Big Bank Shoals of the Timor Sea: an Environmental Resource Atlas

Edited by

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Foreword

In February 1997, the Commonwealth Government initiated the development of a comprehensive Oceans Policy. The development of an Oceans Policy, expected to be completed in the first half of 1998, confirms Australia's position as a world leader in marine conservation and management.

The Oceans Policy will provide a framework for both environmental protection and the sustainable utilisation of our valuable ocean resources. These resources include, of course, offshore oil and gas reserves.

For over twenty years, oil and gas exploration has occurred in the Timor Sea. BHP Petroleum (BHPP) has, in carrying out its activities in the Timor Sea, demonstrated a high level of commitment to environmental protection. This commitment led BHPP, together with the Australian Institute of Marine Science (AIMS), to spend two years studying the ecosystems of the Big Bank Shoals in the centre of the Timor Sea.

This *Environmental Resource Atlas* records the diverse benthic communities, including filter-feeders, hard and soft corals and particularly the wide-spread calcareous algae *Halimeda*, identified by BHPP and AIMS. It also describes encounters with more familiar creatures - sharks, reef fish, cuttlefish, sea cucumbers and even sea snakes. By enhancing our knowledge of the biodiversity of the region, I am confident that the *Atlas* will contribute to the effective conservation of the marine resources of the region.

The development of the *Atlas* demonstrates the potential for effective cooperation between industry and government in developing strategies to minimise the environmental impact of oil and gas exploration and production. In my view, greater emphasis needs to be placed on the development of partnerships between industry, Government and the community if we are to successfully achieve society's environmental and economic goals.

The location of the Big Bank Shoals, adjacent to the Zone of Cooperation between Indonesia and Australia, also highlights the increasingly close relationship between Indonesia and Australia. The fact that the introduction to this *Atlas* is provided in English and Bahasa Indonesia emphasises BHPP's commitment to the region. This complements the Government's involvement in regional initiatives designed to protect the marine environment, including our participation in UNEP's regional seas program.

Perhaps society's greatest challenge, as we approach the 21st century, is to achieve ecologically sustainable development. The successful integration of economic, social and environmental concerns will require an approach from individuals, industry and Government which embraces a greater respect for our environment and a greater willingness to work together.

The development of the *Environmental Resource Atlas* is an example of the commitment of BHPP and AIMS to that process. I encourage all Australians to follow the example of BHPP and work with the Government in developing, through the Oceans Policy, a framework for the protection and sustainable use of our oceans.

Senator Robert Hill
Minister for the Environment

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Introduction

In the centre of the Timor Sea, the shallow platform which is an extension of the Australian Continental Shelf deepens steeply towards the Timor Trough. At this point, a series of shallow carbonate banks rise from depths of 200 to 300 metres to within 20 to 30 metres of the water surface. They form the submerged banks, which until recently were uncharted, and which we have named the Big Bank Shoals (Figure 1). This is a unique area from both a geomorphological, and geopolitical point of view. It lies in the now denominated 'area of overlapping jurisdiction' as proclaimed in the 1997 Sea Boundary Treaty between Australia and Indonesia. In the section titled 'Physical Environment', which follows, a discussion is given of the detailed characteristics of the area.

Standing much shallower than the surrounding waters, these submerged banks form ecosystems which comprise habitats for a range of communities. These differ greatly from those found in the deeper waters surrounding the banks. Partly because of light penetration to the substrate, and partly because of the movement of nutrients carried by the currents eddying around the sea mounts, benthic communities thrive on many of these banks. The second section, 'Biological Environment', includes a detailed discussion of the various ecosystems and biological communities encountered in the Big Bank Shoals area and presents a discussion of the biological and ecological characteristics of those communities. Survey methodology and quantitative analysis of the major benthic groups is also presented.

The final chapter 'Social Environment' is an overview of the area. It includes a discussion on fisheries and documents, an extensive literature research; verbal communications with authorities and fishing communities; and a social study carried out in Indonesia as part of an Environmental Impact Assessment for the Elang Oil Development. The objectives of the social study were to determine the type of fisheries in the area, and fishing routes and destinations used by traditional fishermen as well as the effects of oil development and shipping on these fishermen. These factors are considered to have direct effects on the environment and ecosystem of the Big Bank Shoals area.

In addition to fishing and shipping, the area is also an offshore petroleum province. For over twenty years, oil and gas exploration and production activities have been conducted in the Timor Sea region, including the area surrounding the Big Bank Shoals. Following the 1989 Timor Gap Treaty between Indonesia and Australia, which agreed to the joint exploration and production of hydrocarbons in the unresolved boundary area, exploration was intensified. This has resulted in a number of hydrocarbon discoveries.

BHP Petroleum, as an active petroleum explorer in the area, has conducted baseline environmental investigations to support its exploration and proposed development programs. The Australian Institute of Marine Science has assisted BHP Petroleum in the design of the surveys and in the interpretation of benthic habitats data sets. These baseline studies have included:

- Accurate bathymetric surveys to determine the geomorphology of the banks.

- Acquisition of side-scan sonar for interpretation of substrate features and the preparation of preliminary habitat maps.
- Remote Operated Vehicle (ROV) surveys to confirm inferred habitats, and to determine their distribution and species composition.
- Grab and drop-core sampling to validate ROV video and to provide material for chemical and physical analysis.
- Deployment of current meters, to aid in the formulation of management strategies for the disposal of drilling discharges, and for oil spill contingency planning.
- Water samples to determine the abundance and composition of plankton.

This *Atlas* represents a compilation of the various studies and reports resulting from the individual environmental study programs conducted during 1995 and 1996, as well as a literature research on the various biological communities encountered. It is a joint effort by BHP Petroleum and AIMS to further analyse the results of field investigations and to attempt to draw some conclusions based on the present state of knowledge of the environment. The principal aim of this project is to assist in the development of strategies to minimise the environmental impact of hydrocarbon exploration and production activities. The *Atlas* also serves to make these findings more accessible to the wider community, to demonstrate BHP's commitment to further understand the environment in which the company operates and its willingness to cooperate with Governments and the community to foster environmental protection.

Pendahuluan

Pada Laut Timor, dasar laut yang dangkal dimana merupakan suatu lanjutan dari Benua Australia di bagiab Utara yang menjorok curam ke Palung Timor. Pada lokasi tersebut terdapat sederetan endapan karbonat yang dangkal dan muncul dari kedalaman antara 200 - 300 meter sampai 20 - 30 meter dibawah permukaan laut. Endapan tersebut adalah endapan-endapan terendam yang sebelumnya tidak dipetakan, dan dinamakan Beting Big Bank. Daerah tersebut adalah daerah yang unik baik dipandang dari segi geomorfologi maupun dari segi geopolitik. Letak daerah yang sekarang disebut sebagai 'area jurisdiksi bersama' seperti tercantum didalam Perjanjian Batas Laut antara Australia dan Indonesia tahun 1997. Selanjutnya, Lingkungan Fisik dapat diuraikan menurut karakter fisik pada daerah tersebut secara lengkap.

Endapan dangkal tersebut terendam pada suatu lingkungan kelautan yang membentuk ekosistem dengan lingkungan habitat bagi sejumlah komunitas. Ekosistem ini berbeda jauh dengan yang diketemukan di air yang lebih dalam yang mengelilingi endapan tersebut. Sebagian penyebab dari hal tersebut di atas adalah adanya penetrasi sinar matahari ke dasar laut serta diakibatkan oleh pergerakan zat-zat makanan yang dibawa oleh arus yang berpusar mengelilingi endapan reef (Bank) di dasar laut dimana komunitas bentik bertumbuh dengan subur pada endapan tersebut. Selanjutnya, Lingkungan Biologis dapat diuraikan secara lengkap dengan bermacam-macam ekosistem dan komunitas biologis yang dapat diketemukan di daerah Beting Big Bank dengan dinyatakan dalam suatu diskusi tentang karakteristik biologi dan ekologi mengenai komunitas tersebut. Metodologi survey dan analisa kwantitatif dari kelompok-kelompok bentik yang utama juga akan dibahas pada makalh ini.

Sedang pada bab terakhir akan ditinjau dan dibahas secara luas mengenai Lingkungan Sosial di daerah tersebut. Dalam hal ini, pembahasan akan mencakup diskusi tentang perikanan dan pembuatan dokumentasi tentang riset yang ekstensif, dan komunikasi secara lisan dengan otoritas setempat serta masyarakat nelayan, dan juga adanya studi sosial akan dilakukan di Indonesia sebagai bagian dari Analisis Mengenai Dampak Lingkungan Hidup (Amdal) untuk Pengembangan Minyak di lapangan Elang. Adapun tujuan dari studi sosial ini adalah untuk menentukan baik jenis kegiatan perikanan maupun rute-rute penangkapan ikan di daerah tersebut dan tempat tujuan yang digunakan oleh nelayan-nelayan tradisional serta dampak pemgembangan dan dampak pengangkutan minyak atas lingkungan mayarakat nelayan tersebut. Faktor-faktor ini dianggap mempunyai dampak langsung terhadap lingkungan dan ekosistem di daerah Beting Big Bank.

