensland Government for major tourist developments in the coastal region. We cannot afford to have this type of development if it means the destruction of the mangrove interface between land and water.

There are many examples where humans have been smart enough to take simple steps to protect a sensitive boundary or interface. The road system used to have enormous repair bills because we would drive our cars too close to the edge of the road at the interface between the hard bitumen and the softer soil. Engineers recognised that placing a white line in from the edge to keep cars away from the sensitive area would reduce the pressure and were able to reduce maintenance costs.

Nature's “white line” in much of the coastal regions of the Pacific is the mangrove. One aspect in which we must all become more proficient is communication on the value of mangroves and of the way that their ecosystem must be preserved in order that the biological productivity of our coastline can be maintained and the physical protection offered by this complex of root systems and trees guaranteed for the benefit of future generations.

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PRODUCTION OF GEOLOGICAL STRUCTURES BY THE GREEN ALGA *HALIMEDA*

E A Drew

Introduction

Halimeda is a genus of calcareous green algae found throughout the tropics, mainly on coral reefs. One species also occurs in the subtropics and another in the Mediterranean. Twenty of the world's 30 *Halimeda* species grow, often prolifically, on the Great Barrier Reef (GBR). Most of those not found there are confined to the Caribbean, having evolved there after the closure of the Isthmus of Panama in the Miocene, 20 million years ago.

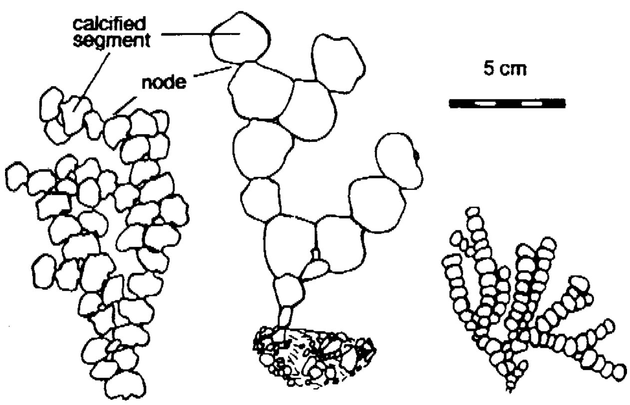

Figure 1 *Halimeda*

The appearance of *Halimeda* plants is shown in Figure 1. They are all composed of numerous flat segments between 0.5 and 3 cm wide, depending on species. These segments are calcified, sometimes very heavily, and they are joined by very short, uncalcified nodes to form branching plants. Studies of these algae have, until recently, concentrated on the prodigious amounts of coarse calcareous sediments they produce on coral reefs when they die and then quickly disintegrate at the nodes to produce piles of calcified segments. However, during the last 10 years, biologists and geologists have combined to show that *Halimeda* can grow and produce sediment even more prolifically on the seabed away from reefs. This work began in the GBR but similar phenomena are now being studied both in Indonesian waters and as far away as the Caribbean.

Between the reefs of the GBR

There are more than 2,000 individual coral reefs scattered throughout the 268,000 km^2 covered by the GBR. The reefs themselves cover only about 13,000 km^2 leaving a lot of non-reefal seabed in between. This seabed slopes gently from the shoreline to depths of 50, or occasionally 100 m, at the outer edge which can 100 km or more offshore. The outermost reefs occur at the very edge of the continental shelf where the slope of the seabed suddenly increases dramatically and rapidly descends to 1,000 m.

The coral reefs of the GBR have been studied much more than the inter-reefal water mass and seabed. Hardly any attention was paid to this enormous area until marine scientists began to suspect that individual reefs did not behave as independent entities. Intensive study of the Crown of Thorns starfish infestations, which have plagued the GBR for decades, has served to emphasise the interconnectedness of reefs over long distances. What happens in the inter-reefal water connecting the reefs has now assumed vital importance.

One researcher in particular provided fundamental information about the inter-reefal seabed well before this part of the GBR became a focus of scientific attention. Over 25 years ago Graham Maxwell, a geologist, organised a series of research cruises to sample and characterise the seabed sediments between the reefs throughout the region. This involved more than 6,000 grab sampling stations and a prodigious amount of sediment sieving and particle analysis. His work initially concentrated on the southern half of the GBR and the results were included in his Atlas of the Great Barrier Reef.[1] However, he extended his studies northwards and, in 1973, published a thorough description of the sediments of the inter-reefal seabed of the whole GBR.[2] It was his maps showing large areas of *Halimeda*-dominated coarse gravels, particularly in the northern part of the GBR (Figure 2B), which first diverted our attention away from *Halimeda* on the reefs and into this much more intriguing environment.

Behind the ribbon reefs

From about Port Douglas north, the outer edge of the GBR consists of a continuous strip of coral reef dissected

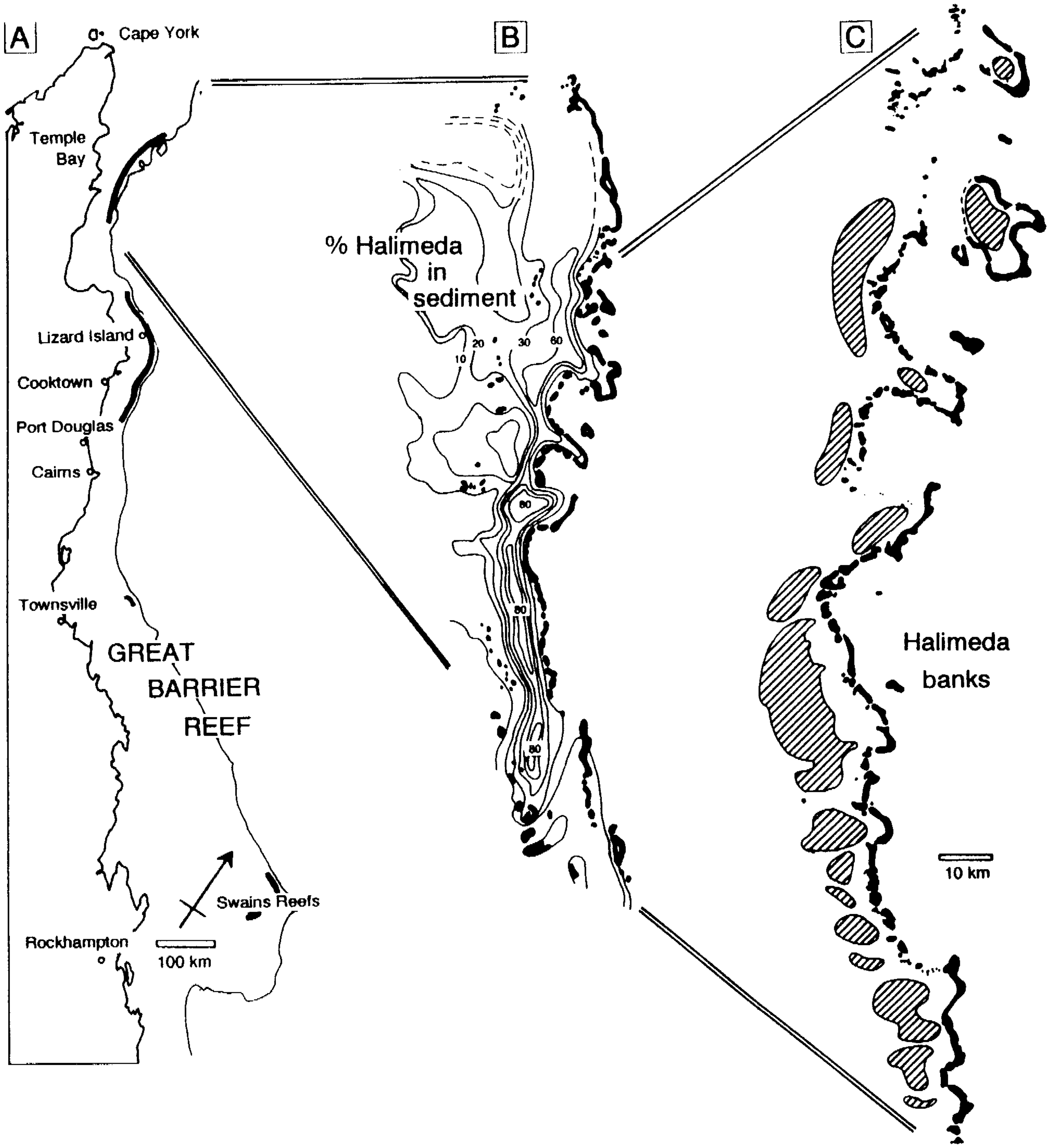

Figure 2. *Halimeda* sediment deposits in the far north of the GBR.
A Distribution along the length of the whole GBR.
B Part of *a Halimeda* sediment map from Maxwell (1973).
C Discrete *Halimeda* banks found in the same area.

every few kilometres by narrow passages about 1 km wide. The resulting string of long, narrow ribbon reefs forms an effective barrier between the Coral Sea and the waters on the continental shelf. This barrier extends for nearly 1,000 kilometres. Maxwell's studies, since supplemented by others,[3,4] revealed that *Halimeda* gravels form major sediment deposits in a strip a few kilometres wide just behind this outer barrier and along most of its length. Our recent discovery of similar sediment behind Escape and Agincourt Reefs, just north of Port Douglas, extends the known *Halimeda*-rich deposits to the very bottom of the ribbon reefs.

The rest of the inter-reefal sediments of the northern GBR are, in the main, muddy and contain varying amounts of debris from the hard body parts of such organisms as molluscs and echinoderms. However, within a few kilometres of the reefs themselves the sediments turn into sand which consists mainly of coral fragments. It seems that such reefal debris is seldom transported very far from the reefs. *Halimeda* is typically a plant of shallow water on coral reefs. It was, therefore, surprising to find such large amounts of *Halimeda* debris several kilometres from the nearest reefs, particularly as those deposits are always separated from the nearby reefs by expanses of either coral sand or mud.

Orme et al[3] hinted at an explanation when he mentioned, almost casually, seeing large areas of luxuriant *Halimeda* plants on the deposits near Lizard Island. He probably also saw at least as much *Halimeda* sediment devoid of vegetation as he saw covered by algae and, as a geologist, he did not pursue this botanical observation any further.

In 1983 the opportunity arose for us to work from HMAS KIMBLA, a boom defence vessel used by the Navy for hydrographic work. During that cruise we were able to visit not only the Lizard Island *Halimeda* gravel deposits but also two other areas further north. Despite atrocious weather with 40 knot winds, we were able to sample the seabed with grab and dredge at all three localities, and even managed to dive every day to photograph and sample directly the luxuriant *Halimeda* vegetation. Living *Halimeda* did indeed cover wide areas of the seabed and it was growing on sediment consisting of up to 96% *Halimeda* fragments. The unprecedented success of that, my first geo-botanical research cruise, is almost entirely due to the massive proportions and draught of HMAS KIMBLA which travelled sedately through very rough seas at about 6 knots and hove to for sampling with virtually no motion!

The full extent of the phenomenon

Quite clearly, the extensive deposits of *Halimeda* gravel, which seem to interest sedimentary geologists just as much as algologists, were being generated *in situ* by luxuriant meadows of living algae. We have now studied the outer GBR in considerable detail from the northern limit of the GBR Marine Park, level with Cape York, to the bottom of the ribbon reefs off Port Douglas.[5,6] These surveys have confirmed Maxwell's map (Figure 2C), with the notable exception of the large area he showed in the far north. Maxwell took only a few samples there and he was not to know that this area, which has the usual barrier of ribbon reefs on the map, has a sufficiently different hydrographic structure to preclude the formation of *Halimeda* meadows and gravel deposits.

The extent of the *Halimeda* meadows in the GBR is indicated in Figure 2A. They mostly reach to within 30 m of the surface and they essentially cease at Agincourt Reef. There are a few isolated meadows in the Townsville region which extend to at least 95 m in deep water near the shelf break and we have also investigated a few on the top of shallow reefal platforms in the Swains reefs at the southern end of the GBR. Neither of those rather different situations will be discussed here.

One important lesson we learned early during these surveys was that Halime*da* meadows are extremely difficult to locate by grab sampling but they are extraordinarily easy to locate using the ship's echo-sounder even when steaming at 8 to 10 knots. This is because they are not, as our initial dives had indicated, flat expanses of wall-to-wall algae. They are actually composed of many small mounds, just a few hundred metres in diameter and up to 20 m high (Figure 3B), although these may sometimes grow together to form ridges.

This vertical relief still puzzles us somewhat but there are distinct clues as to the origin of the mounds and what keeps them as such. There is usually little or no living *Halimeda* on the sediment in the hollows between the mounds, so the meadows are seldom continuous from one mound to the next. This has been confirmed by observations from the Australian-built Platypus submersible[7] off Cooktown and also by underwater video transects we have surveyed throughout the GBR. The submersible cruises also found pinnacles of old, eroded coral rock between the mounds. These had some living corals on them but the rock was found to be of Pleistocene age. They must, therefore, have been exposed to aerial weathering during the last ice-age when sea-level was as much as 80 m lower than now and the GBR was dry land. We have also encountered similar lumps of coral rock in the depressions between mounds on many of our video-transects. In fact, they are a major hazard to the towed video camera which only survives because it is inside a heavy duty mesh cage!

The mounds probably originated as isolated patches of sediment between the pinnacles as sea level began to rise after the ice-age 10,000 years ago. Those patches would have had little *Halimeda* on them initially but the algae would have begun to grow as the water got deeper. Herbivorous fish ranging out from the coral pinnacles may then have kept nearby sediment free of *Halimeda* vegetation. Prolific sediment production by the ungrazed patches of vegetation further from the pinnacles would then, over thousands of years, produce mounds capped by *Halimeda* meadows.

Whatever the reasons for this vertical irregularity of the *Halimeda* gravel deposits, there is no doubt such deposits cover considerable areas of seabed. In the northern GBR they may cover up to 2,000 km^2, a substantial area approaching half that of the reefs themselves. We have been able to map these accumulations in detail because of their distinctive echo-sounder signature. They form discrete patches, several kilometres long, behind each ribbon reef, with a more or less distinct break associated with each major passage through the outer barrier (Figure 3A). This has led us to subdivide the larger areas of *Halimeda* gravel into

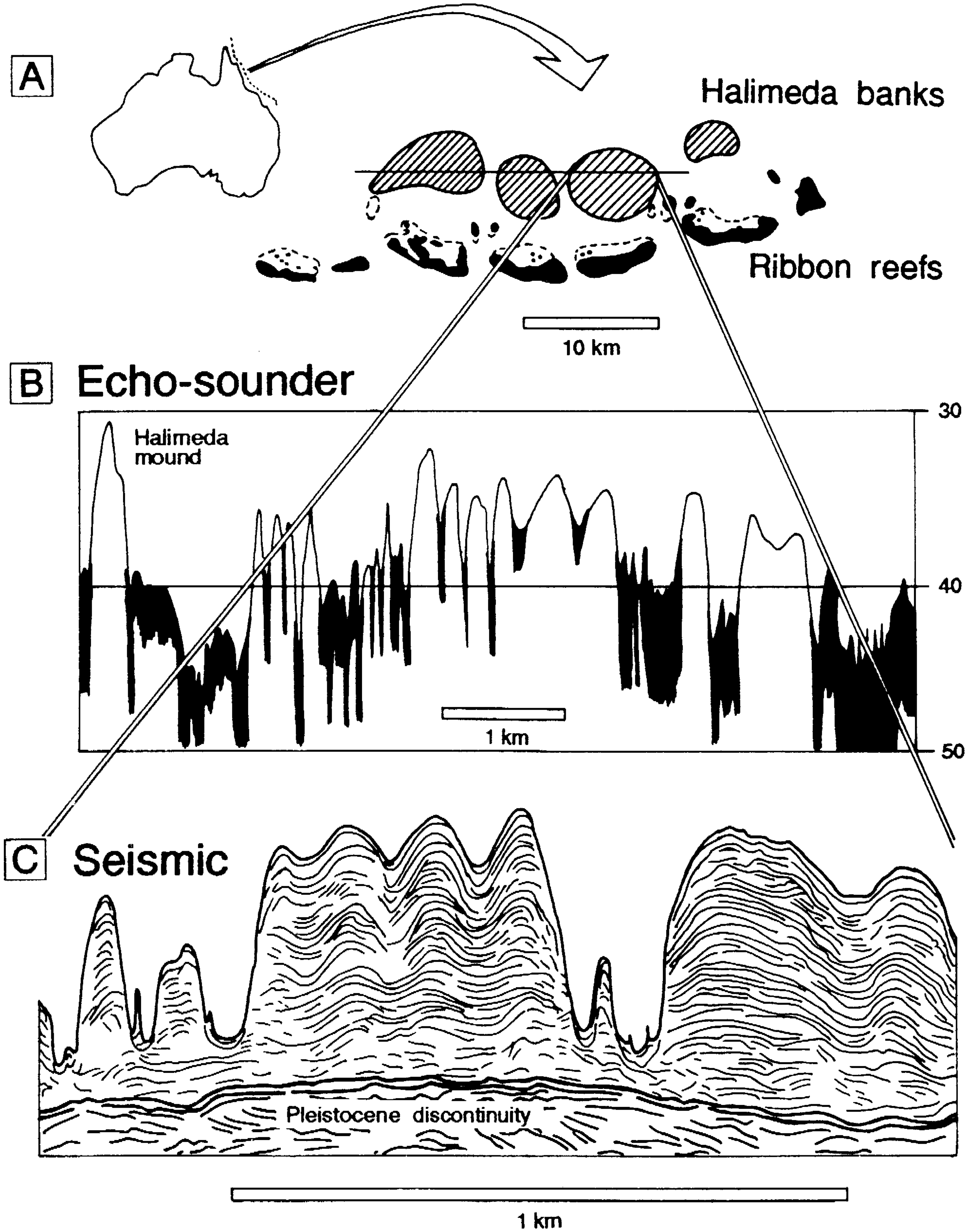

Figure 3. The structure of *Halimeda* gravel deposits.

A *Halimeda* banks associated with ribbon reefs off Cooktown

B Echo-sounder profile across a *Halimeda* bank

C Seismic profile of the same bank (courtesy of P.J.Davies)

Halimeda banks, which can be conveniently named after the ribbon reef they lie behind. These banks are composed of numerous mounds of gravel themselves covered by dense meadows of sediment-generating *Halimeda* plants. However, this far from the end of the story, for this unique ecosystem has much more to tell us.

Vertical structure in the *Halimeda* gravels

The teams led by Orme, working near Lizard Island, andby Davies, working off Cooktown, both carried out extensive sub-bottom seismic profiling. They showed that *Halimeda* sediment is extremely uniform in seismic reflectance and, although it was not very dense as compared with nearby coral sands, a distinct layered structure was clearly visible. These features are illustrated in Figure 3C, which also shows that the *Halimeda* gravels form a layer up to 20 m thick on top of the Pleistocene discontinuity, a particularly reflective structure which was formed during aerial exposure during the last ice age.

Cores taken by the geologists through the upper 5 m of the *Halimeda* sediment have confirmed their uniform, *Halimeda* dominated, composition although no structure has been detected which would explain the layered appearance on seismic profiles. Because 5 m is the deepest core which can be taken with current vibro-coring equipment and the deposits are 15 to 20 metres thick, it was necessary to core on the edges of the deposits and in the depressions between the mounds in order to sample the bottom layers. Such cores indicate that the older sediments near the bottom contained less *Halimeda* and more fragments of other calcareous organisms, especially the skeletons of the disc-shaped calcareous protozoa called foramenifera. Even more significantly, these sediments rest directly on a thin layer of mangrove peat, deposited when this part of the GBR seabed was the continental shoreline!

Rates of sediment accumulation

Carbon-14 dating of the *Halimeda* fragments at the bottom of 5 m cores shows them to be 3,000 to 5,000 years old, indicating a vertical accretion rate of up to 1 m per thousand years.

Fortunately, we had already investigated the rate at which *Halimeda* vegetation dies, disintegrates and turns to sediment on reefs. By following the growth and loss of tagged parts of plants[8] we found that quite modest *Halimeda* vegetation, with 1 kg of plants per m^2 could generate at least 2 kg of calcareous sediment per year. The species composition and rates of photosynthesis determined for the inter-reefal meadows was very similar to those found on the reefs, so we can confidently extrapolate the reef results to the inter-reefal situation. As the density of the *Halimeda* gravels from vibrocores was abut 0.7 g per cm^3, one kg of calcareous debris spread over a square metre would raise the seabed by about 2.8 mm per annum, more than enough to account for the thickness of sediment now present. Some areas of *Halimeda* vegetation actually have more than 3 kg of plants per m^2, and so could generate sediment even more rapidly. There can, therefore, be little doubt that in-situ meadows of *Halimeda* can generate large sediment masses unaided. Indeed, they clearly rival the reefs themselves in laying down massive calcium carbonate structures for inclusion in the geological record.

Why do *Halimeda* banks grow only in the lee of the ribbon reefs

We have ascertained that the relatively insubstantial alga *Halimeda* could and almost certainly has generated these large structures. We can see the meadows and sediment banks on one series of standard aerial photographs of the GBR taken when the water was particularly clear (Figure 4). The banks have even been assigned numbers in the same sequence as the real coral reefs on the Great Barrier Reef Marine Park Authority zoning maps! Those photographs were initially mis-interpreted as an eroded karst topography.[9] Hopley saw the dark circular patches as erosion hollows, presumed to have been generated when the shelf was last exposed, but our echo-sounding surveys and diving confirm that the dark areas are *Halimeda* meadows atop mounds of sediment and the light areas are either the unvegetated hollows between them or the tops of currently unvegetated mounds. It is even possible, as will be explained below, that we can see the chlorophyll within the plants on images from satellites in space.

We must now ask why *Halimeda* banks occur only in that narrow belt a few kilometres behind the outer barrier reefs. More directly, we might ask how can a luxuriant algae vegetation develop and thrive for thousands of years beneath waters virtually devoid of essential nutrients. Algae, like most plants, require both inorganic nitrogen (nitrate, nitrite or ammonium ions) with which to synthesis new protein for growth, and they also need phosphate to support their complex biochemistry. The levels of these nutrients in the shallow shelf waters (0.04 mM nitrate, 0.07 mM ammonium and 0.14 mM phosphate) are insufficient to support any significant algal growth. However we also know there is more than enough of these nutrients tantalisingly close, for in the adjacent Coral Sea we find 0.7mM phosphate and nitrate levels as high as 8 mM, but only at depths greater than 80 to 100 m.

The reason these nutrients are in short supply in surface waters even in the Coral Sea is that biological productivity binds them into living organisms. These then die and sink below the depths reached by the mixing processes driven by wind and tide. This leaves the upper, mixed layer of the ocean depleted of nutrients and therefore relatively unproductive. Because the passages between the reefs

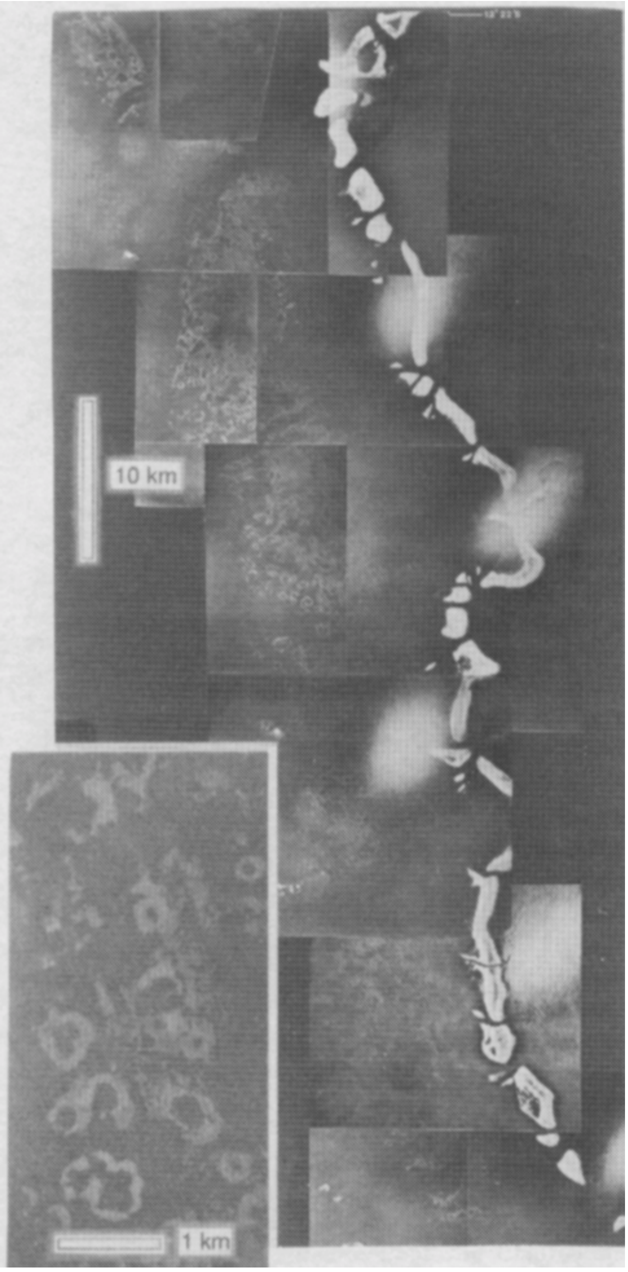

Figure 4. *Halimeda* banks on aerial photographs
The inset shows the size and shape of vegetation patches on top of sediment mounds.

are typically about 45 m deep, tidal exchange cannot be expected to transport water other than that from the mixed layer onto the shelf, so it is not surprising the shelf waters are also nutrient depleted.

But things are not quite what they seem on the surface. Firstly, there are the strong tidal currents in the passages through the outer barrier to consider. Research elsewhere on the GBR had shown that the deeper water in these passages is somewhat colder than the rest of the mixed layer. Oceanographers generally associate cold water with nutrient-rich water from beneath the thermocline, which is also situated at 80 to 100 m depth in the Coral Sea. Perhaps we do, after all, have a potential source of nutrients for bottom-dwelling algae.

The second part of this equation comes from classical hydrodynamics which predict that a strong flow through a narrow opening will continue as a discrete jet far beyond that opening. Computer simulations of the reef passage situation confirmed this possibility and also indicated that a few kilometres inside the opening the flow should slow and separate into two rotating vortices situated precisely where the *Halimeda* banks grow (Figure 5A).

We carried out a large multidisciplinary experiment to test the hypothesis that strong tidal currents caused nutrient upwelling through the reef passages. This experiment involved a dozen current meters, a CTD profiler able to measure salinity and temperature to several hundred metres depth, Niskin bottles to collect water samples at similar depths, some surface drogues to follow water movement, and aerial photography of the jets from a light aircraft. That experiment (Figure 5B) showed that our computer predictions were indeed correct.[10] On the incoming tide we detected cold water brought up from below the thermocline and propagated through the reef passage onto the shelf in a layer nearly 20 m thick (Figure 5C). Once through the passage, that water slowed down, formed vortices and eventually reached the *Halimeda* banks 12 hours later. Considerable nitrate and phosphate enrichment of the water at the bottom of the passage was also detected (Figure 5D) but, unfortunately, we could not detect propagation of these nutrients far onto the shelf. Perhaps there was too much dilution with depleted shelf water or some of the nutrients were taken up by phytoplankton during their 12 hour journey from the shelf-break to the meadows. In any event, it was reassuring to observe that neither cold water nor nutrients were exported through the passage on the outgoing tide because, as predicted, the out-going water came from directly behind the ribbon reefs which had not been enriched at all by the tidal jet.

This mechanism effectively pumps a considerable amount of nutrient-rich sub-thermocline water onto the shelf every time the tidal currents are strong enough to lift water from below the thermocline, at about 80 m, over the 45 m deep sill of the reef passage.