Selanjutnya tentang kegiatan perikanan dan pengangkutan pada daerah tersebut juga suatu kegiatan aktifitas pengeloaan minyak pada daerah lepas pantai. Selama lebih dari 20 tahun, aktifitas eksplorasi dan produksi minyak serta gas telah dilakukan di daerah Laut Timor, termasuk daerah yang mengelilingi Beting Big Bank. Melanjuti Perjanjian Celah Timor antara Indonesia dan Australia pada tahun 1989, yang menyetujui gabungan eksplorasi dan produksi hidrokarbon termasuk di daerah batasan yang belum terselesaikan, dimana kegiatan eksplorasi dipacu sehingga dapat diketemukan sejumlah prospek sumber hidrokarbon.

BHP Petroleum, sebagai perusahaan eksplorasi yang aktif di daerah tersebut, telah melakukan penyelidikan dasar mengenai lingkungan daerah itu untuk menunjang eksplorasi dan usul-usul program pengembangannya. 'The Australian Institute of Marine Science' (AIMS) telah membantu BHP Petroleum didalam merancang survey dan menginterpretasikan kumpulan data dari habitat bentik.

Studi-studi dasar ini mencakup:

- 'Bathymetriks' (pengukuran kedalaman) survey yang lebih akurat untuk menentukan geomorfologi dari endapan-endapan itu.
- Mengumpulkan data dari 'side-scan sonar' (alat pengamat yang menggunakan sonar) untuk menginterpretasi ciri-ciri lapisan dasar dan menyiapkan peta dasar mengenai habitat.
- Survey dari Kendaraan Kontrol Jarak Jauh (ROV) untuk memastikan habitat-habitat yang diduga ada, dan untuk menentukan penyebaran dan komposisi spesisnya.
- Contoh dari 'grab' (mengambil contoh tanah) dan 'drop-core' (alat yang menancapkan tiang besi ke dalam tanah dan mengumpulkan contoh tanah yang menempel di tiang tersebut) untuk mengkaliberasi dan mengkonfirmasikan secara pasti dengan mengkombinasikan hasil pemotretan oleh ROV, dan menyediakan material untuk analisa secara kimiawi dan fisika.
- Penyebaran pengukur arus, untuk membantu didalam pembuatan suatu strategi manajemen mengenai pembuangan dari kotoran pemboran, dan untuk perencanaan kemungkinan tumpahan minyak.
- Contoh air untuk menentukan jumlah produksi dan komposisi dari plankton dan mikrorganisme.

Peta - peta ini mewakili penggabungan dari bermacam-macam studi dan laporan yang berasal dari program studi lingkungan secara individu antara 1995 - 1996, juga merupakan suatu bahan riset tentang bermacam-macam komunitas biologi yang diketemukan. Usaha bersama dilakukan oleh BHP Petroleum dan AIMS untuk menindaklanjuti tentang analisa hasil dari penyelidikan di lapangan serta untuk mencoba menarik kesimpulan berdasarkan pengetahuan lingkungan yang ada sekarang. Tujuan utama dari proyek ini adalah membantu pengembangan suatu strategi yang memperkecil dampak lingkungan hidup dari aktifitas-aktifitas eksplorasi dan produksi hidrokarbon. Peta - peta tersebut akan memberikan kemudahan pada masyarakat luas untuk menjangkau penemuan prospek hidrokarbon dan BHP bertekad untuk lebih mendalami dampak lingkungan hidup di sekitar perusahaan beroperasi serta berkeinginan untuk bekerja sama dengan pemerintah dan masyarakat setempat dalam pemeliharaan serta perlindungan lingkungan hidup di sekelilingnya.

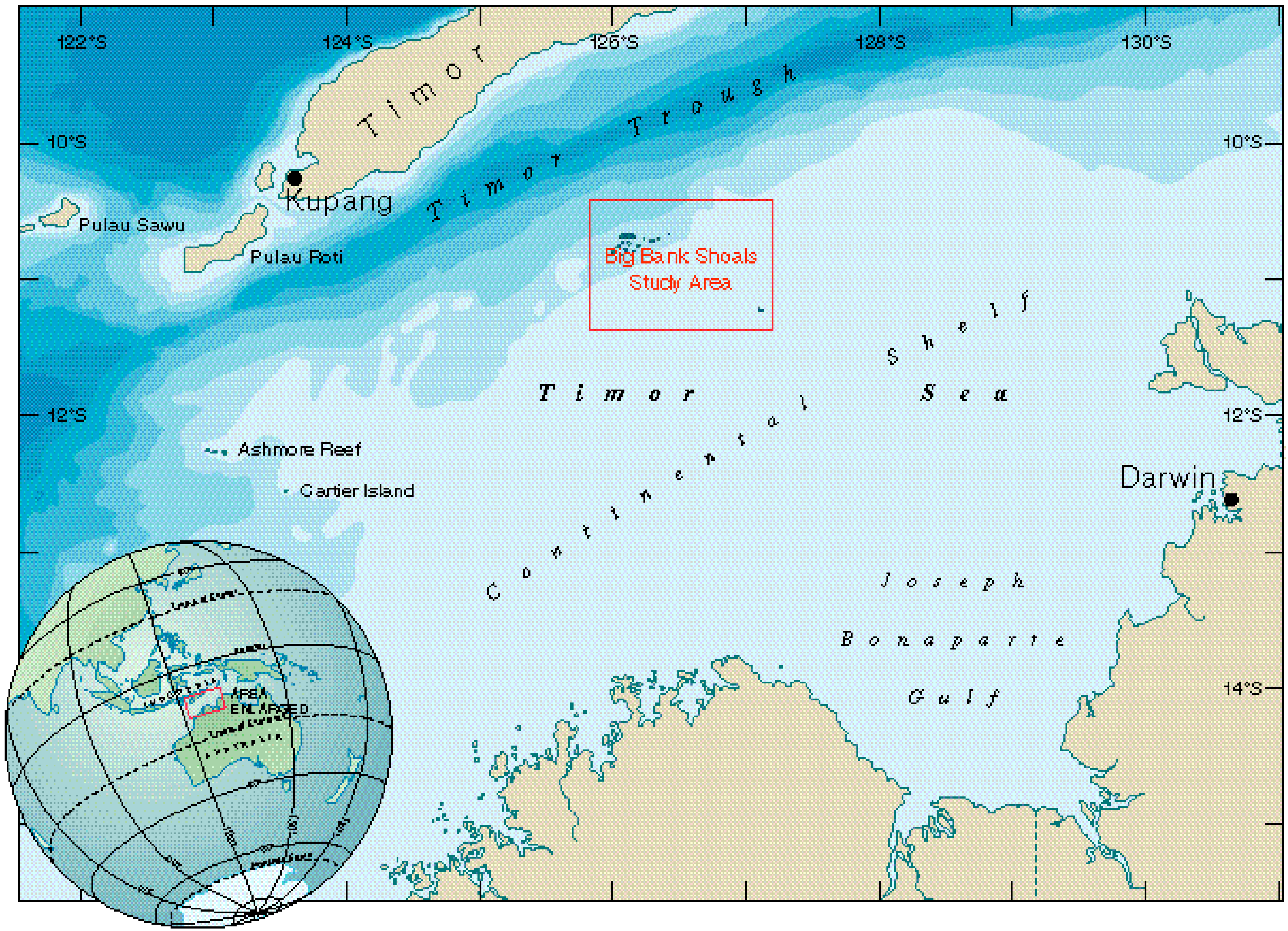


Figure 1. Map of the region showing the area of study.

Physical Environment

Edward Pinceratto

This section deals with the physical nature of the region, including the geological history, geomorphological features, climate and oceanography of the area.

The physical environment

The Timor Sea, located off the coast of northwestern Australia, broadly separates Australia from the Island of Timor, and covers the Sahul Shelf, the Shelf edge and the Timor Trough (Figure 1). These features are the surface expression of the complex geology of the area, with a history of rifting at various times from the late Devonian to the Jurassic and more recent modification by the collision between the Australian and Eurasian plates. The tectonic history of the area has caused the shoreline to change significantly over geological time. Evidence of this is clearly seen in the present morphology of the sea floor.

This *Atlas* focuses on a group of submerged banks, known as the Big Bank Shoals. These lie between Karmt Shoals and Echo Shoals, stretching for approximately 50 km in a NE-SW direction along the edge of the Sahul Shelf. They comprise some 13 significant submerged banks, ranging in size from 0.05 km^2 to 40 km^2. They emerge from a water-depth of 200 to 300 metres and rise steeply to within 16 to 30 metres below the water surface (Figure 2).

The Sahul Shelf - geomorphology and palaeogeography

The Sahul Shelf is a broad, shallow platform off the northern Australian coast, ranging from 300 to 500 km in width, and is considered to be a recently drowned part of the Australian continent. It has been established that as recently as 18,000 years ago, most of the Sahul Shelf was exposed. Shoreline positions have been identified in locations which now lie 100 to 140 metres below sea level. Extensive palaeo-river channels, some up to 150 km long and 5 km wide, connect the Bonaparte Depression to the old shoreline. These channels are up to 240 metres deep (Figure 4). This suggests that extensive sub-aerial erosional processes, probably dominated by fluvial systems, formed as a result of uplift of the Shelf due to the plate collision to the north. The Bonaparte Depression, located to the southeast of the Big

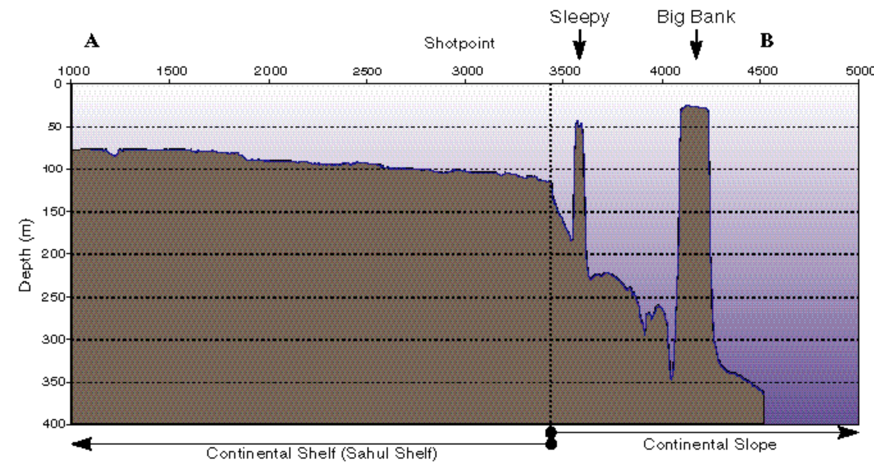


Figure 2. Cross-section of the Shoals region showing the Continental Shelf and two banks (vertical exaggeration = 300).

Bank Shoals, is believed to have formed an estuarine embayment or a shallow lake with depths of 18 to 28 metres (Lavering, 1993). Between 15,000 and 13,000 years before the present day, a rapid rise in the sea level inundated most of the Sahul Shelf.

Presently, water-depth on the Sahul Shelf ranges from 50 to 120 metres. It drops sharply to 3,000 metres in the Timor Trough, which runs parallel to the Island of Timor. At the outer edge of the Sahul Shelf lies a series of submerged carbonate banks. They are thought to represent drowned carbonate formations which formed a string of islands seaward of the palaeo-coastline, and which have been unable to keep pace with sea level rise in the past 20,000 years (Lavering, 1993).

Various theories exist for the origin and evolution of these Shoals. One possible origin is that they represent drowned platforms, after subsidence or sea level rise exceeded upbuilding. The platforms were submerged below the euphotic zone, terminating rapid production and accumulation of carbonate by photosynthetic organisms (Kendall and Schlager, 1981).

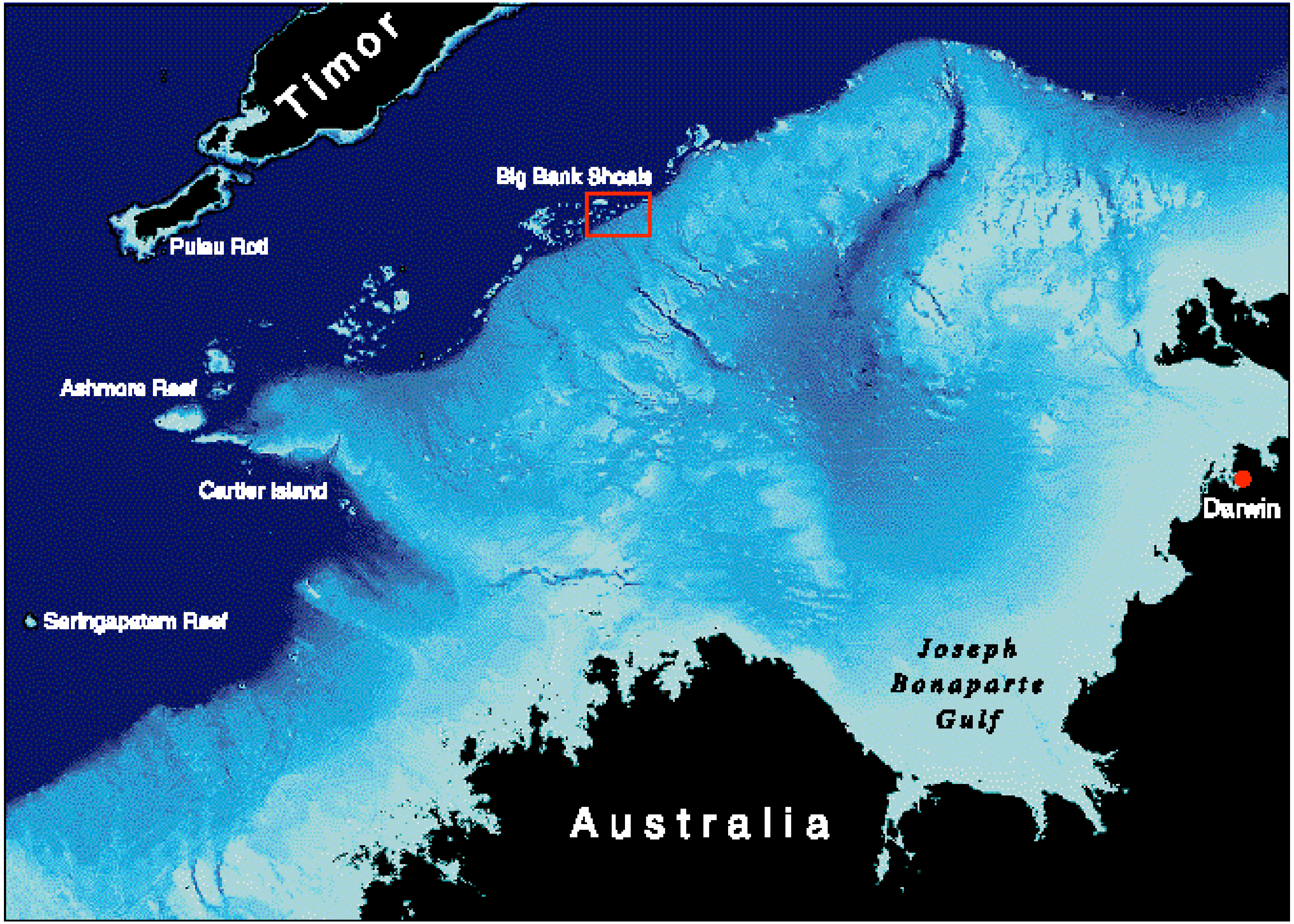


Figure 3. The Timor Sea region showing the Big Bank Shoals (satellite imaging map provided by Australian Geological Survey Organisation).

The euphotic zone extends down to 100 metres, but may be as little as 30 metres in basins where fine grained carbonates or clastics are abundant. During drowning, numerous isolated build-ups may have developed on the deeply submerged platform. These consist of narrow pinnacle reefs to broad shelf-rimmed banks or 'shelf atolls' and down-slope banks (Klovan, 1974; Read, 1985).

During rapid sea level rise, these banks may have undergone three phases of accumulation:

- a lag phase, during which the accumulation lagged behind the rising sea level, and deeper water biotas were established, such as sponges and branching corals. (e.g. Sneezy, Wicked and South Bank).
- a catch-up phase, when the upward growth exceeded the sea level rise, and a shallow sequence developed. (e.g. hard and soft corals at Kepah, Kepting and Tiram).
- a keep-up or tracking phase, when the build-up kept pace with relative sea level rise, and the substrate was colonised by communities best adapted to their relative static water-depth. (e.g. the *Halimeda* banks such as Big Bank, Snow White, Happy, Grumpy and Udang).

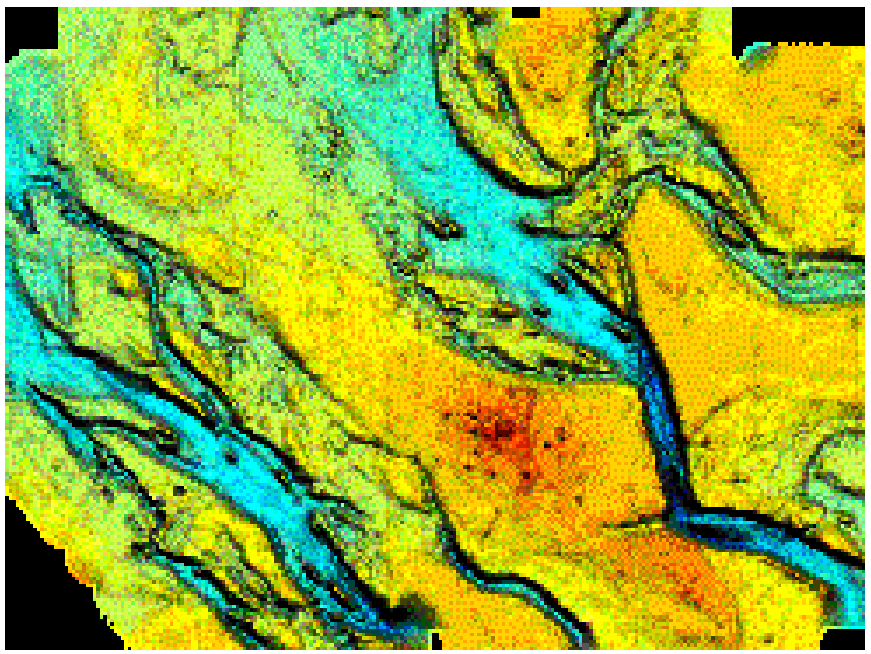


Figure 4. Map of Continental Shelf showing palaeo-river channels.