In the passage we studied, the tidal currents appear to be strong enough to do this on both tides each day for up to 3 days either side of high spring tides. We have evidence, albeit less complete, of this phenomenon in several other passages, so it probably occurs along the entire length of the ribbon reefs. However, the upwelling will only occur if the reef passage is at least 40 m deep. Most passages through the outer barrier are deep enough, but a few are not and passages less than 40 m deep do not have Halimeda banks associated with them. This further supports our hypothesis, and also explains the absence of *Halimeda* gravel deposits in the

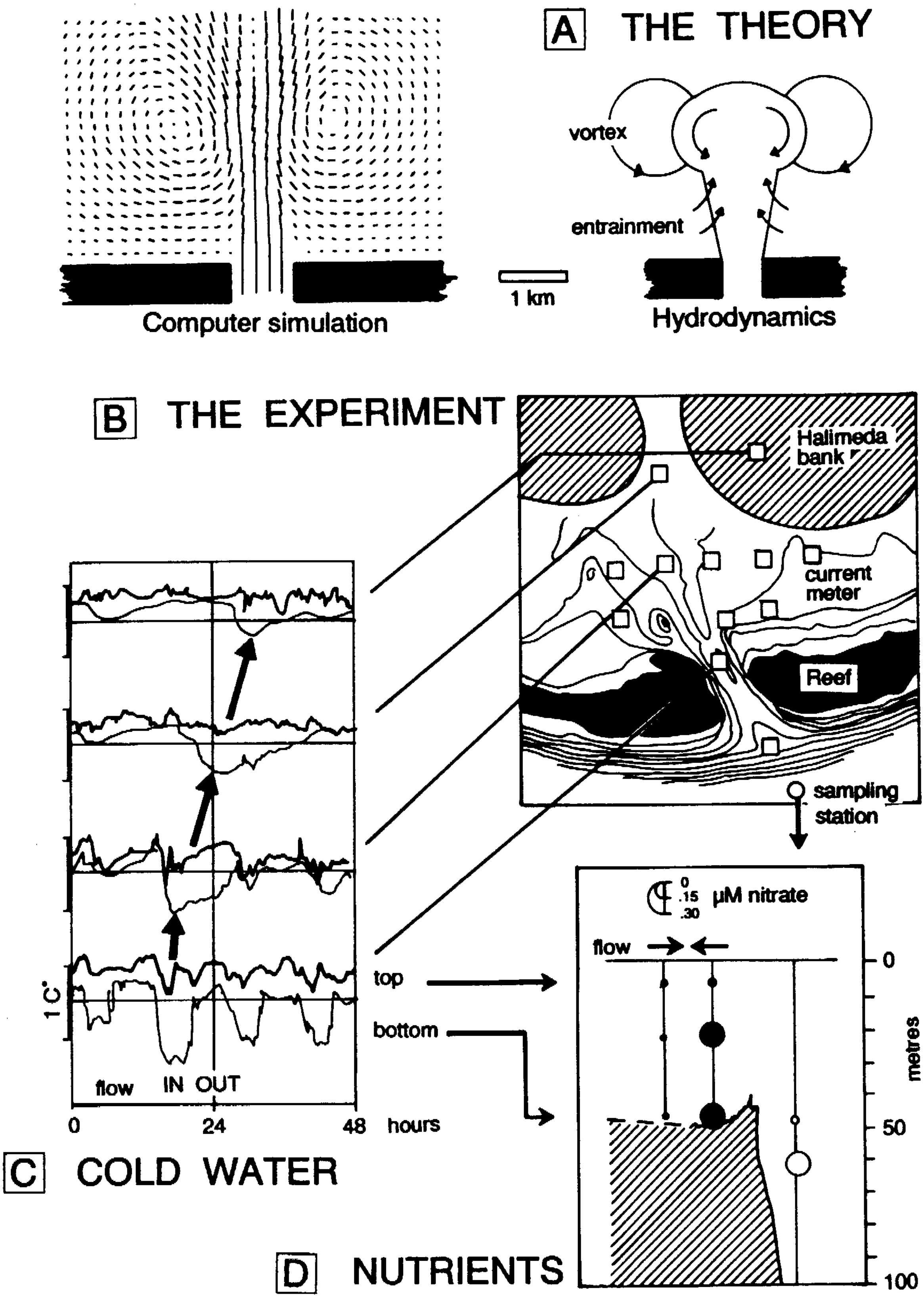

Figure 5 . The physical and chemical oceanography of upwelling through a reef passage off Cooktown.

A computer simulation of water flow and the hydrodynamics of a tidal jet; the many short lines in the diagram indicate strength and direction of predicted currents.

B the reef passage studied showing bottom contours at 10 m intervals and disposition of current meters.

C the intrusion of cold water through the passage and onto the shelf.

D nutrient status of water in the passage during outgoing and incoming tides (filled circles) and in deeper water outside the passage (open circles).

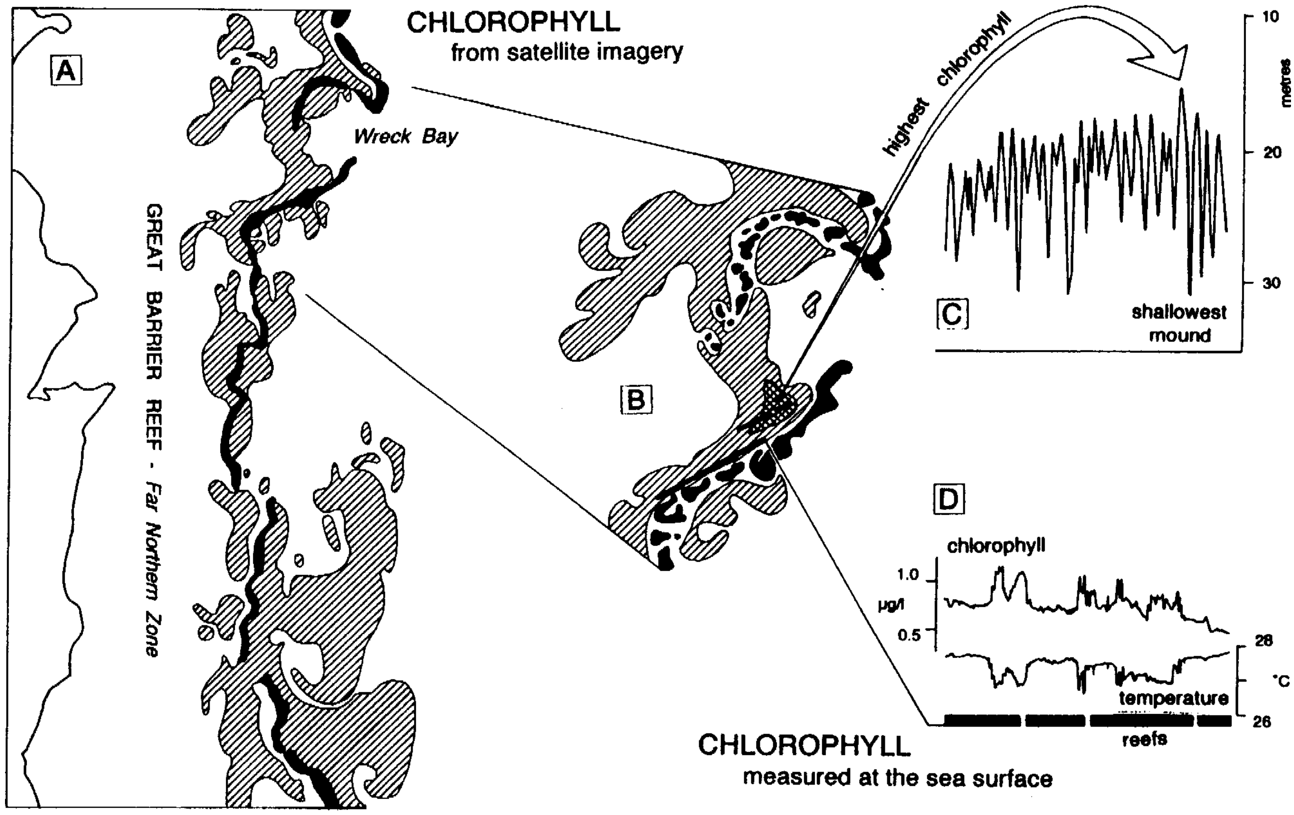

Figure 6. Chlorophyll as a measure of phytoplankton at the shelf break in the far northern GBR.

A chlorophyll distribution (hatched area) from a specially enhanced satellite image (courtesy D Jupp, CSIRO).

B details of chlorophyll distribution in Wreck Bay; cross hatched area = high chlorophyll, open circle = single pixel of even higher chlorophyll.

C echo-sounder profile of a very shallow Ha*limeda* mound coincident with the single pixel marked in B.

D recording of chlorophyll content and sea surface temperature along the transect shown in B, close behind the ribbon reefs.

extreme north where Maxwell predicted them but we could find none, for here none of the reef passages are more than 30 m deep.

We have concentrated here on events during the incoming tide. A similar tidal jet and upwelling from below the thermocline also occurs in the Coral Sea during the outgoing tide. This process effectively enriches the surface waters just outside the ribbon reef and may directly benefit those reefs. It may also not be coincidence that boats fishing for black marlin patrol exactly these outgoing tidal jets and associated vortices.

Possible intervention by the phytoplantkon

Our calculations of inorganic nitrogen fluxes indicate that 58 metric tonnes of nitrate are imported each year through a typical reef passage 40 m deep and 1 km wide. The 15 km^2 of Halimeda meadow associated with each such passage actually required abut 48 metric tonnes per year so such upwelling would be sufficient to allow algae to thrive behind the ribbon reefs below shelf waters otherwise too depleted of nutrients to support their growth. The reason the alga which grows there is usually *Halimeda*, and therefore can generate substantial sedimentary structures, is not so clear, whilst the absence of detectable nutrient enrichment over *Halimeda* banks themselves suggests that the processes involved may be less direct than we initially hypothesised.

We are now in the process of refining our hypothesis. Satellite images of the northern GBR indicate dramatic and dynamic accumulations of chlorophyll along both sides of the ribbon reefs (Figure 6A). As satellite cameras can certainly “see” 20 m or more through clear waters, some of this chlorophyll may actually be that in the benthic *Halimeda* vegetation. A single pixel of especially high chlorophyll almost exactly over the top of the shallowest mound we know, which is only 16 m below the surface, supports this possibility (see Figure 6C). Nevertheless, most of the chlorophyll undoubtedly represents phytoplankton growing in response to shelf-break upwelling events such as the one we have described, and therein lies a possible solution to our dilemma.

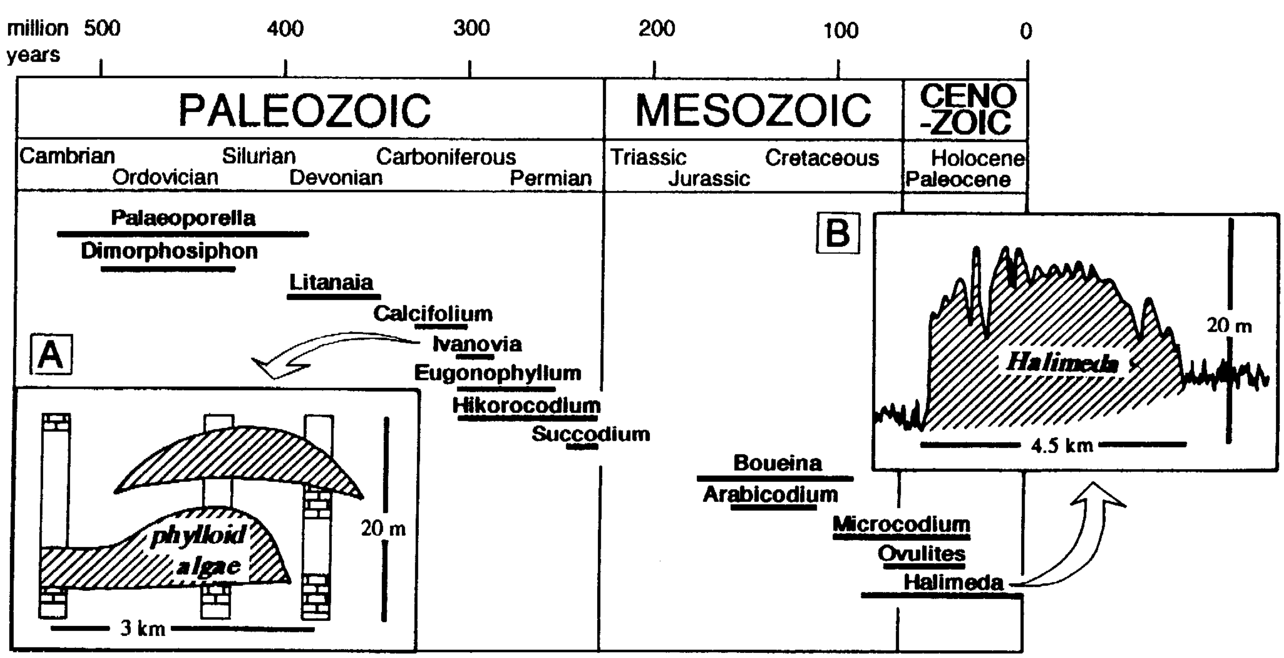

Figure 7. The fossil record of calcareous algae similar to *Halimeda*

A phylloid algal bioherms (hatched) in a North American oil field; drill holes also contain shales (unshaded) and layers of limestone.

B Ha*limeda* bank in northern GBR. N ote that the bank and the bioherms are very similar in shape, thickness and horizontal extent.

Continuous recording of chlorophyll in surface waters has revealed that this can be transported from the Coral Sea onto the shelf through the reef passages, just as cold water and some nutrients are. Detailed examination of one such area showed plumes of cool water rich in particulate chlorophyll, i.e. phytoplankton, flowing through the passages and even splitting into a double peak suggestive of the twin vortices of a tidal jet (Figure 6D). Uptake by this phytoplankton could certainly account for the disappearance of some of the nutrients freshly upwelled into the reef passage before they could progress far onto the shelf. This phytoplankton, just like our cooler water and nutrients, passed in through the passages but not out again So it could reside a few kilometres behind the reefs for some time, again just as our cooler water did. During that time the processes of zooplankton grazing and defaecation would certainly cause particulate, nutrient-rich material to fall on the *Halimeda* banks, awaiting only the final bacteria-mediated remineralisation before becoming available to the alga on the sea bed as inorganic nutrients.

Thus, we should perhaps add passage through phytoplankton, grazing zooplankton and bacteria to the route we originally proposed for nutrients travelling from below the thermocline to the *Halimeda* banks. These processes await quantification but do promise even greater quantities of nutrients to support the banks than did our original model which took account only of the dissolved inorganic nitrogen upwelled through the passages. It now appears that nitrogen bound organically within the phytoplankton cells accompanies those nutrients and this has now been tracked all the way to the *Halimeda* banks using the spectral signature of phytoplankton chlorophyll.

A larger geological dimension

The biological, oceanographic and geological processes we have discovered whilst studying the *Halimeda* banks are helping us understand just how the Great Barrier Reef functions as an entity. However, they have a greater significance which extends beyond our region, for very similar deposits have been accumulating elsewhere for not thousands of years but hundreds of millions of years.

Halimeda is the most recent of a long line of foliose calcareous algae collectively recognised as phylloid algae in the fossil record (Figure 7). The internal organisation of the segments, which is so important for identifying living species of *Halimeda,* is mirrored in the calcium carbonate skeleton which becomes preserved intact in the sediment. Similar structures can be recognised in rocks hundreds of millions of years old, rocks which have been formed by lithification of sediment deposits. These rocks tend to form lens-shaped domes several kilometres in extent and many metres thick, usually in the outer regions of ancient reefal systems. These reefal systems may pre-date the evolution of the corals, but the phylloid algal bioherms they contain closely resemble the sediment deposits we have been studying in the northern GBR (Figure 7 A,B).

Why do we know so much about the ancient phylloid algal bioherms, and why have geologists laboured long and hard to understand just how and why they were formed? These deposits are porous, just like *Halimeda* gravel, because of all the small spaces retained within the skeletal fragments. And because of this porosity, they have come to form major oil reservoirs in many parts of the world. However, the *Halimeda* deposits of the Great Barrier Reef will not attract exploration for some time. The GBR is so young geologically that, even if its *Halimeda* banks do have the composition, texture and appearance of potential bioherms, none of them will become commercially interesting for millions of years.

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ZOOPLANKTON AND CORAL REEFS: AN OVERVIEW

J.H.Carleton

Abstract

Early studies concerned with the role of zooplankton within coral reef ecosystems suffered from a poor understanding of fine-scale hydrodynamics near reefs and the inadequacy of traditional plankton sampling procedures in the reef environment. As a result, the quantity of zooplankton entering reefs from the surrounding sea and residing within various reef habitats, was severely underestimated. The introduction of scuba as a research tool enabled reef ecologists to make direct observations on the behaviour and distribution of zooplankton near reefs and to develop innovative sampling procedures appropriate for their capture. A plethora of information presently exists on the abundance and distribution of reef associated, demersal plankton. In future we must concentrate our investigations on the behaviour, life histories and physiological requirements of specific taxa, if we are to assess correctly the true role of zooplankton within coral reef ecosystems.