Another possible origin for these banks is carbonate accumulation associated with hydrocarbon seeps. Fault systems, up which hydrocarbons (oil and gas) may have seeped, are known to occur along the shelf edge in the vicinity of the Shoals. Research indicates that microbial utilisation of hydrocarbons creates by-products (carbon dioxide and bicarbonate) that catalyse precipitation of authigenic carbonates, such as aragonite and dolomite (Roberts, 1992). These products form the basis of the hard substrate required for colonisation by reef-building and bioherm-building organisms. Elevated hard substrates provide ideal habitats as they provide substrate to which organisms can adhere and expose filter-feeders to the maximum amount of passing nutrients.

Coring at Big Bank to a depth of 55 metres showed an extremely high *Halimeda* rubble content and a marked absence of terrigenous sediments. This indicates the in situ growth of these banks by accumulation of *Halimeda* skeletons, which has continued since the late Pleistocene.

Climate

The climate of the region is tropical with two distinct seasons: the Northwest Monsoon and the southeast monsoon. The northwest monsoon season occurs from November to March (i.e. the southern summer) and the southeast monsoon occurs from April to September (i.e. the southern winter). Brief transitional periods occur in April and September/October.

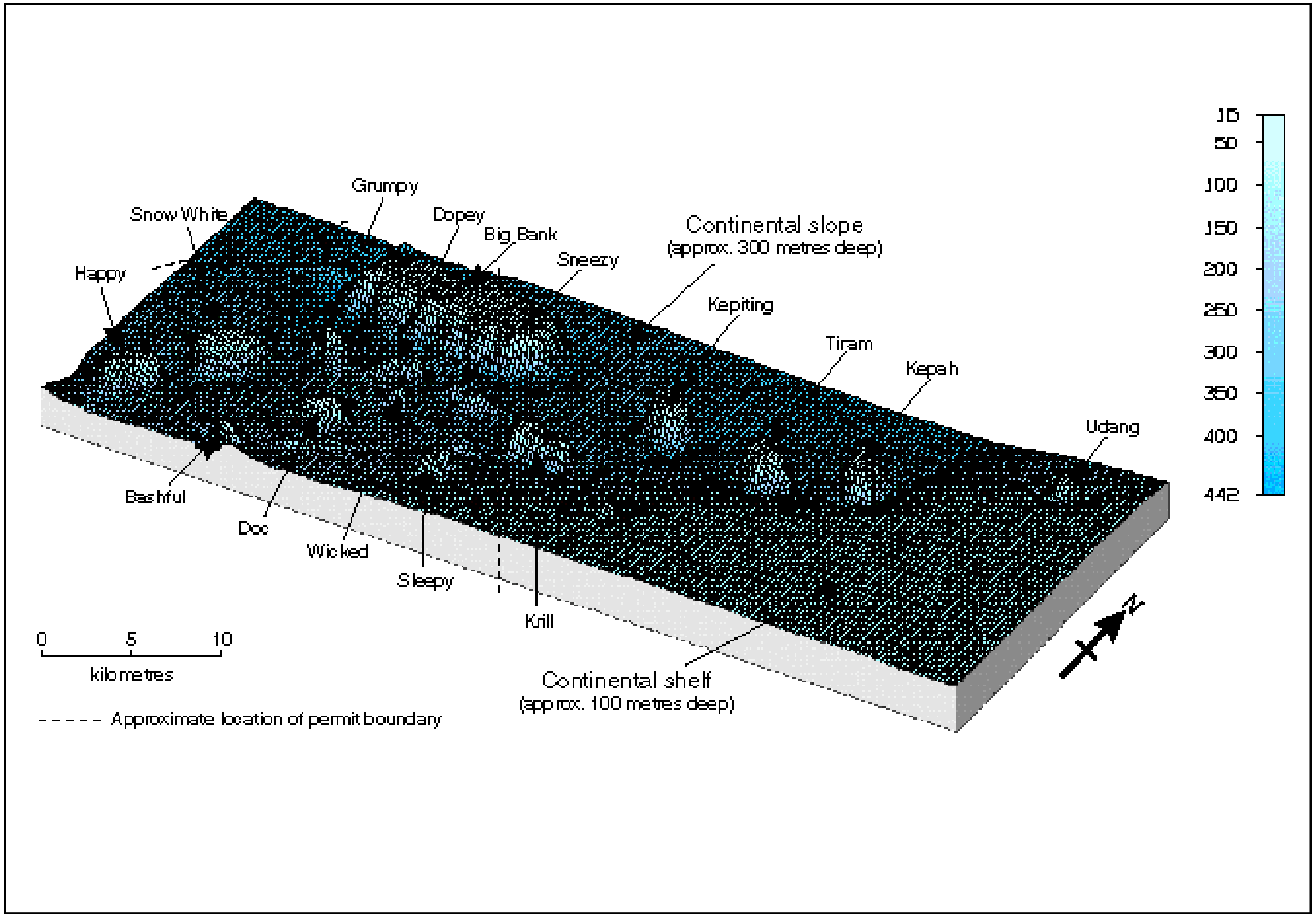


Figure 5. A three-dimensional map of the Shoals showing the individual banks.

Rainfall

The rainfall within the region is monsoonal, with high rainfall associated with the Northwest Monsoon and low rainfall associated with the Southeast Monsoon. Heavy rainfalls are also associated with tropical cyclones and thunderstorm activity.

Cyclones

Tropical cyclones form south of the equator, in the general area of the eastern Indian Ocean and in the Timor and Arafura Seas. An analysis of the Bureau of Meteorology cyclone records, dating back to 1964, indicates that most cyclones approach the area from the east-northeast. Since 1964 an average of 2.6 cyclones per year have occurred in the region bounded by 5^{o}S to 16.5^{o}S and 121^{o}E to 132^{o}E.

The majority of cyclones occur between December and April. Most (75 percent) of these cyclones are not fully mature, having an estimated wind speed of less than 80 km/hr. Severe cyclones, with wind speeds exceeding 100 km/hr occur, on average, once every 2.6 years.

Air temperatures

The average mean air temperature is about 28^{o}C and there is little variation in this. The variation recorded at the Jabiru Oil Field (1983-1993) was from 28.3^{o}C in summer to 27.0^{o}C in winter.

Relative humidities

The highest humidities occur from October to May, corresponding to the Northwest Monsoon season. Lower humidities exist during the Southeast Monsoon season because the air mass is of continental origin.

Winds

Two distinct wind regimes are associated with the monsoons; a steady southeasterly airflow originating over the Australian mainland during the southeast monsoon, and a steady, moist, west to northwest wind during the summer months or northwest monsoon.

As noted above, tropical cyclones occasionally occur during the northwest monsoon period and result in short-lived, severe storm events, often with strong but variable winds. The mean wind speed recorded at the Jabiru Oil Field (1984-1990) was 4.8 ms^{-1} during the southeast monsoon period and 4.3 ms^{-1} during the northwest monsoon period.

Oceanography

The most extensive site of oceanographic investigation in the Timor Sea is the area around the BHP Jabiru Oil Field, located southwest of this area, and much of the regional data presented below are from these studies. BHP also commissioned studies of the currents at the Elang Field, located to the southeast (BHPP, unpublished data), and these findings are also summarised below.

Water temperature

Seawater temperature profiles have been measured over the Continental Shelf at South Bank, Elang and Jabiru Oil Field. The surface waters at South Bank are similar to those at Elang with well mixed surface waters with temperatures of 30^{o}C and bottom waters of between 27^{o}C and 30^{o}C. Bottom temperatures are slightly lower at Elang (between 26^{o}C and 27^{o}C). This reflects the shallower depth at South Bank and also the mixing due to the interaction between the thermocline and the slope of the bank. The temperature profile at Elang is similar to that at Jabiru.

During summer there is a weak thermocline with a decrease in temperatures of 3° to 4°C from the warmer surface waters to the cooler mid-depth to bottom waters. In winter, the upper 70 metres of water are isothermal, with no significant variation in the vertical temperature profile. Earlier studies, undertaken by the Commonwealth Scientific Industrial Research Organisation's (CSIRO) oceanographic studies (see Cresswell *et al.*, 1993), found a similar vertical pattern, suggesting that this is characteristic of shelf waters.

The waters over Big Bank are also well-mixed with surface temperatures of about 30°C. The temperatures were found to be variable and oscillate between 27°C and 31°C. Bottom-water temperatures were also found to oscillate between 23°C and 29°C.

Temperature profiles taken in deeper waters off the Shelf, at the Laminaria field and south of Big Bank, suggest similar surface temperatures (27°C to 31°C) and cooler bottom temperatures (22°C to 25°C, and down to about 10°C). This reflects the greater depths (>150 metres) at these sites.

Waves and tides

Total waves are composed of sea-waves, locally generated in response to wind conditions, and swell-waves that result predominantly from storms in the Southern Ocean or southern portion of the Indian Ocean. High sea-wave conditions will normally occur within 250 km of tropical cyclones and swell-waves may occur at further distances.

Tides in the Echo Shoals area, the northeast region of the Sahul Shelf, are semidiurnal, with a typical tidal range of 4 metres at springs and 1.8 metres at neaps (Australian National Tide Tables—Echo Shoals). Tidal transformations for the Laminaria location indicate a 10% increase in amplitude, and a phase-lead of 40 minutes (BHPP, unpublished data). Tidal currents are expected to flow east-northeast, and ebb west-southwest, in the upper 100 metres of the water column, while flooding southeast, and ebbing west-northwest in the lower portion of the water column (Pinceratto and Oliver, 1996). Tidal current speeds in the order of 0.6 ms^{-1} (springs), and 0.2 ms^{-1} (neaps), are anticipated for the region.

Currents

Surface currents are expected to reflect seasonal wind regimes, with easterly to northeasterly currents in summer, and in winter westerly to southwesterly currents. Local wind driven surface currents may attain speeds of 0.6 ms^{-1} during monsoonal or Trade Wind surges. More typical speeds would be in the range of 0.2–0.3 ms^{-1}. The Timor Sea region is influenced by the Pacific-Indian Ocean Throughflow, which contributes to the westward flowing South Equatorial Current (between 8° and 15° S latitude), and floods the North-West Shelf with relatively warm, low-salinity water. This current may introduce a small (0.1 ms^{-1}) southwesterly component to the current regime in the Karmt Shoal area. The Throughflow appears to be subject to the pronounced inter-annual variations of the El Niño-Southern Oscillation (ENSO) events.

Biological Environment

Luke Smith, Craig Humphrey, Richard Hortle, Andrew Heyward and Darren Wilson

This section deals with the biological communities of the Shoals. Video cameras were used to survey the animals that live upon the sea floor, while grab samples were taken to look at the communities that live within the sea floor sediments. Fine meshed nets were used to sample the plankton assemblages found in the waters surrounding the banks.

Epibenthic communities of the Big Bank Shoals

Surveying methodology

Many of the major advances in our knowledge of the marine benthic environment have stemmed from technical innovations which have reduced the difficulties inherent in observing, counting and measuring the underwater world. Until the 1950s, such advances centred on the technological improvement of ships with more refined equipment, such as grabs, trawls and sleds. These tools enabled scientists to collect samples from the sea floor and to bring them back to the surface, well beyond the depths normally observable from the surface. However, this type of remote sampling can often leave scientists relying heavily on inference to build up a picture of the marine community which they are studying. In many ways it is analogous to describing the nature of a forest or city from a subset of aerial photographs. The advent of self-contained underwater breathing apparatus (SCUBA) provided a tool to overcome this tyranny of depth. In recent decades it has permitted a great deal of first-hand observation of underwater ecosystems.

The majority of diving-based research has occurred in habitats less than 30 metres in depth and has permitted and required new sampling protocols, many of which are derived from terrestrial methods. The modern armoury of sampling tools and techniques have created a variety of options for scientific investigations in almost every type of marine habitat. Some, however, still prove problematic. Studying the submerged shoals of the Timor Sea presents several practical difficulties. Reef habitats are topographically complex and can be awkward to sample with equipment, such as grabs and trawls, since cables to the surface may snag. Furthermore, the remoteness of the area and the general depth of the shoals means that a diver-based sampling program would prove a major logistical exercise, well beyond the scope of general scientific diving undertaken in Australia to date. A solution was sought by combining elements of remote sampling techniques with diver-based approaches, using remotely controlled underwater video cameras simulating diver-held video line transects.

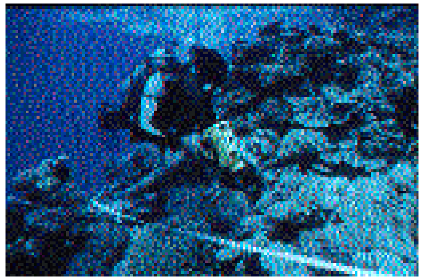
Evolution of the ROV video methods

Describing the living things attached to the sea floor poses sampling problems similar to those that ecologists encountered with terrestrial plant communities, such as forests. Faced with large and complex plant communities, botanists developed sampling procedures which were relatively rapid, yet provided a statistically meaningful measurement of abundance and diversity. One such approach, known as the line intercept method, was adapted for surveys of coral reef communities in the 1970s (Loya, 1976) and subsequently found general acceptance. It is now widely used in diver-based surveys of the marine benthos. The line intercept method usually uses calibrated tape measures laid directly on the seabed, which then permit a diver to record what is directly under it and what distance of tape lies over each type of benthic organism. Although a wealth of information can be collected, it is moderately labour intensive. It requires identification of the benthic organisms and direct recording of the data while the diver is underwater. A more recent modification of the line intercept approach has evolved with the development of compact, reliable underwater video cameras. This enables the diver to simply record the benthos under the line. The video tapes may then be analysed later in the laboratory in order to determine the abundance and diversity of the benthic life present along the transect. The greatest advantage of the 'video transect' approach is that many more line transect samples can be collected in the same amount of field time. This gain in efficiency makes extensive and comprehensive sampling of epibenthic communities more feasible.

Methodology

The use of video cameras to survey and monitor coral reefs, together with scientific assessment of the validity of such methods, commenced at the Australian Institute of Marine Science (AIMS) in 1987 (see Carleton and

Done, 1995). In 1992, AIMS initiated a comprehensive long-term monitoring program of the Great Barrier Reef (GBR), (which was expanded to include numerous Western Australian reefs in 1994). The most appropriate monitoring technique for acquiring information in the field over such a broad geographic scale, was the video transect approach. In order to deal with the very large number of video transects that this initiative began to generate, AIMS developed specialised computer software (Bainbridge, 1995) that streamlined both video analysis and database management.



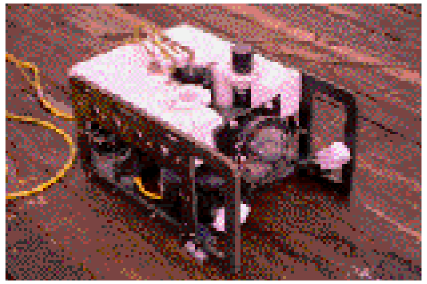
An AIMS scientist videoing a coral reef on the Great Barrier Reef (AIMS).

In 1996, when the petroleum industry approached AIMS concerning methods to survey a range of habitats in the Timor Sea, diver-held cameras were not a feasible option, since diving has limitations in terms of depth and duration. Consequently, video technology was developed to allow remotely operated vehicles (ROVs) to replace divers.

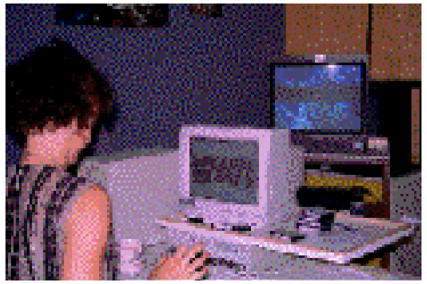
Sampled area and sampling region

A total of 205 video transects were undertaken on or around the Big Bank Shoals. These transects were 50 metres in length and ranged in depth from shallow banks of 16 metres to depths of 300 metres. At the beginning of each transect the ROV recorded a panoramic 360^{o} view, to show the general habitat. Videoing then commenced, with the ROV moving slowly along the transect. The camera was held perpendicular to, and 25-30 cm above the substratum. On completion of the transect, a close-up video of the epibenthic community was obtained, which could then be used for identification purposes.

The abundance (percentage cover) of benthic organisms and other benthic categories (e.g. sand, mud, rock etc.) was quantified using a point sampling technique (Carleton and Done, 1995). While looking at the video, the tape was paused at each transect, approximately 50 times at regular intervals. The identity of the organism, or type of substratum lying beneath each of five fixed points marked on the video monitor, was recorded using an assigned identifying code (Oliver *et al.*, 1995). A total of 48,000 sample points on 205 video transects provided the quantitative data presented in this *Atlas*. Identifying codes assigned to each point incorporate information, such as benthic group and life-form as described in Christie *et al.* (1995). All organisms were identified to the most accurate level of taxonomic detail achievable by the observers.



The remotely operated vehicle (ROV) used to survey the Big Bank Shoals (BHPP).



A trained marine biologist analyses video transects (AIMS).

Staff of the Institute used the AIMS computer software package AVTAS (AIMS Video Transect Analysis System) while undertaking all quantitative video tape transect analysis and data entry. The development and application of this software (Bainbridge, 1995) permitted the integrated computer control of the video playback and freeze-frame, together with menu-prompted direct data entry of all benthic categories, into a relational database. Data were then extracted from this database, for subsequent analysis, on the basis of abundance and diversity.

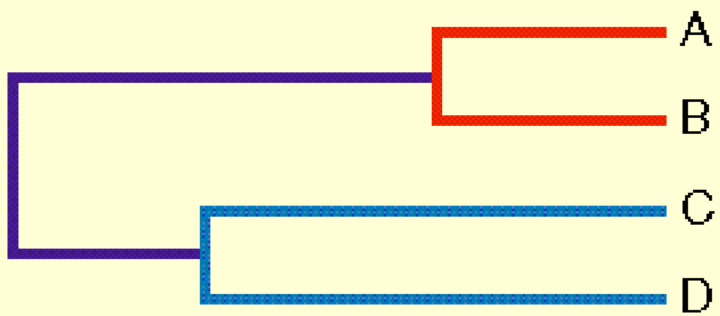
Classification of banks using video data

Field techniques, video analysis protocols and data formats were kept consistent throughout the ROV surveys. This mass of information, collected in a systematic fashion from all banks, provided a unique opportunity to look for patterns and similarities at a range of spatial scales. Multivariate analysis, in the form of cluster analysis, was used to reveal spatial variability of the benthic communities of the Big Bank Shoals.