Introduction

In a discussion on conditions favouring the growth of coral reefs, Charles Darwin concluded that "the relations which determine the formation of reefs on any shore, by the vigorous growth of the efficient kinds of coral must be very complex, and with our imperfect knowledge quite inexplicable". Since that time reef ecologists have attempted to resolve the apparent dilemma of the existence of such enormously diverse and dense assemblages of organisms in oceans poor in nutrients and plankton.[2-8] Coral reefs were initially viewed as highly efficient, self-sustaining entities isolated from the surrounding seas. This view was based on rates of primary production by reef benthos several times higher than in the surrounding seas[4] and the belief that extremely small quantities of plankton were imported to reef systems across the windward face.[5,6]

Recent studies suggest that these initial beliefs were incorrect and that plankton does play a significant role in reef trophodynamic processes. The development of a better understanding of fine scale hydrodynamics on and around coral reefs[9] has changed the view of reefs as "closed systems". It is now realised that close links to the surrounding seas exist in terms of water exchange,[10-14] nutrients,[15-17] planktonic egg and larval stages of reef animals[18-20] and the input of oceanic plankton.[8,21-24]

In addition to the input of oceanic plankton, reefs also harbour an abundant, diverse community of resident plankton which differs both qualitatively and quantitatively from those in the surrounding sea. These unique resident zooplankton assemblages are found throughout the water column within lagoons,[21,24-28] residing near the lagoon floor,[29,30] adjacent to coral outcrops[24,31,32] or within the reef substrate itself.[33]

In this paper I discuss the findings of a few selected papers from the more recent literature which have, through the application of innovative sampling procedures, significantly extended our knowledge of the role of zooplankton on coral reefs.

Oceanic plankton

Early studies concerned with the abundance, diversity, flux and fate of zooplankton as it approaches and crosses a windward coral reef face suffered from the limitations of traditional sampling procedures in reef environments[31,32,34] and a poor understanding of fine scale physical oceanographic processes near reefs.[9] Odum and Odum,[5] investigating trophic processes on coral reefs, measured both primary production and flux in plankton biomass as the water flowed unidirectionally downwind across the reef flat from the reef crest to the lagoon. They were unable to sample on the reef face at Eniwetok Atoll due to the enormous turbulence generated by wind and breaking waves and their most seaward station was located just behind the breaker zone. Plankton samples from this station contained a mixture of algal fragments, fecal material and even sand, but no zooplankton. Subsequent studies employing a similar upstream/downstream sampling regime corroborated these findings[6,8,35] and it was generally concluded that there was little input of open ocean zooplankton to coral reef ecosystems.

Hamner et al.[22] hypothesized that planktivorous fish on the windward reef face form a "wall of mouths" which removes most zooplankton from the water near the reef face before that water physically impinges upon the reef surface. To test this hypothesis they simultaneously collected zooplankton and representative specimens of plankton eating fish for gut analysis, visually estimated the abundance of these planktivores and measured small-scale water movement over the windward reef face. Davies Reef, a platform reef in the central region of the Great Barrier Reef, was chosen for the study as it lies downwind of several other reefs which considerably reduce the fetch and wave height, allowing scuba divers easy access to the windward face.

Zooplankton samples were collected over the outer reef slope at surface, 5 and 10 m depths, just in front of the breaker zone, just behind the breaker zone, and over the reef flat. At the deep sampling stations on the outer reef slope a diver propulsion vehicle was used to manoeuvre the plankton nets close to the reef substrate. Zooplankton densities were highest in deep water away from the reef and decreased steadily towards the reef. As in earlier studies, plankton sample taken over the reef flat behind the breaker zone contained little zooplankton.

Fluorescein dye released by divers at various depths near the reef face indicated that the oceanic water that crosses the reef top is not simply from the surface layer as previously believed, but comes primarily from deeper layers. Thus the denser assemblages of zooplankton found in the deeper water off the reef are carried upwards across the outer reef slope and over the reef crest. Water flowing from a depth of 25 m to the surface over a 1 m wide swath of reef is inspected by some 500 individual fish of 13 different species. By analysing the contents of fish guts and measuring zooplankton flux from deep water to the reef crest, they estimated this assemblage of fish to consume 1,180,000 food items per day. This would translate to 0.5 metric tons of plankton per linear kilometre of reef front per day.

These important findings, in contrast to earlier studies, demonstrate the importance of oceanic zooplankton as a source of nutrient for coral reef ecosystems, albeit in a rather indirect manner. It appears that most zooplankton approaching coral reefs is eaten by planktivorous fish which in turn defecate onto the reef surface, a process which enhances the growth of corals and benthic algae. Breaking waves tear fragments of benthic algae off the reef crest which together with fecal material, flows onto the reef flat. It is the nutrients within this mixture of by-products from secondary production on the reef front, and not the zooplankton itself, which enter the reef trophic economy.

Reef ecologists now appreciate the importance of having a good understanding of water movement around and over coral reefs if they are to have any hope of explaining biological processes within these systems.[9] The traditional view that all material imported to reefs enters across the windward face is now known to be too simplistic. Reefs with exposed back reef slopes or lagoons which are open to the surrounding sea on their leeward side are subjected to tidal flushing.[9,12,14,36] Ocean material is carried onto back reef slopes or into leeward lagoons by the flooding tide[23,36] and reef products are dispersed by the ebbing tide.[18,20]

Roman et al.[23] investigating abundance and grazing rates of zooplankton on coral reefs noted that within the reef lagoon, maximum daytime densities of oceanic copepods occurred during high water, indicating an input of external plankton during flood tide. These copepods are not only a source of food for larger reef predators, but also recycle nutrients within the reef lagoon through their grazing activity. The greatest abundance of zooplankton biomass occurred during high water at night. However, on these occasions the oceanic copepods comprised a much smaller proportion of total zooplankton numbers. The nocturnal samples were dominated by mysids, ostracods and decapod shrimps, animals which reside on or near the lagoon floor during the day, entering the water column only at night.

Reef associated plankton

The existence of unique assemblages of zooplankton within the lagoons of reef atolls was noted by early researchers.[25,26,37] These communities differed from those in the surrounding seas, both in terms of species composition[21,27,28,38] and in terms of numbers of individuals.[21,25,26,37] However, the presence of resident communities of zooplankton in close proximity to coral was not realised until the introduction of scuba as a research tool. Scientists could then make direct observations on the behaviour and distribution of zooplankton near reefs and sample in areas previously inaccessible to traditional sampling methodologies.

Emery[31] while scuba diving on reefs in the Florida Keys, observed swarms and schools of zooplankton which were capable of maintaining their position on the reef through active swimming and by utilizing crevices, caves and coral heads as protection from predators and currents. He also noted that large numbers of resident plankton appeared only at night and apparently spent the day within the reef substrate. Porter[39] defined this assemblage of animals which burrow or hide within the reef substrate during the day, rise up into the water column at dusk and return before dawn, as demersal plankton. He also suggested that most of the zooplankton ingested by corals was nocturnal, coming from the reef itself. Subsequent researchers referred to the presence of demersal plankton on reefs,[40,41] although their actual existence was based primarily on inferential evidence from net tows and gut-content analysis of nocturnal feeding fish and corals.

Alldredge and King[42] were the first scientists to actually sample demersal plankton as it moved into the water column from the reef substrate at night. By using "emergence traps" (transparent perspex boxes open to the bottom and containing an internal, inverted perspex funnel) they collected quantitative data on the abundance, distribution and substrate preference of these animals. Six substrate types and five reef zones were sampled over a 3-week period at Lizard Island, in the northern section of the Great Barrier Reef.

They discovered that the abundance of demersal plankton varied significantly with substrate types and reef zones. The highest mean density of zooplankton emerged from coral (11,264/m^2) and the lowest from reef rock (840/m^2). The density of demersal zooplankton was 6 times greater on the face than in any other zones, averaging 7,900/m^2. They suggested these differences were due to the availability of physical niches in which demersal plankton could hide. Living coral had the greatest level of 3-dimensional relief whereas reef rock had the least. The significantly higher densities of emerging plankton on the reef face was most likely due to a greater variety of substrate types.

Their estimate of demersal plankton biomass emerging into the reef waters at night was very much higher than the biomass of the total plankton (both oceanic and demersal) obtained at night over coral reef by previous investigators. Their estimate from Lizard Island of 79.5 mg dry weight/m^3 was 1.5 times higher than those from the Caribbean,[8] 2.7 to 5.3 times higher than atolls in the Indian Ocean,[21] and 9.0[43] to almost 100[6] times greater than Bermuda. Alldredge and King[42] argue that plankton nets and water sampling devices (Niskin or Nansen bottles) are ineffective at capturing plankton in the immediate vicinity of coral and that previous studies using standard sampling techniques had greatly underestimated the abundance, and therefore importance, of plankton over coral reefs.

The study of Alldredge and King[42] initiated a plethora of similar investigations[33] employing a great variety of emergence traps to study spatial and temporal variability in these organisms. In spite of increased interest into reef associated plankton, little attention was paid to those organisms which form visible aggregations over reefs.[31] These zooplankters do not enter the reef substrate and are not, therefore, sampled effectively by emergence traps.

In order to obtain realistic estimates of copepod densities within swarms on coral reefs in the central region of the Great Barrier Reef, Hammer and Carleton[32] employed four independent sampling methodologies. Quantitative data on copepod densities were first obtained by divers swimming nets through swarms. Swarms were next sampled with a plankton pump. The third method required divers to rapidly open a large plastic bag, in a manner similar to a pelican's pouch, to engulf discrete portions of swarms. Finally, swarm densities were directly recorded photographically.

The density estimates they obtained were quite variable as each sampling methodology had a distinctive bias. Mean density from net tows was 166,800 m^3, equivalent to 570 mg dry weight m^3. Plastic bag sampling produced a mean swarm density of 210,000 m^3 a figure 20% higher than that obtained with nets, and photographic sampling produced the highest estimates (325,000 - 586,000 m^3). The plankton pump was a dismal failure. The copepods reacted immediately to the suction generated by this device and avoided capture.

These values for local densities of zooplankton on reefs were 3 to 15 times higher than previous estimates and emphasized the importance of using imprecise but distinctive sampling techniques to obtain credible results, rather than relying on a single methodology, no matter how precise the replicates.

At night the swarms disperse throughout the water column, wash over the reef top, and presumably become available as food to the many nocturnal planktivores. Plankton net samples taken over the reef top at night contained mostly demersal plankton and swarming species of copepods. At midnight, 63% of the zooplankton captured were species of copepods which form swarms by day.

Swarming appears to be widespread among tropical copepods. At least seven species and probably more have been noted to engage in swarming behaviour in three of the world's oceans.[32] The reasons for swarming are numerous but protection from predators is undoubtedly very important. Large schools of mysids (small shrimp like crustaceans) which are potential predators on copepods[44] blanket the floor of coral reef lagoons in the immediate vicinity of swarms. To minimize predation by mysids, copepods always aggregate in close proximity to coral outcrops. The swarms are sufficiently far enough away from the coral as to be out of the foraging range of the smallest fish yet close enough to be afforded protection against mysids predation by the larger fish. The larger planktivorous fish (10 cm and longer) swim through the swarms oblivious to their presence, but readily devour any mysids which venture too near.

Mysids are a highly visible component of resident coral reef plankton.[31] Their aggregations occur in many reef habitats [31,32,45] and they function as macrophages, carnivores and detritivores within coral reef ecosystems.[44,46] They dominate the epibenthic community within coral reef lagoons forming large, patchily distributed shoals which vary in length (5 to 7 m), width (1 to 3 m) and depth (0.3 to 0.9 m). They are strong swimmers with well developed eyesight and easily avoid capture by standard sampling devices such as plankton nets, plankton sleds and diver swum nets.[34]

In order to collect detailed information on seasonal, daily and small-scale spatial variations in the species composition and abundance of epibenthic lagoon mysids Carleton and Hammer[34] developed a unique sampling device which made use of the mysids' escape response to effect their capture. Lagoon mysids, along with many other epibenthic taxa, do not burrow into the sediment when disturbed but move horizontally away from the source of aggregation without rising more than a few centimetres above the substrate. This behaviour pattern enables a large portion of the lagoon epibenthic community to be herded. The device they developed is similar to pound or Fyke nets[47] used to capture fish. The epibenthic trap consisted of two sets of components: a horizontal perspex funnel with a detachable collection box fitted to its apex and a variable air lift attached to the posterior end of the collection box, and a set of plastic curtains (two clear plastic side curtains and an opaque "driving" curtain). The open side of the funnel, driving curtain and side curtains, which were supported by fence pickets driven into the substrate, enclosed a 10 m^2 area of the bottom. Two divers, by pushing the driving curtain slowly along the lagoon floor, herded all entrapped organisms living on or up to 1 m above the bottom into the funnel. The animals were moved through the funnel and into the collection box by activating the air lift and by continued motion of the driving curtain. They also used standard plankton nets to collect samples from discrete depths through the water column both day and night, and the same photographic techniques used in the study on copepod swarms to estimate densities within schools.

During the course of the study twelve species of resident epibenthic mysids were collected. Six of these were new records for the Great Barrier Reef and one was new to science. These results again emphasize the need to develop specific sampling procedures for studying resident reef plankton. The mysids community comprised of these species differed from that in the overlying water, was faunistically uniform, but formed characteristic seasonal and diel groupings. Total mysids abundances ranged between 100 and 790 m^3 (31 to 220 mg dry weight m^3) with peak abundances occurring during the Austral spring (October). Of the seven dominant species, five engaged in schooling behaviour. Schooling species occurred at local densities ranging between 10,500 m^3 for the larger species and over 500,000 m^3 for the smaller species. The biomass equivalent would be 2,940 to 140,000 mg dry weight m^3. The upper estimate is 1.5 to 80 times greater than the biomass estimate for swarming copepods. However, unlike the copepods, only one of the schooling species moved into the surface waters at night, the restt remaining on or near the lagoon floor. For this reason lagoonal mysids contribute little to the food of sessile reef planktivores such as corals.

Lagoon mysids may play an important role in nutrient regeneration. Coral reef lagoons are considered zones of net heterotrophy requiring a continuous input of organic material (algal fragments, coral mucus, fecal material, etc.) from areas of high primary production[48,49] to sustain a complex of secondary, detritus-based food webs.[50] Most coastal and littoral mysids utilize organic detritus to a considerable extent[51] and it is possible that the epibenthic mysids community is responsible for the remineralization of substantial proportion of lagoon detritus. Large areas of Indo-Pacific reefs are either sandy lagoons or back-reef slopes and, given the extremely high density and relatively large size of lagoon mysids, their trophodynamic contribution to the reef as a whole may be considerable.