Cluster analysis is a technique that groups or clusters sites together based on the diversity and abundance of selected benthic categories. The clusters are shown graphically as a branched tree diagram or dendrogram (see *What is a dendrogram?* on this page). A number of major benthic categories were used in the cluster analysis. These categories were *Halimeda*, hard corals, the soft coral *Xenia*, other soft corals, encrusting sponges, other sponges, macro-algae, and other organisms. When a cluster analysis of the entire data set was completed the banks were found to cluster into four broad groups, which reflected four dominant types of epibenthic communities (Figure 6). The largest group comprised banks where a significant presence of the calcareous alga, *Halimeda*, and encrusting sponges, were the common feature. The three other types of habitats distinguished were coral-dominated banks, deeper water filter-feeding communities and soft-bottom, Continental Shelf communities. The identification of these four types of communities provides the basis for the structure used to present the results in subsequent sections of this *Atlas*. Information has been organised into four sections, covering *Halimeda*, coral, filter-feeders and Continental Shelf Communities.

What is a dendrogram?

A dendrogram is a graphical representation of a cluster analysis showing the relationship between a number of groups. It can be thought of as a hierarchical tree, with groups on the same branch more closely related than groups on other branches. For example, in the figure below, A has greater similarity to B than either C or D. Furthermore, the shorter branch length of A and B (compared to C and D) indicates that the former show a greater similarity to each other than the latter.



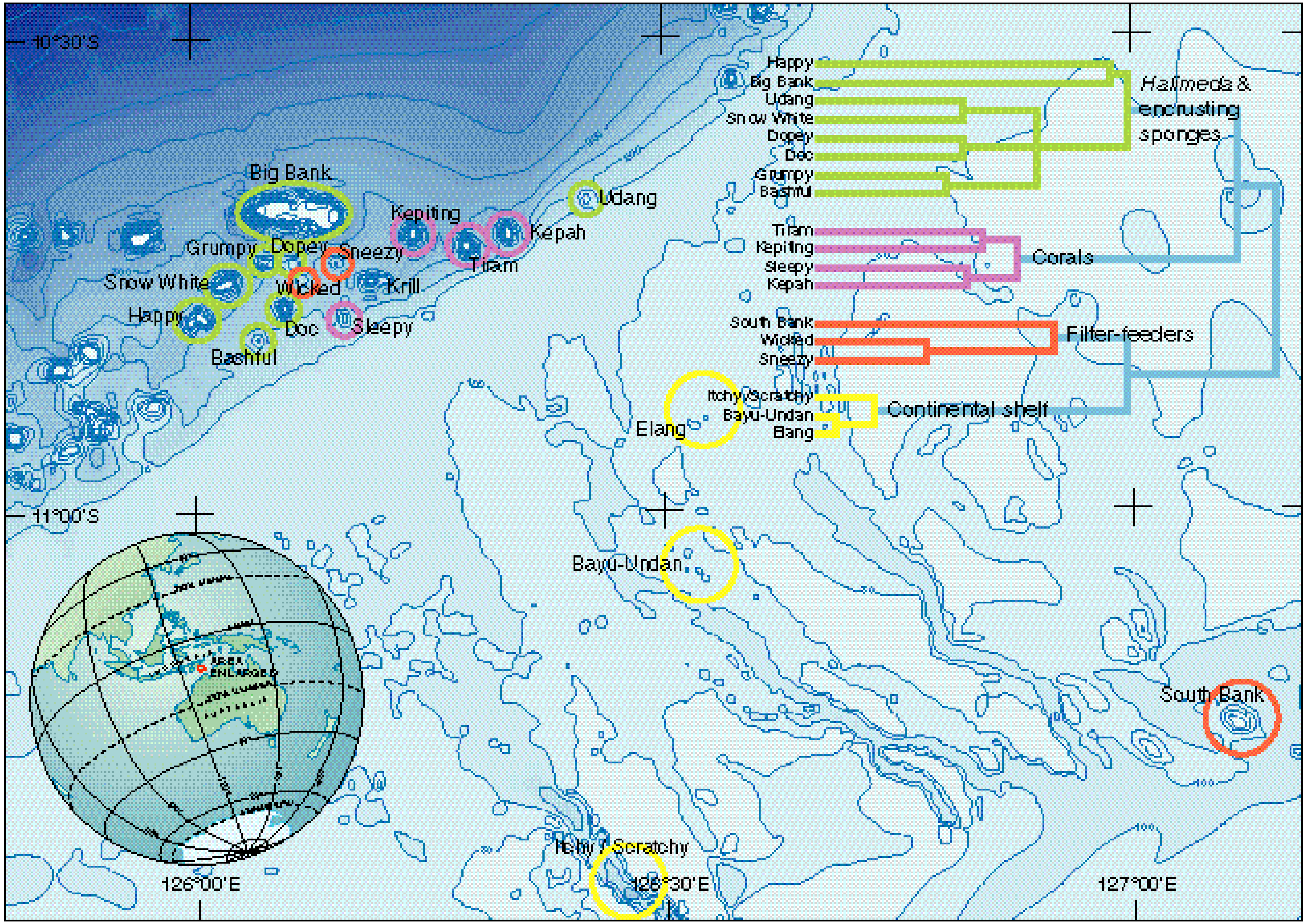


Figure 6. Map of the Big Bank Shoals with a dendrogram showing the relationship between the banks.

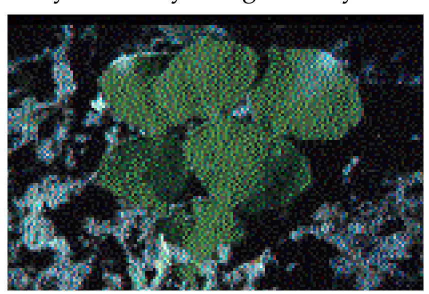
Halimeda ecosystems

Many *Halimeda* banks at the Big Bank Shoals are characterised by moderate to high coverage of the calcareous algae, *Halimeda*. These are Bashful, Big Bank, Doc, Dopey, Grumpy, Happy, Snow White and Udang. In various places, the *Halimeda* occurred in thick, almost meadow-like patches with little else present. However, sponges, soft corals and hard corals were common. Frequently the surface of the *Halimeda* plants supported encrusting sponges and a diverse collection of other organisms, such as bryozoans, foraminifera, tunicates and fishes. On these banks large amounts of calcareous sediment, consisting mostly of *Halimeda* skeletal material, were visible in unoccupied patches of the substrate.

Halimeda appears to be an extremely important component of the Timor Sea ecosystem. Geological evidence suggests that *Halimeda*-derived carbonates have played a key role in building the banks themselves and that these algal communities rank amongst the highest in terms of carbon fixation. The following section outlines the general biology and ecology of *Halimeda*, followed by the survey results from the eight banks which share an abundance of this alga as a common feature.

The general biology of *Halimeda*

Halimeda is a genus of macroscopic, calcareous, green algae belonging to the order Caulerpales (Chlorophyta). They are easily recognised by their articulated, plate-like and calcified segments. These are joined together by small, uncalcified nodes into branching chains, to produce a more or less bushy plant. Thirty species of *Halimeda* have been identified in marine science studies, and have been classified according to the shape, size and internal structure of their segments.



A *Halimeda* plant (AIMS).

A *Halimeda* plant surrounded by dead *Halimeda* segments (E. Drew).

Halimeda are among the most abundant seaweeds in tropical habitats and are of global importance. They are substantial components of many reef ecosystems. *Halimeda* has generally been considered as a plant of sand substrata, growing most commonly in shallow, lagoonal environments. Some species do indeed grow in sand, where they are fixed by a relatively large holdfast of 13 cm or more in length. However, a large proportion have very different habitats and growth forms (Figure 7). Several species are attached by a single, small holdfast and grow on rock surfaces or hang in large draperies from rocks. These may sometimes appear as if they also grow in sand, as the rock itself may be buried in the sediment. A third group of species sprawl across rock, sand or coarse algal and coral debris. They attach by thread-like filaments produced at intervals along

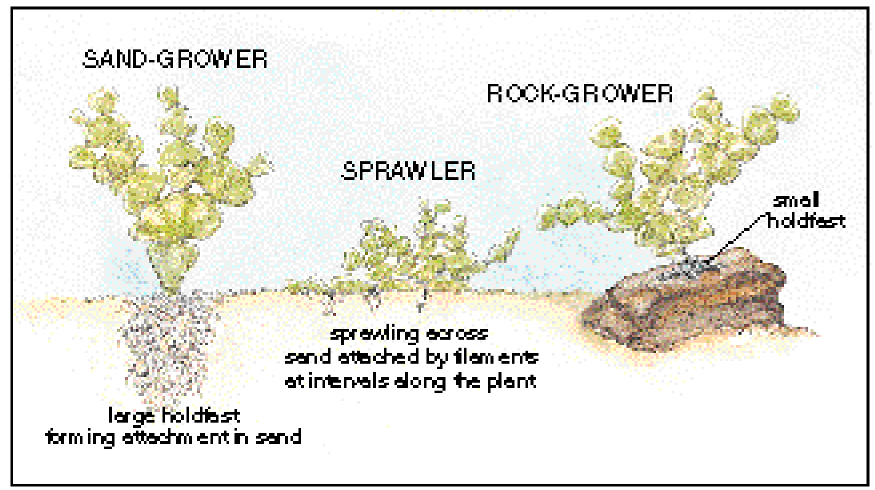


Figure 7. *Halimeda* growth forms and holdfast systems (modified after Hillis-Colinvaux, 1980).

the plant. *Halimeda* may grow in depths up to 100-150 metres, where light levels are calculated to be only 0.05-0.08 percent of the surface intensity (Hillis-Colinvaux, 1980). Since most other algae are restricted to only one of the above substrata, and to relatively shallow waters, the ability of *Halimeda* to grow in a very wide range of habitats is notable. This capability undoubtedly contributes to the considerable success of the genus on tropical reefs.