Conclusions

The initial view that zooplankton plays an inconsequential role in coral reef trophodynamics is now known to be incorrect. A better understanding of small-scale hydrodynamic processes near reefs had led to a revised estimate in the quantity of ocean material entering reef ecosystems. At the same time the development of unique procedures for sampling zooplankton in the reef environment has produced realistic estimates for the abundance and variability of resident zooplankton.

Reef associated zooplankton have evolved complex behavioural adaptations to ensure their survival within coral reef systems. To treat them as behaviourly inept, passive particles, existing solely as a food supply for larger reef animals, is not only ecologically naive, but also perpetrates a great disservice to an interesting, highly evolved group of reef organisms. We must extend our research efforts beyond studies concerned simply with distribution and abundance, and concentrate on investigations into the behaviour, life histories and physiological requirements of specific taxa, if we are to correctly assess the true contributions of zooplankton to coral reef ecosystems.

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THE AMAZING NEMATOCYST

Jacquie Rifkin

Summary

Granular electron-dense material is contained both within the tubule and the capsule. The matrices contained within each compartment are different chemically from one another. During discharge, the cnidocil apparatus on the nematocyte is triggered. Polymerisation of the capsular matrix occurs, water rushes into the capsule and discharge of the tubule takes place. As the tubule everts, granular matrix contained within it emerges progressively as discharge occurs. As tubules transfix capillaries in the dermis, tubular matrix (venom) passes into them. The capsular matrix emerges once the entire tubule everts. Venom obtained by disruption of nematocysts of *Chironex fleckeri* was injected into mice by the intravenous, intraperitoneal and subcutaneous routes. Mice survived injections delivered by the intraperitoneal and subcutaneous routes. This suggests that only material delivered by the intravenous route is responsible for the rapid systemic effects manifested after a serious sting.

The implications of this mode of envenomation for the first aid treatment of *C fleckeri* are discussed.

Cnidarians

The cnidarians are a very large group of animals comprising at least 7,000 species with a variety of forms and a diversity of habits. The group name means nettle because each species is armed with millions of minute stinging capsules or nematocysts. Some examples of cnidarians include all corals, sea anemones, sea whips, sea fans, stinging hydroids, the bluebottle and the box jellyfish.

The cnidarian which is of greatest importance to humans in the Indo-Pacific region is the box jellyfish or *Chironex fleckeri*. This animal has been responsible for at least 70 recorded fatalities in the past 100 years.

Nematocysts

A.nematocyst consists of a capsule containing a tightly coiled and pleated inverted tubule. This tubule may or may not bear spines. The microbasic mastigophore from the box jellyfish has a cigar-shaped capsule which is slightly wider at the apical end. The noun mastigophore refers to those nematocysts in which the distal tubule continues beyond the shaft. The adjective microbasic refers to those nematocysts bearing a short tubule which is less than three times the capsule length. In *Chironex fleckeri* mastigophores, the basal shaft region bears long spines and the distal tubule region bears shorter spines. Endean and Rifkin[1] determined that these nematocysts were important in mammalian envenomations.

Nematocysts are stimulated to discharge when mechanical and chemical stimuli such as those delivered by prey species are applied to the triggering apparatus or cnidocil. The cnidocil is the putative sensory receptor, or "hair trigger", found at the apical end of nematocytes from most cnidarian classes. Each consists of a flagellum surrounded by two series of microvilli.

Once stimulation of the cnidocil is effected, the operculum, which is located at the apical end of the capsule, (Figure 1) is tripped, then the tubule begins to evert. Spines, which are found on the inside of the nematocyst tubule (Figure 1) emerge in a rotary fashion that assists the tubule to penetrate flesh.

Material which is present on the inside of the capsule passes out of the end of the fully discharged tubule. That material which was present within the undischarged tubule is released gradually as the tubule everts (Figure 1).

Toxic material from within disrupted nematocyst capsules was injected intravenously, intraperitoneally and subcutaneously into mice. Those mice that were injected subcutaneously and intraperitoneally with the contents of

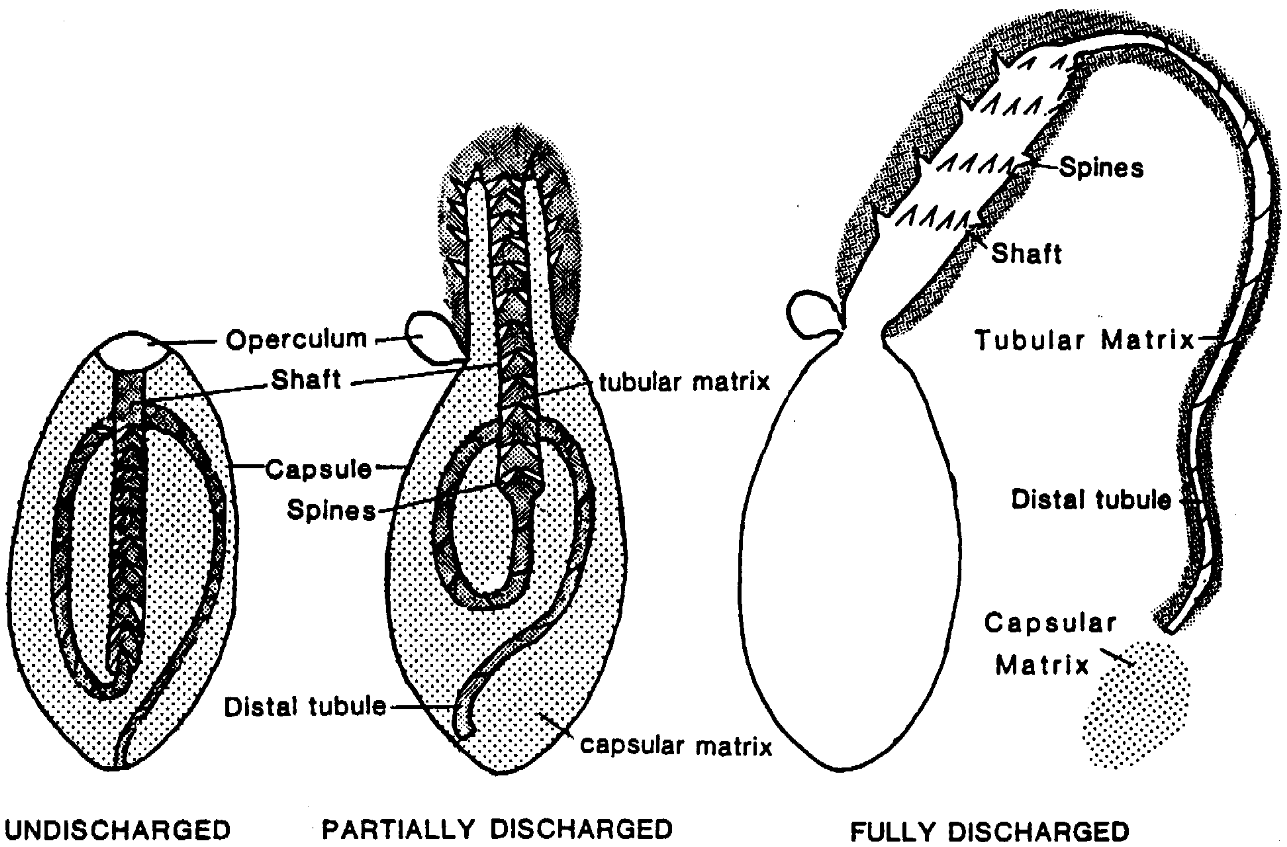

Figure 1. Stages in the discharge of nematocyst tubules. Note the manner in which capsular and tubular matrices are released.

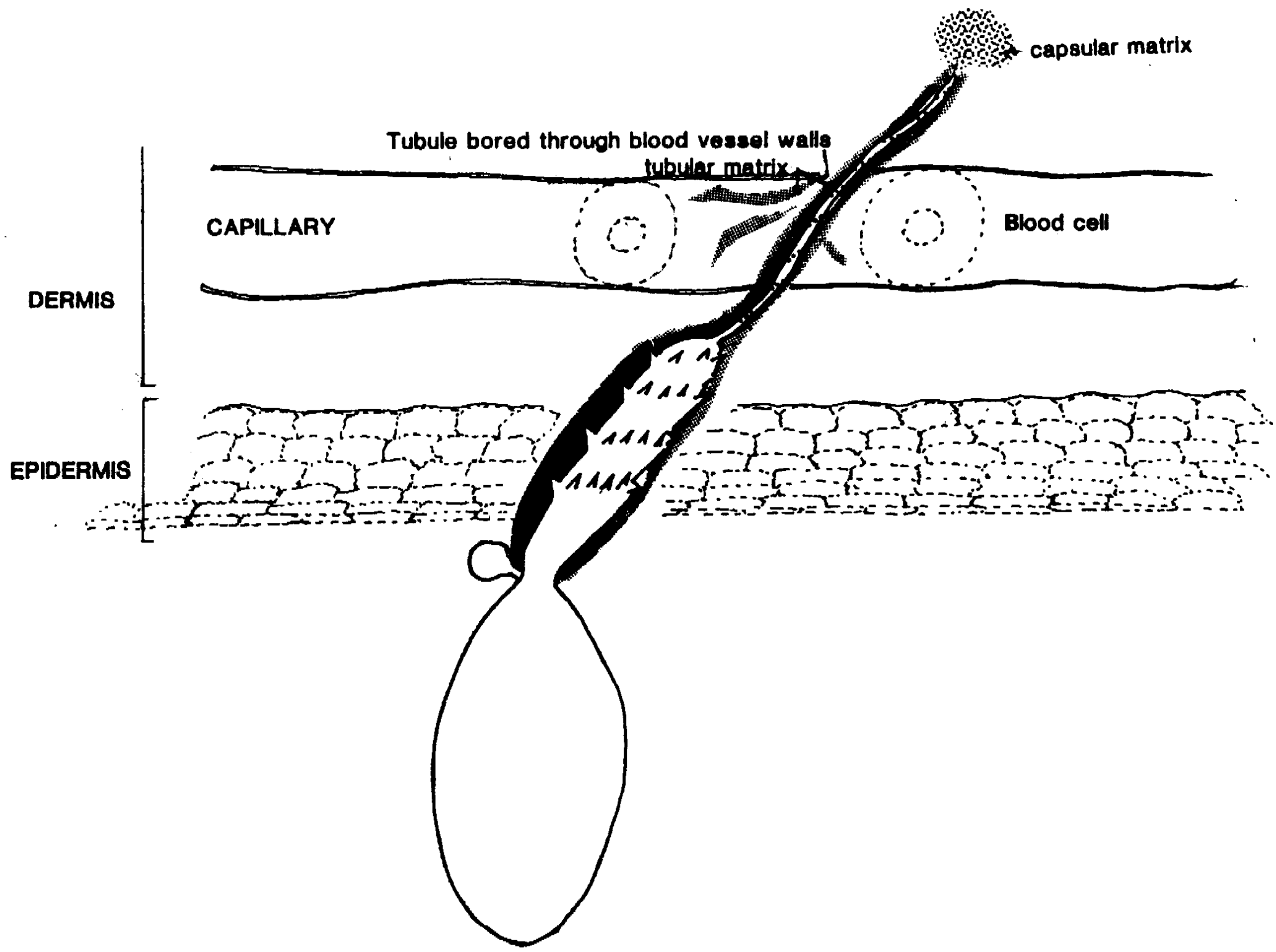

Figure 2. Diagram showing the fate of the capsular and tubular matrices in a nematocyst discharged into mouse skin.

up to 512,000 nematocysts survived. Those mice that were injected intravenously with the contents of more than 25,000 nematocysts died within 2 minutes of the injection. This suggests that during envenomation of mammals, only toxic material that is introduced directly into blood vessels is responsible for fatalities, at least in the short term.[2]

Thin sections of undischarged nematocysts show that there is granular electron-dense material present within undischarged tubules. Granular electron-dense material is also present within the capsule.[2,3] Scanning electron micrographs show granular tubular matrix scattered over the surface of discharged nematocysts and between the spines.

Histochemical tests and histological dyes clearly show that the material within the tubule is of a different nature to that found within the capsule.[2] The material within the tubules of the microbasic mastigophore nematocysts stains with basophilic dyes while that found within the capsule stains with acidophilic dyes.

Histochemical tests including the periodic acid-Schiff test for polysaccharides, the mercuric bromophenol blue reaction for proteins and the toluidine blue for metacromatic substances show that the capsule contains protein and polysaccharide material while the intratubular material contains acid polysaccharide material.[2]

The skin of hairless mice stung by tentacles of *Chironex fleckeri* were sectioned, stained and examined. The numerous capsules of discharged mastigophores were found on the surface of the skin (Figures 2,3). The tubules from discharged nematocysts could be traced as deeply as 0.5 mm into the dermis. The layers of cornified regions of the skin in the region of penetrating nematocysts were also separated from one another. In the Malpighian layer cells were shrunken and the nuclei were pycnotic. Many tubules did not pursue a straight course through the skin and many were seen to transfix blood vessels (Figures 2,3).

Klug et al[4] showed that the tubular matrix contained venom. They discharged isolated nematocysts from a variety of cnidarians into a film of blood cells. Red blood cells that were in contact with discharged tubular matrix lysed, whereas those red blood cells in the vicinity of the capsular matrix did not.

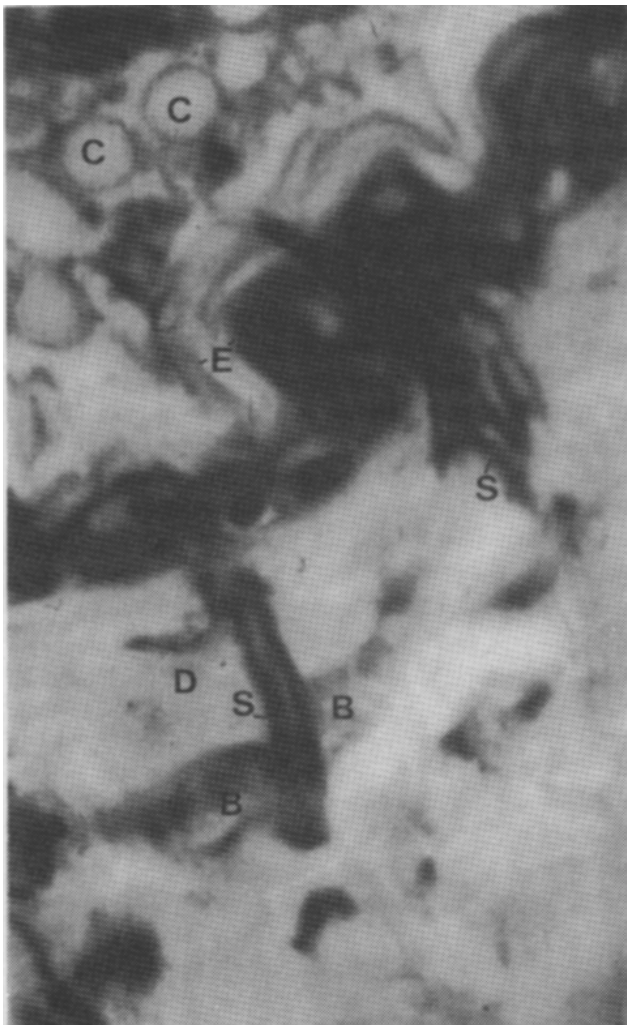

Figure 3. Photomicrograph showing nematocysts discharged into mouse skin x 1,000 C=capsule, D= dermis, E=epidermis, B=blood vessel, S=shaft.