A *Halimeda* plant showing the calcified segments (E. Drew).

Growth

A *Halimeda* plant showing the calcified segments (E. Drew).

Growth of *Halimeda* involves the development of new segments as well as the loss of old segments, shed somewhat like leaves from deciduous trees. The development of a new segment is signalled by the appearance of a white, conical protrusion from the apex of the last segment. Within 24 hours this white protrusion has grown into a fairly complete, although slightly spongy and somewhat greenish, segment. Calcification of the new segment begins after approximately 36 hours. The pattern of a segment, its length and width, are fixed within the first couple of days. Subsequent development is mostly in the calcification of the segment, with some change in thickness, depending on the species and the segment's location within the thallus. It can be seen that the oldest leaves will be found closest to the stalk or holdfast.

New segments may develop daily, or every second day on each branch, so that many segments can be added in a relatively short time. Drew (1983) showed that a single plant could produce 359 new segments in 68 days. Such rapid growth can be related to the amount of sediment that *Halimeda* is able to produce.

Sediment formation

A *Halimeda* segment (AIMS).

There have been a number of studies investigating the importance of *Halimeda* in sediment production. Figures range from 4.2 g of calcium carbonate m^{-1} $year^{-1}$ in Florida (Bach, 1979) to 2,234-3,000 g of calcium carbonate m^{-1} $year^{-1}$ on the Great Barrier Reef (GBR), (Drew, 1983). The larger value represents an enormous production of carbonate sediments and would suggest that *Halimeda* can be a major contributor to reefal structures.

The first indications of the importance of *Halimeda* in producing carbonate came from cores taken at Funafuti Atoll in 1904. A core drilled into the reef to a depth of 339 metres was mostly composed of *Halimeda* and other calcareous algae. In the lagoon area of the reef, 80 to 90 percent of the material in the first 18 metres was *Halimeda* debris.

The importance of *Halimeda* in sediment production and reef formation was confirmed by Maxwell (1968), working on the GBR. He showed that 10 to 30 percent of the reef surface was composed of *Halimeda* rubble, 5 to 65 percent of inter-reef sediments were *Halimeda* derived and that, in the Swains region, *Halimeda* frequently created over 65 percent of the sediment.

Reproduction

Halimeda can propagate very successfully through vegetative cloning, which enables copies of the same plant to be produced. Many species can produce runners or filaments. These filaments can grow up to 20 cm long, spread laterally through the substrate, then push up to form new segments. These new buds can quickly grow new segments, sometimes at the rate of one a day per growing tip. Eventually the physical connections between the young and parent thallus are lost.

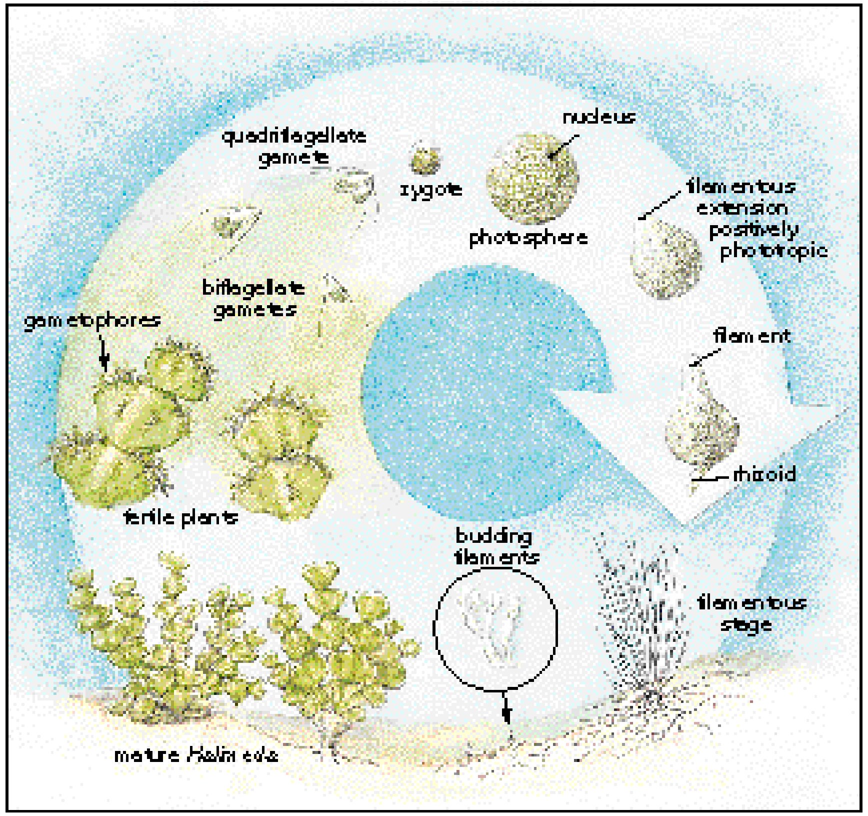


Figure 8. A generalised *Halimeda* life cycle.

Other variations of vegetative reproduction have been identified. Sprawling *Halimeda* may produce rhizoidal filaments between segments. These initially provide additional anchorage but they also facilitate division of the alga into separate thalli as the older segments of the branch die and drop off. This method of reproduction appears to be important in maintaining large patches of *Halimeda.* In addition to these more specialised modes, *Halimeda* may also survive and flourish after being fragmented by storms, waves or animals. Healthy branches, which have been separated from the main thallus, can develop holdfast systems. Under favourable conditions they can attach, become established and develop into complete thalli.

A *Halimeda* plant with gametophores (AIMS).

Sexual reproduction (Figure 8), rarely seen in *Halimeda* because it is a short-lived phenomenon, has recently been described for one species from direct observations in the field (Clifton, 1997). The process is brief, perhaps 36 hours from start to finish, and after spawning the thallus completely disintegrates. The spawning process is initiated after sunset. Overnight the plant becomes white with a number of green dots on the surface or around the edges of its segments. These green dots are gametophores and consist of filaments upon which are borne grape-like clusters of globular gametangia. Virtually the entire cell contents of a plant is diverted towards gamete production. Each gametangium contains hundreds of chloroplasts, nuclei, mitochondria and protoplasm. Just before dawn the following morning, the gametangial contents will have dissociated into gametes which are explosively released through special discharge papillae. This event leaves the gametangia empty, although a microscope shows them to be still intact. After the gametes have been released the thallus dies and quickly disintegrates. The dead segments are shed until, within two or three days, the plant has gone and the carbonate segments become part of the surface sediments.

Released gametes are highly motile and within a few minutes many will fuse with other gametes to form zygotes. Although zygotes have been observed to settle on solid substrate, or even the surface of spent plants, they develop only very slowly in the laboratory. Artificially raised zygotes have never been seen to develop beyond a small, filamentous plant, showing no signs of calcification or differentiation into the characteristic segments. There is still conjecture as to whether a mature thallus can grow directly from this filamentous structure or whether the organism has to pass through another phase before a mature plant is formed.

Recent observations have shown that sexual reproduction in *Halimeda* plants is to some extent synchronised (Clifton 1997, Hay 1997). Many individuals in a population may become fertile within a period of only a few days, and sometimes on the same day. Synchrony can be so exact that fertility events have been observed to occur simultaneously in the field and in a laboratory aquarium (Drew and Abel, 1988). Synchronised species, particularly the large-segmented ones, seem to be very seasonal and the entire population may effectively be replaced annually. Some species, however, appear to be more opportunistic, growing rapidly, and possibly with a life cycle of only a few months.

Herbivore avoidance

Halimeda are among the most abundant seaweeds in tropical habitats, yet they suffer low levels of consumption by the herbivorous fishes, even in areas of intense grazing pressure (Hay, 1981, 1984; Hay *et al.*, 1983; Littler *et al.*, 1983; Paul and Hay, 1986). The ability to survive in areas in which other seaweeds are unable, may be attributed to a suite of novel defences.

High levels of calcification, found in most species of *Halimeda*, has been proposed as a defence against herbivores (Ogden and Lobel, 1978; Lobel and Ogden, 1981). It is thought that calcification deters herbivory by making the algae harder and more difficult to bite or by diminishing the nutritional value, due to the presence of indigestible material (Hay, 1984; Duffy and Hay, 1990). Although some herbivores readily consume calcified tissues, calcium containing seaweeds are not preferred.

Halimeda also produces two chemicals which are believed to act in deterring predators; halimedatrial and halimedatetraacetate. Both of these chemicals have been demonstrated to deter feeding by tropical, herbivorous fishes in aquarium assays (Paul, 1985) and form an active defence in conjunction with calcification. Younger *Halimeda* plants and newly produced segments, which are not heavily calcified, contain halimedatrial, the more potent feeding deterrent, while older segments tend to contain the less potent halimedatetraacetate (Hay *et al.*, 1988; Paul and Van Alstyne, 1988).