The results of the studies by Endean and Rifkin[2] and Klug et al[4] suggest that the material within the tubules is different from the material within the capsule and that the material found within nematocyst tubules of many species is toxic. The histological studies done by Endean and Rifkin[2] which showed tubules passing through blood vessels suggest that it is by this route that the venom reaches the heart, where the rapid cardiotoxic effects are manifested.

Mechanism of discharge

The mechanism of nematocyst discharge is not understood although various hypotheses have been proposed:

1 Intracapsular pressure increases by uptake of water or ions. This occurs at the moment of discharge or just before it. Uptake of water could occur either because of an altered permeability of the capsule wall or by entry of water into the capsule wall or by entry of water into the capsule when the operculum has been dislodged. The tubule is then forced out by eversion.[5,6]

2 Energy is produced at the moment of discharge by enzymatic reactions in the cytoplasm of the cell surrounding the nematocyst.[7,8]

3 Contractile material in the capsule wall or contractile elements surrounding the capsule are activated and thus increase intracapsular pressure.[9,10,11]

4 Energy for eversion of the tubule is contained within the highly coiled and pleated tubule within the nematocyst. Once the operculum is tripped, eversion would occur.[12]

The latest research on the mechanism of nematocyst discharge was proposed by Endean et al.[13] This theory proposed that once the cnidocil apparatus is triggered by mechanical and chemical stimuli, the operculum is tripped. This applies tension to the contractile filaments surrounding the nematocyte.

The capsular matrix, which normally contains material that is not polymerised becomes polymerised and forms clusters of regularly spaced, electron-lucent granules arranged in hexagonal patterns. Immediately after polymerisation, water rushes into the capsule, increasing the intracapsular pressure. This pressure is maintained throughout the entire eversion process.

The time required for *C fleckeri* nematocysts to discharge into mammalian skin is not known, although the speed of discharge of nematocysts of *Hydra attenuata* was measured at 3 milliseconds.[14]

Effects of discharge

Nematocysts that had been pulled out of the tentacle during a feeding episode or during an envenomation would normally be replaced by the migration of new nematocysts to the area.

Granular electron-dense material is present within the tubule as well as in the capsule of the mastigophore. The tubular matrix passes out of the tubule progressively as eversion takes place. Passage of tubular matrix through the skin may account for full thickness skin necrosis that has been reported after envenomation from the box jellyfish.

Some of the tubular matrix passes into blood vessels, although the bulk of material from within the tubule appears to enter the extravascular spaces. The discharged capsular matrix, emerging at the tip of the fully everted tube, would normally be deposited extravascularly as the chances of the tip of the fully everted tubule being in the lumen of a blood vessel are remote.

Two ways in which toxic material may enter the blood stream are:

1 Directly intravascularly or

2 Indirectly from the tissues into the lymph vessels. Toxic material entering the blood stream directly would reach the heart more rapidly than that entering the blood stream by an indirect route.

Sections through mouse skin reveal that adhering tentacles contained many undischarged nematocysts. In human envenomation, it is necessary to inactivate any remaining nematocysts which had the potential to discharge. Dilute acetic acid (vinegar) has been shown to inactivate *C fleckeri* nematocysts. After the application of vinegar, to inactivate nematocysts with the potential to discharge, immediate application of a pressure immobilization bandage to retard passage of injected venom from the tissues into lymph vessels is recommended. This bandage should be left in place until the sufferer is under medical care, in a hospital equipped with *C fleckeri* antivenom, and all preparations havebeen made to cope with collapse of the patient.

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THE WORK OF THE INTERNATIONAL CONSORTIUM FOR JELLYFISH STINGS

John Williamson

Introduction

The "International consortium for Jellyfish Stings"[1] arose from the earlier collaborative work of a small group of clinicians, marine biologists, "in-the-field" workers and toxinology researchers scattered around North Queensland, Australia and in the U.S.A. It was conceived in particular by Professor Joseph Burnett, whose laboratory in Baltimore, Maryland, is at the forefront of jellyfish venom toxinology.[2,3,4] Its prime function is to create a focus for international communication between interested workers in the subject of human jellyfish envenomation. The Consortium was formed, with its letterhead symbol, in 1987.

INTERNATIONAL CONSORTIUM • FOR JELLYFISH STINGS •

Current participants

Medical, biological and marine scientists, scuba diving instructors and distinguished underwater photographers all feature in the current international mailing list. Some of these people are making original and pioneering observations in this field of study.[5,6,7,8,9,10] The countries at present involved are the United Kingdom, Portugal, Yugoslavia, Greece, Italy, South Africa, Sultanate of Oman, Sri Lanka, India, Pakistan, Thailand, Malaysia, China, Japan, Eastern Russia (Vladivostok), Canada, U.S.A., Argentina, New Zealand, Fiji, Australia, Papua New Guinea, Sarawak and the Philippines.

Activities

1 COMMUNICATION

This a prime function of the Consortium in an attempt to harness, and to a small extent, co-ordinate research and publication efforts internationally.

To this end the Consortium publishes a bi-annual "Newsletter", complied mainly by Joe Burnett in Baltimore. This is distributed to the American and European regions from Baltimore, and to the Middle East, Indian, Asian, Australasian and Pacific areas from Adelaide. The mailing list currently numbers 115 on the latter, and 30 on the Baltimore list.

An annual "Sting Report Summary", which is prepared by myself in Adelaide and Dr Peter Fenner in Mackay, Australia, is sent to the same mailing list. This is a compilation and analysis of confirmed envenomations world wide, and although obviously incomplete, provides on-going epidemiological and medical insight.

The Consortium mailing list also allows notification of relevant scientific meetings internationally, and research, publications and significant advances in understanding by and to Consortium participants.

2 RESEARCH

This is increasingly active, but still in the early stages of development. For some years past, captured specimens and freeze-dried tentacle material has been exchanged between Baltimore, Brisbane, North Queensland, the Mediterranean area, and more recently Karachi and the Australian Northern Territory. This exchange of scientific material will expand in the future. Current efforts are directed towards both classification and identification of specimens and life cycles,[11] laboratory toxinological and immunological studies,[12,13] clinical research[14,15,16,17] and epidemiological efforts.[18]

3 PUBLICATIONS

These are increasing in both quality and quantity, and some are listed in this report.

4 EPIDEMIOLGOY OF STINGS

Apart from the Consortium's regular review based upon documented or confirmed first-hand reports,[18] communications of unpublished observations, direct investigative enquiries (e.g. museum specimens) and some publications have now confirmed that human mortality, or life-threatening envenomation from jellyfish stings have occurred, or are occurring over a very wide area. Envenomation has been reported in the mid- and south Atlantic Ocean, the Pacific Ocean, the Sea of Japan (North China Sea), throughout the Indo-Pacific region (the major number of known deaths), the Indian Ocean, the Gulf of Oman and parts of the African coastline.

The future

In addition to increasing the international "membership" of the Consortium (there is at present no joining fee), it is hoped that its existence will encourage international visits, and the cross-fertilization of experience and ideas that is so necessary for progress with understanding.[19] Jellyfish envenomation is an event which is far more common than was previously realised and has been a neglected area of study.

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SYMBIOSIS BETWEEN EDUCATION, RESEARCH AND TOURISM

Andrew Dunstan

Reef Biosearch is a group of nine marine biologists employed within the Quicksilver Connections company. Quicksilver runs two high speed wave-piercing catamarans to the outer reef and a large sailing catamaran to Low Isles daily, employing biologists on board for educational and interpretive activities.

A common question asked of us is “Do they actually pay you to do this every day”? Increasingly in tourism it makes economic sense not only to ensure the long term survival of the reef but to provide the educational and interpretive options demanded by a more environmentally aware tourist/client population.

For the marine biologist this means being able to spend valuable time in the reef environment, daily accruing knowledge in the field. It also gives the chance to educate many thousands of people not only to the wonder and beauty but the importance and fragility of the reef system. It also means that biologists, generally a group with highly protective moral standards towards their reef subjects are on hand to ensure the integrity of an operation.

This is a healthy outcome from a trend towards ecotourism. Ecotourism has been defined by the Ecotourism Association of Australia as “Ecologically sustainable tourism that fosters environmental and cultural understanding, appreciation and conservation”. This does not mean just having a reef guide on board to take rudimentary tours but a policy spanning all company activities.

This type of attitude equates well with the Great Barrier Reef Marine Park Authority (GBRMPA) guidelines which dictate that tourism activities must “provide for the protection, wise use, understanding and enjoyment of the Great Barrier Reef (GBR) in perpetuity." The enjoyment aspect is well catered for by tourist operations, while reef understanding is an increasingly integrated part of the whole package.

At Reef Biosearch, since its inception in 1986, we have taken approximately 70,000 people out on extended snorkelling tours, captivating their interest and knowledge of the reef. About half a million people have been subjected to our indoctrination procedures during slide presentations and talks, and over 100,000 during naturalist walks at Low Isles.

Education is accepted as possibly the best conservation tool and we have extended this beyond the boat/reef operations to within the regional school and community. Programs have been developed in conjunction with the environmental educational division and local teachers which are compatible with existing curriculum requirements. These involve students in four to eight week long school programs devoted to the reef. A great thing about these programs is the enthusiasm generated for subjects otherwise seen as boring. Community talks and activities such as beachcombing, rainforest and mangrove walks are also conducted frequently. Quicksilver’s commitment to the school program has been invaluable, providing biologist time and greatly reduced fares to Low Isles.

The other half of the GBRMPA requisite, for protection and wise use of the reef, is the area of most concern and contention between reef tourist operators and conservation minded groups. This is certainly a valid point when you consider the vast increase in tourist reef use over the last decade. The number of day trippers to the reef has increased 35 fold while the number of operators is up by a factor of 10. This is largely due to the advent of high speed catamarans offering fast and comfortable transport to the outlying reef areas on a large scale.

It could also be argued that the speed of development has overtaken the speed of acquisition of the knowledge needed to ensure the protection of the very reef they visit. Certainly now there are strict requirements operators must adhere to right from the initial proposal and accompanying environmental impact statement (EIS) to continued monitoring of the reef area of operation. These are at the moment being formalised and structured to monitor the effects tourist operation has on the reef and to develop methods to keep these effects well below an acceptable level.

Reef Biosearch has over the last 4 years been carrying out research and monitoring programs. The site of a pontoon installation at Agincourt 4 is being examined for changes in fish and coral communities and water quality. This research is a requirement of the operators permit and information from it will result in increasingly better management guidelines for tourist reef use.

The symbiosis between tourism and reef education has led to large scale employment of marine biologists in the field. Increased public awareness of the reef and its importance leads not just to the employment of marine biologists as educators but also to corporate funding for relevant research. Money in research is always in hot demand and short supply. The research carried out by on site biologists can be very productive in data intensity and sampling frequency due to the greatly reduced boat costs and easy accessibility.

The biologists of Reef Biosearch have expertise in a variety of fields including coral taxonomy, marine mammals, biochemistry and statistics. Rostering of work times is flexible enough to allow for irregular research programming while still maintaining full-time work status. The result is a variety of research programs run by Reef Biosearch and also in collaboration with other research institutions. Daily interaction in reef waters gives invaluable recorded observations, through all seasons, to investigate otherwise unforeseen or unconnected biological events of importance.

In general at Reef Biosearch we are in the unique position to combine education and research in a tourist framework. This should be increasingly carried out by other operations both on the GBR and areas such as the rainforest and mangroves.

The most important aspects are:

1 The conversion from tourist to ambassadors for reef protection via education and involvement.

2 The overall expansion of research funds and projects.

The employment of concerned biologists can only increase the concern and care a tourist operation has for their immediate environment.

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DIVING AND THE LAW
A SHORT HISTORY OF THE REGULATION OF SCIENTIFIC DIVING IN AUSTRALIA

E.A.Drew

Introduction

The first scientific diving in Australia was carried out under the direction of (Sir) Maurice Yonge at Low Isles during the 1928-29 Great Barrier Reef Expedition. They used the diving helmet shown in Figure 1, a piece of equipment initially developed by a Paris fire chief to allow access to smoke-filled buildings and subsequently used by Professor Milne Edwards to study marine biology down to 7.5 m (25 ft) in Sicily in 1856. Similar equipment was used in the Caribbean in the 1920s by William Beebe to depths of 18 m (60 ft) and was still being used by Jack Kitching to study kelp in Scotland in 1940.

Although the aqualung was brought to Australia in 1952, early scientific diving work by CSIRO in 1957 to study the pearl beds of northern Australia used Greek sponge divers with hard-hat diving equipment. Indeed, scientific diving in conjunction with both the pearl and abalone industries in Australia still uses the same equipment as the commercial operators in those industries, namely hookah (surface supplied air from a petrol driven compressor) diving. Initially, use of the aqualung was restricted to recreational spearfishermen, but scuba-based scientific diving in Australia began in the late 1950s and blossomed during the 60s.

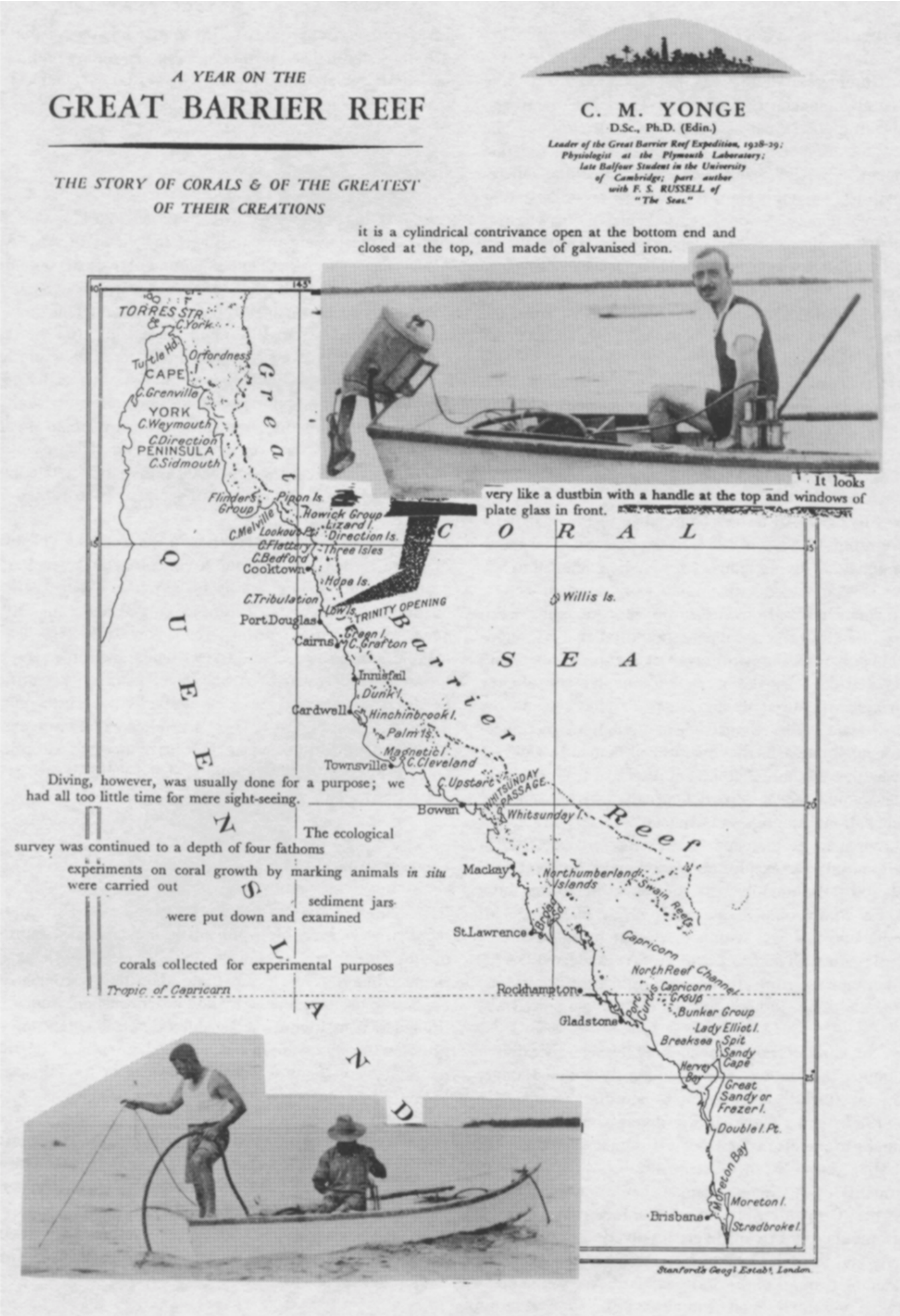

Figure 1. The diving helmet and hand pump used on the 1928-29 Great Barrier Reef Expedition. Photographs and map from C. M. Yonge (1932) "A year on the Great Barrier Reef".

Early regulations

Commercial diving was first regulated in Australia by Australian Standard CZ18 - 1972 (Work in Compressed Air) which applied to caisson workers as well as divers. The underwater component was incorporated into a separate document, AS 2299 (Underwater Air Breathing Operations), in 1979 and this applied only to professional and/or commercial underwater operations. Scuba diving was limited in that document to 20 m. There were scientific divers on the committee which developed that Standard, but it was decided not to include such activities in its scope. So, the scientific diving representatives were dropped from the committee. An amendment was subsequently added to AS 2299 (1979) allowing short dives to 30 m on scuba specifically for research diving operations, presumably to allow the commercial divers to do work for scientists!

Start of the present problem

Standards Australia's Committee SF17 began work on redrafting AS 2299 in 1984. A document was issued to the commercial diving industry for public comment in late 1986. This coincided with a number of important factors. There was a marked down-turn in work for commercial divers, the federal government proposed that all states should begin to develop uniform Occupational Health and Safety (OH&S) legislation, environmental consultancy companies who used diving began to emerge, and the police rescue divers wanted clear regulations to protect them against unreasonable operational demands. The result was that the public comment response from the state regulatory authorities in particular called for other forms of occupational diving, and especially rescue and scientific diving, to be included in the scope of AS 2299 in order to provide a basis for regulation under future OH&S legislation. Presumably with an eye to obtaining more work for commercial divers, particularly in the area of consultancies but also within the research organisations, the Professional Divers Association of Australasia (PDAA), a trade union exerting rigid closed-shop control over the commercial diving industry, wholeheartedly supported this.

So, without actually consulting the scientific diving community, their activities were summarily included simply by rewriting the Scope section of the new draft Standard. In early 1987, whilst the scientific divers were themselves beginning to exercise a degree of self-regulation through the Australian Marine Sciences Association (AMSA), we learnt unofficially of this major change. We immediately contacted the 30 organisations we knew did scientific diving to determine the number of divers involved, their degree of activity and their thoughts about a number of potentially threatening features of the draft Standard. We were able to get two representatives on Committee SF17. One was from the Australian Marine Sciences Association and the other from the archaeologists' association, the Australian Institute for Maritime Archaeology (AIMA). Standards Australia also suggested at that time that we should develop a preliminary draft for a standard which would be acceptable to scientific divers.

Strategies

At this point we formed a National Working Group on Scientific Diving to coordinate the views of AMSA, AIMA, the universities, state government research organisations and the consultants. AMSA also carried out a more detailed survey of scientific diving activities over the previous 11 years (1977 to 1987) and the results from the responses from 203 divers are set out in Figure 2. Particularly interesting was the overwhelming emphasis on boat diving, the lack of surface support personnel, the number of usually fairly shallow dives amounting to an average of 36 dives per year, the large proportion of divers doing at least some decompression diving, a significant amount of hookah diving (8%) and the small number of accidents (see Table 1).

Armed with annual updates of such statistics (Table 2), an Australian Scientific and Archaeological Divers Register, currently listing details of 984 individuals in 120 institutions throughout Australia (Figure 3), and a quarterly newsletter called Scientific Diving News we have been making some progress, some new friends, and some waves. In January 1991, we also formed the Australian Scientific Divers Association to provide a unified voice for the purposes set out in Figure 4. Our data indicate that more than 40,000 scientific dives are carried out each year in Australia with, on average, only one diving-related accident such as a bend.

Current situation

Despite this concerted activity and excellent safety records, we were unable to prevent the inclusion of scientific diving within the scope of the AS 2299 (1990) - Occupational Diving. This means that, when this document is applied to us, as it now is by law in Queensland, scuba is limited to 20 m, lifelines and standby-divers are mandatory, no decompression diving is allowed on scuba, on-site recompression facilities must be available for all dives below 20 m and some shallower, and training must be according to a separate Standard, AS 2815, which has no provision for recognition of recreational training and certification. The Queensland situation was slightly eased late in 1990 by a general exemption allowing scientific divers to use scuba to 30 m, dispense with lifelines, have the standby diver in the water (as the buddy), and combine the roles of dive supervisor and diver's attendant on the surface. This exemption applies to.

"Employers who employ a diver in underwater diving operations solely for the gathering of environmental data

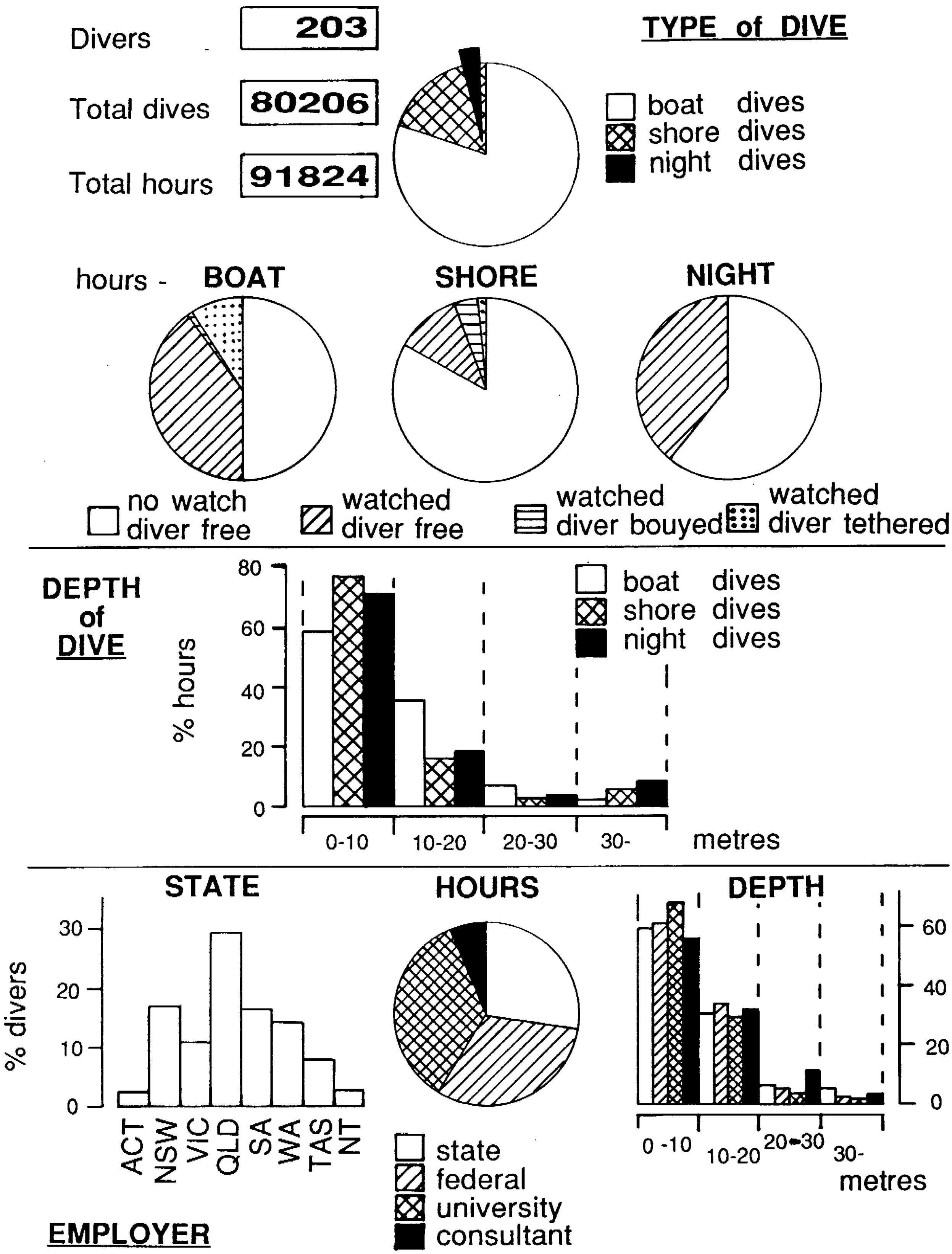

Figure 2. Summary of results from the AMSA Scientific Diving Survey, 1977-87.

TABLE 1

SCIENTIFIC DIVING ACCIDENTS FROM THE AMSA SURVEY, 1977-87.

Type	Number	Nature	Subseqent diving
Heart attack	1	fatal	not applicable
Bend	3	serious	temporarily stopped
Embolism	2	serious	permanently stopped
Ear	1	serious	permanently stopped
	4	minor	temporarily stopped
Sinus	2	minor	temporarily stopped
Tooth	1	minor	temporarily stopped
Eye	1	minor	temporarily stopped
Hypoxia	1	minor	temporarily stopped
Salt water aspiration	1	minor	temporarily stopped
Blackout	1	minor	not stopped
Shock	1	minor	temporarily stopped
Broken rib	1	minor	temporarily stopped
Burn	1	minor	temporarily stopped
Sting	1	minor	temporarily stopped

TABLE 2

ANNUAL UPDATES FOR AUSTRALIAN SCIENTIFIC DIVING.

Year	1988	1990	1991
Respondents			
Active divers	90	105	104
% female	23.3	21	23.5
Total dives	4,489	5,071	5,322
Total hours	4,579.6	4,416.4	5,073.2
Mean duration (minutes)	61	52	57
% from boat	85.4	89.4	
% at night	1.3	1.9	
Accidents			
bend	1	1	0
other			5
Dives/ active diver	49.9	48.3	51.2
Dives/ respondent			46.3

From the 1991 survey figures the 967 scientific divers on the Australian Scientific and Archaeological Divers register would have carried out

44,772 dives

and spent

42,533 hours underwater in 1990.

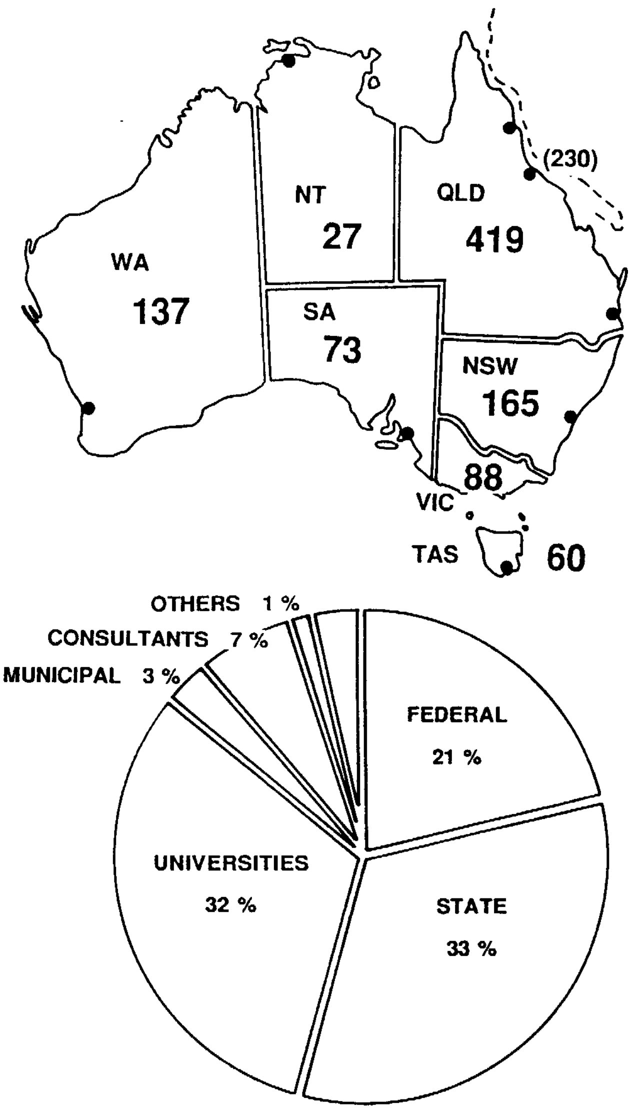

Figure 3. Distribution of Australian scientific divers by location and type of employer. Note the large concentration in Queensland, near the Great Barrier Reef, and particularly in Townsville with its three major marine-oriented research organisations.

or specimens for a research, environmental management or science education organisation or institution."

Also, the AS 2815 certification for Commercial Scuba Divers was available to us under a grandfather clause for a few months in 1990. A 3 week, $Aust3,000 course, only available so far at one locality in Australia, is now required to be able to use scuba to 20 m, and about 7 weeks, costing at least A$7,000, to go to 50 m using the mandatory SSBA equipment. However, despite the recent exemptions, a surface recompression chamber is still required for dives below 20 m, whether on scuba or SSBA, as are diver-surface communications for all dives! Queensland now has two

Started in January 1991

derived directly from the Australian Scientific and Archaeological Divers Register

to provide an independent national forum for scientific divers

to maintain a strong mandate for negotiations about the regulation of scientific diving in Australia

to maintain a national register to demonstrate:

how many scientific divers there are

who employs them and in what capacities

the amount of scientific diving done using SCUBA and HOOKAK

the excellent safety record of scientific diving

fully endorsed by AMSA and AIMA

Figure 4. The mandate of the Australian Scientific Divers Association

diving inspectors actively policing these regulations, together with other regulations which apply specifically to recreational diving instructors. Most other states will almost certainly call up AS 2299 when an accident occurs, although Western Australia is applying AS 2299 in advance to all work associated with the petroleum industry, including inshore environmental surveys nowhere near oil platforms.

Scientific divers visiting from overseas can still operate even in Queensland provided they can demonstrate training and experience equivalent to AS 2815, although the exact details of who can authorise them to dive are unclear as the scuba part of the Standard is still to be finalised. A number of visitors have already had to do a 1 week, A$900 upgrade course.

Up to now, the 200 scientific divers in federal government organisations, such as the CSIRO and AIMS, are exempt from such State laws and the federal OH&S organisation, ComCare, has not yet adopted any particular regulations. However, this is set to change within the next year or so.

Erratic progress

Recent developments have included the formation of a special Standards Australia committee (MS53) to develop an Australian Standard for Scientific Diving. That committee consisted mainly of representatives of organisations involved in scientific diving. On their recommendation, Standards Australia issued the draft developed by the National Working Group, generally known as the AMSA Standard, for public comment between May to July 1991. It is basically a prescriptive subset of the UNESCO Code of Practice for Scientific Diving with additions from various other national and organisational documents. It aims to set out in detail our current practices which have, after all, allowed us to do a lot of diving very safely. As recompression facilities are relatively scarce in Australia, one important recent addition we have made to this document is Dr Des Gorman's risk assessment criteria to decide when a surface recompression chamber is really necessary on site. Also, we have incorporated a training and certification scheme (Table 3) into this draft Standard to avoid the need for more than one regulatory document. The level of certification of Australian scientific divers is set out in Table 4. There is probably some room for improvement on the 61% with only Basic Scuba certification although the majority of those have 20 to 30 years diving experience.

Unfortunately, the work of Committee MS53 has now stopped because another organisation, Worksafe Australia, declared that, as they rather than Standards Australia are now responsible for occupational standards, they will develop a single new, all-embracing, hazard-based standard for occupational diving. That initiative was to see the National Standards Commission, aided by a 12-person Expert Group themselves supported by a much larger reference Group including the old Standards Australia committees, create a better and more widely applicable version of AS 2299 within a few months. Intensive lobbying by a wide range of non-commercial divers caused that initiative to collapse on September 17, 1991 and it was replaced with a decision simply to call for further submissions from the various interested parties. While the Worksafe Australia initiative rose and fell, the Queensland Government's Division of Workplace Health and Safety had become increasingly aware that the blanket application of AS 2299 was unsatisfactory for others beside the scientific divers. Eventually, after many complaints, culmination in heated interaction with the Underwater Visual Producers Association of Australasia led by the well-known underwater photographers Ron and Valerie Taylor, they instituted a Review of

TABLE 3

PROPOSED LEVELS OF CERTIFICATION FOR AUSTRALIAN SCIENTIFIC DIVERS.

ALL SCIENTIFIC DIVERS MUST
- be at least 18 years of age
- have a current certificate of medical fitness to dive

Trainee scientific divers
Certification to CMAS two-star.

Scientific divers
As for trainee, plus
- At least 15 hours experience with at least 7 hours below 10 m.
- Current recognised certification in CPR, oxygen resuscitation and first aid.
- Knowledge of and ability to use decompression tables for single, combined and repetitive dives.
- Knowledge of the current diving regulations.

Advanced scientific divers
As for scientific diver, plus
- At least 15 hours additional experience with at least 7 hours below 20 m.
- Certification equivalent to CMAS three-star.
- Other appropriate certifications.
- CMAS Scientific Diver Brevet recommended for international reciprocity.

Diving officers
- Certification equivalent to CMAS four-star.
- At least 3 years scientific diving experience.

Visiting scientific divers
- To be temporarily assigned to visiting trainee, visiting scientific or visiting advanced categories according to certification and log-books presented and subject to a check-out dive.

TABLE 4

CURRENT CERTIFICATION STATUS OF AUSTRALIAN SCIENTIFIC DIVERS.

Recreational		
Basic/ Open water/ C card		237
Highest certification for 61% of divers		
Advanced		61
Highest certification for 13% of divers		
Divemaster		31
Advanced divemaster		3
Instructor		17
Rescue/ Research/ Deep diver		10
Commercial		
AS 2815.1	Scuba to 20 m	135
AS 2815.2	SSBA to 20 m	9
AS 2815.3	Scuba to 50 m	1

the Regulation of Occupational Diving. The first information paper was circulated at exactly the same time as the Worksafe initiative faltered, and it contains a number of refreshing comments including the possibilities of having specific codes of practice for the different sectors of the industry, acceptance of recreational certifications, no surface personnel under safe and sheltered conditions, specific reference to hookah diving, and re-examination of the stringent medical requirements.

Future possibilities

With all other discussions on diving regulations in Australia virtually suspended, this Queensland initiative became the current focus. Could they at last produce some rational regulatory documents acceptable to all sectors of the occupational diving community and free from the overwhelming influence of the commercial diving industry and the PDAA (now amalgamated with the Seamans Union of Australia)? We shall certainly be advocating use of our own self-regulatory document which has already been declared acceptable by all our scientific divers.

Imminent developments

At this moment, June 1992, we await details of the new Queensland Code of Practice for Occupational Diving which will, in theory, replace mandatory compliance with AS 2299 in low risk occupational diving. However, we still do not know on what basis the risks have been classified and how appropriate the classification will be. With an amended, slightly more acceptable version of AS 2299 now very close to publication, our major concerns at present centre on training requirements. We do know that, under the new Queensland Code of Practice, persons with recreational rather than AS 2815 certification will be permitted to do some low risk work. This is probably the biggest step forward this document will bring and may set a more reasonable stage for the next big national initiative on occupational diving.

The Worksafe Australia initiative, begun almost 2 years ago, is now under way again and they will hold the first meeting of their Expert Group on Occupational Diving very soon. That initiative, which aimed from its inception to produce a new, fully risk-based national standard for occupational diving within less than a year, appears to have been held up for some time by a lack of concensus on which so-called “experts” should be on the committee! The similarity of the Expert Group to Standards Australia's Committee SF17 is probably unavoidable, but so too, it seems, is the associated controversy Worksafe thought they could avoid.

Epilogue

Australia's 1,000 scientific divers accept that we have stimulated much of the current controversy over occupational diving regulations. We do not, however, regret in any way the firm stand we have taken, at all levels of bureaucracy, against arbitrarily imposed, restrictive regulations. The largest single occupational diving community in Australia has been carrying out research essential to the national economy in a demonstrably safe and cost effective way for more than 30 years. We cannot allow that to be compromised by convenient but inappropriate over-regulation and the hidden agendas of other occupational diving groups.

We await with bated breath, and not a little apprehension, the new Worksafe document.

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AQUATIC WORLD AWARENESS, RESPONSIBILITY AND EDUCATION IN DIVER TRAINING AND TOURISM

Drew Richardson

Introduction

We know little about the ultimate impact of man's destructive activities on the world's oceans, such as pollution, dredging and dumping. However, there is another activity we are learning a great deal about through direct observation. Interaction between divers and the sea has never been greater. Unfortunately, some of it has been at the expense of the marine ecology. Damage to coral reefs is an example.

Unfortunately divers can endanger an ecosystem. The coral reef environment is a precious resource we, as divers, hold close to our hearts. However, we are fortunate that we, as individual divers, have the power to protect it.

In general, divers genuinely care about the well-being and welfare of the ocean and its inhabitants. Certainly, we are not a destructive or malicious group. Given that scuba divers actively interact with the sea, we are in an excellent position to shed laissez-faire attitudes to conservation and do our part to actively preserve the reef evironment.

As divers and diving educators, the responsibility for protecting this resource falls on all of our shoulders. Our numbers have grown. We are not just a small band of adventurers, but a growing and vital community. Let us take a lesson from the deterioration of our terrestrial natural wonders. Multiply one foot-print, one broken twig, one aluminium by one thousand, and each is no longer insignificant.

Our non-destructive coexistence with the coral reef hangs on a thread of awareness. Although an individual presence may seem insignificant in a vast ocean, the numbers visiting the same area over time can leave a visible trail. Each careless swipe of a fin, hand or camera is another proverbial "nail in the coffin" of the coral reefs.

The first step toward responsible interaction with the coral reef system (or any marine ecosystem) is an accurate understanding of how your personal activity can affect the creatures who make it their home. Diving instructors have a key responsibility to help divers appreciate the coral reef environment. The entire ecological system will benefit from divers who have learned how to interact appropriately with the coral reef environment. This begins with education.

Aquatic world awareness

As an individual, it is imperative that you become a role model in your actions around, and discussions of, the coral reef environment. Consider the benefits of embracing a marine awareness philosophy in your diving behaviour. Would divers at large wantonly destroy a sea lion or starfish? Of course not. However, because many aquatic organisms do not look like the plants or animals we find on land, it is difficult for people to appreciate them as fragile life forms. Hence, brain coral may be associated with a terrestrial rock. Most organisms, including those found on the reef, are perceived from our narrow perspective as land dwellers. Or as Biologist Charles Seaborn writes in The Encyclopedia of Recreational Diving: "In general, people consider animals without fur, complex behavioural patterns or eyes as inanimate objects. Aquatic animals that fit into this category include sponges, corals, sea stars, tubeworms... and other slow-moving or attached organisms." If this is the mind-set of a passing diver, it may lead to the end of the diver-animal relationship and any further interaction.

In fairness to the uniformed, passing diver, he may be totally oblivious to the fact that he is kicking over a sponge or rubbing off the mucus covering from a coral structure. It becomes our job as responsible diving educators to sensitize and educate all divers whom we influence. All of us must respect corals, sponges and others as living animals with special needs, vulnerabilities and fragility. This educational process must occur throughout training and tourism and at all levels. There are many opportunities to presenting this information in a special format, such as a slide show, social, seminar or specialty course.

With this understanding and perspective, previously oblivious divers may now approach a reef with a sense of reverence and sensitivity. They take pains to exercise the buoyancy control skills they learned in diver training, and are aware of the placement of their hands, fins and equipment. It is nearly impossible to enter the coral environment and not have some physical contact with its inhabitants. The goal is to create the informed diver who is aware of the animals surrounding himself and who minimizes contact to that which is purely accidental.

Consider the benefits of making a pledge of personal commitment and contribution to conserving the realm that we bring others to explore. No single, greater force can speak with such authority as we who interact directly with the underwater realm. Do your part to educate those that you can influence to be informed, controlled and sensitive divers.

Teaching good diving habits and education

The best designed diver training course relies entirely on the field instructor to use it properly to produce a well-trained diver. Certification is a matter of performance-based education. A student needs to master both knowledge and a series of motor skills before he is released from supervision.

Diving educators are encouraged to illustrate the impact that an adeptly performed skill has on the preservation of a fragile coral reef, which gives each skill added value. For example, buoyancy control, fin pivoting and hovering have direct application to staying up and over the coral. Other instructional opportunities abound in training toproduce environmentally aware divers:

It is important to ensure that the student has mastered all the necessary skills in confined water to the point that he is relaxed and comfortable.before taking him or her into open water. Buoyancy control starts with the kind of breath control that only relaxation brings.

Encourage divers to use less lead. A well-trained, relaxed diver will not need to overcompensate his buoyancy with too much weight or an overinflated BC. A pre-dive buoyancy check at the dive site will help ensure this. Proper weighting will also ensure that the diver's fins are not below his body and colliding with any delicate marine life. Proper weighting begins in confined water and continues into open water. Before an open-water dive, students should be weighted according to tank type, body weight, type of exposure protection and water density. A diver may then relax, enjoy the dive and avoid coral damage.

Underwater instructors can choose to position students to perform skill demonstrations out in the open sandy areas between coral formations (where the anchor should be, if the boat is not on a mooring). Students may often need to perch on the bottom during training, so careful selection of the instructional site will ensure it is truly an inanimate substrate, such as sand.

Dive guides can swim with their group beside the reef rather than over it. This will prevent damage from the downstroke of fins.

In warm water, consider not using gloves. In general, avoid touching the living reef. The possibilities for cuts, scrapes and stings will be minimized if the diver knows that nothing should be touched. Encourage the attitude that the reef does not need protection from me, so why should I need protection from it?

Allow manoeuvring room for the scuba tank. Encourage divers to turn sideways when looking under ledges to avoid banging the reef with their tank. Do this yourself. Additionally, be aware that the tank may strike coral when one moves backwards or sideways.

As a role model demonstrate exceptional buoyancy control yourself. Watch your body attitude and position at all times. Neutral buoyancy and proper positioning will minimize the tendency to kneel, stand or sit on the coral.

Take time to identify examples of delicate living corals, which will develop knowledge and respect and ultimately foster a sense of conservation based on understanding.

Recognize that, no matter how well-trained a diver is upon certification, unused motor skills will deteriorate over time. As a result, it is important to encourage divers to undergo scuba review programs, spring "tune-ups" or similar refresher programs before going on dive vacations. Resort operations may need to provide refresher programs before open water diving for travelling divers.

Underwater photographers are often among the worst offenders when knees, fins, legs and bottoms are concerned. When a photographer finds it necessary to stop without hovering, a sandy or non-living, hard bottom area can always be found. Placing your feet or knees on the sand will save a lot of live coral.

Be certain to secure dangling alternate air sources in the triangular areas of the upper body. Instrument consoles, mesh bags and other equipment should be secured to avoid the likelihood of dragging them against coral or other delicate life forms. Divers sometimes do not allow for the extra clearance required.

Do not use a knife to poke, prod, or destroy creatures. Do not kill animals to feed fish.

As a diver, you are unique in that you are a window to the aquatic environment. You can use the Aquatic World Awareness, Responsibility and Education philosophy to help develop an ethic to share with others. To many of your friends and family, particularly if they are not oriented toward the outdoors, pollution and environmental destruction that is "out of sight" is truly "out of mind". As one who has chosen not to ignore nature, you can show others that these problems are not "out of sight."

Responsibility

I have attempted to identify the importance of quality training and education to produce responsible animal-diver interactions. The first step occurs in accepting a personal responsibility to minimize reef damage. The new conservation rationale outlined in this article will only have impact if individual divers actively participate in its implementation. The marine environments are degraded by pollution and stresses of many descriptions; do your part to foster ecological awareness both in yourself and in the divers you influence.

Unscathed, the coral community represents life in the balance, and the epitome of the beauty we seek as divers.

Battered, this ecosystem becomes a depressing monument to our carelessness and disregard. Let us be the leaders in the protection of the marine environment through our influence and actions.

As a diver, you are able to influence other divers and their families, who by virtue of their love and interest in nature will influence others. As you read this, there are over 500,000 divers certified each year. In the 1990s, it is anticipated the industry will certify more than 10 million divers. If we join together now to develop and practice an environmental ethic, we can make a difference.

In terms of protecting the magnificent corals reefs, the responsibility begins here, with us.

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