The Big Steal

There are a number of 'slug-like' gastropods, the ascoglossans, which have evolved a variety of unique and interesting adaptations. These gastropods have specialised radulae, a rasp-like organ, that they use for piercing and feeding on green algae, such as *Halimeda.* At least five species within the ascoglossan genus *Elysia* are reported to feed on *Halimeda* spp. These 'slugs' are able to ingest and then use algal chloroplasts, obtained from the *Halimeda*, to fix carbon through photosynthesis. The chloroplasts, once ingested, may remain functional within the animals for a period from 24 hours or less, to six weeks. In fact, it has been shown that the maximal net carbon fixation rate was higher for *Elysia tuca* than for *Halimeda discoidea* (Stirts and Clark, 1980). The carbon formed in this manner is used in the production of mucous. In addition, *Elysia* may take up defensive chemicals from *Halimeda*. The gastropods are able to slightly modify the halimedatrial and store it within their tissues for later use. When the *Elysia* are harassed, this modified compound is released within a mucous secretion and acts as a deterrent towards fish. Similar high levels of this compound are found in their egg masses. The behaviour of obtaining defensive chemicals from their food source is seen in a number of nudibranch species. Other sources of defensive chemicals include soft corals and sponges.

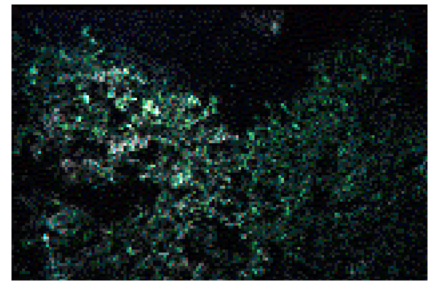
The impact of larger herbivores, such as fishes, on local populations of *Halimeda* is balanced by the ability of fragments to form rhizoids and grow into new plants. Targett *et al*. (1986) have shown that 40 percent of bites taken from *Halimeda incrassata* were rejected immediately, suggesting that the fish rapidly sensed the noxious chemicals and expelled the fragments without further chewing. Fragments as small as 15 mm^2, with damage to three sides, were able to produce rhizoids within three days (Walters and Smith, 1994). Moderate herbivory may increase the spatial extent of *Halimeda* beds through such fragmentation and dispersal.

Halimeda beds create complex microhabitats which provide refuge and food for a diverse range of invertebrates. The ravages of surface scraping predators are frequently visible as thin white lines meandering all over the segments. Much of this type of damage is attributed to a small, bright green, ascoglossan mollusc which may be attempting to harvest *Halimeda* chloroplast's for its own use (see *The Big Steal* box, page 23). *Halimeda* has the ability to avoid the loss of its photosynthetic chloroplasts, using a unique preservation mechanism, by moving them beneath the calcium carbonate skeleton at night. They are redistributed to undamaged surface areas the next morning.

The combination of chemical, behavioural and morphological defences, described above, make *Halimeda* one of the few algae that can persist in areas of intense grazing. Herbivory plays a major role in determining the distribution and abundance of seaweeds throughout the world. *Halimeda*'s ability to minimise losses to herbivores ensures that it is often able to thrive in areas where other algae are unable to maintain viable populations.

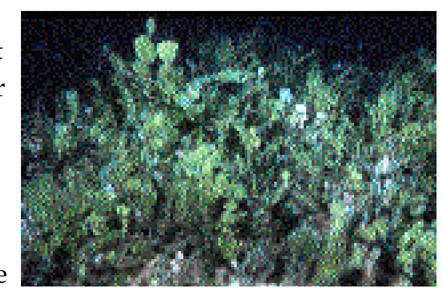
***Halimeda* communities, meadows and banks**

The ability of *Halimeda* to reproduce vegetatively and to minimise the effects of herbivory enable it to form, under favourable conditions, dense stands termed meadows. The low, lush vegetation of such meadows attracts an epibenthic fauna of molluscs, foraminiferans, bryozoans and other animals. Marshall and Davies (1988) have likened these areas to forest communities. The extensive holdfast systems of *Halimeda* plants, and other sedentary animals that are associated with them, serve to trap sediment produced within and transported to the meadows. This process stabilises the meadow, for much of the sediment produced remains amongst the biological community and is not swept off the bank into deep water. The ability to produce and accumulate carbonate sediment is a key attribute. These *Halimeda* communities have been described as vast 'carbonate factories' by Marshall *et al*. (1994) and have the ability to form geological structures, such as bioherms and banks.



A *Halimeda* bed (AIMS).

Bioherm is a term that was coined by Cummings in 1932 to describe reef-like structures that are *in situ* accumulations of organically derived carbonate. *Halimeda* bioherms have been observed on the Great Barrier Reef (Orme *et al*., 1978; Marshall and Davies, 1988), in the Java Sea (Phipps and Roberts, 1988; Roberts *et al*., 1988) and the Carribean Sea (Hine *et al*., 1988). Single bioherms may vary substantially in size but have been reported up to 150 metres long and 100 metres wide and slightly flat-topped. They are topped by a dense covering of *Halimeda* and associated fauna. Bioherms are likely to increase their profile as a meadow continues to retain carbonate it has created and sediments that are washed to it from elsewhere. There is evidence that *Halimeda* communities that persist over geologic time accumulate material to such an extent that prominent structures, such as banks, can result. The analysis of a core into Big Bank and its implications, in relation to the formation of banks, is discussed below.



A *Halimeda* meadow (E. Drew).

Halimeda banks of the Big Bank Shoals

The *Halimeda* banks were linked by extensive *Halimeda* beds on the bank plateaux, as a common feature of their epibenthic communities. *Halimeda* segments also dominate the sediments of these banks, which are usually riddled with burrows, holes and depressions. These are likely to be formed by a range of animals, such as burrowing worms, fishes and crustaceans, or fish making nests for egg laying (see *Infauna of the Continental Shelf,* page 78*)*. There was a high degree of variation both between and within banks in the abundance of *Halimeda* and its relative importance to the various benthic communities encountered. Between the banks there was a six-fold difference in average *Halimeda* coverage (Figure 9 and Figure 10). For example, Big Bank has a mean cover of less than 4 percent (1997 survey) while Grumpy Bank has cover greater than 30 percent. Within single banks the variability is even greater. For example, Udang Bank has over 60 percent coverage of *Halimeda* on the southern end but less than 5 percent was recorded on the northern end. Large spatial variability was a feature of all the major benthic groups.

In places the *Halimeda* growth was particularly lush, with plant thalli, up to 30 cm high, forming a dense, carpet-like covering of the bottom (see film strips *HA01*, *HA02* and *HA05*)*.* A diverse fauna of invertebrates, including bryozoans, foraminiferams, ascidians and other sessile, filter-feeders, was usually encountered in the *Halimeda* beds, but the most dominant organism

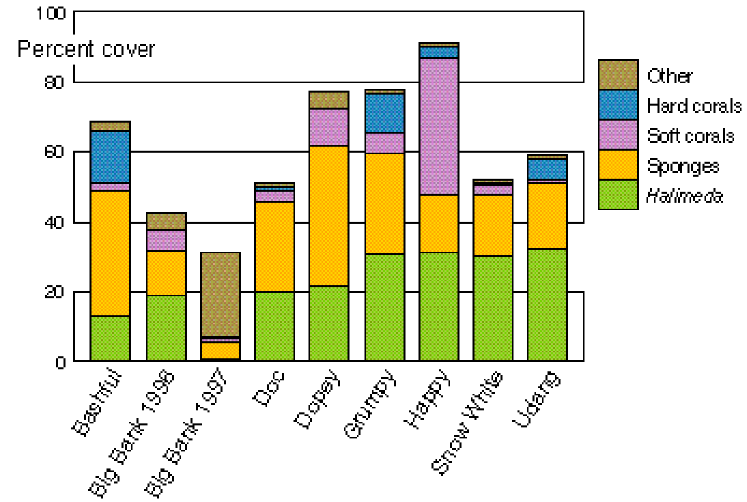
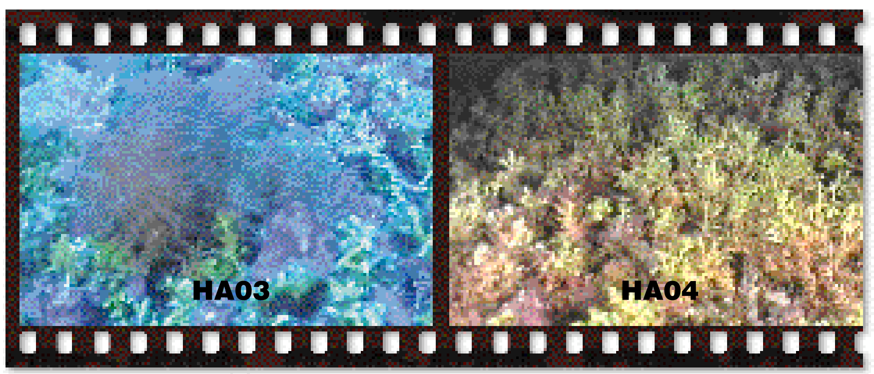


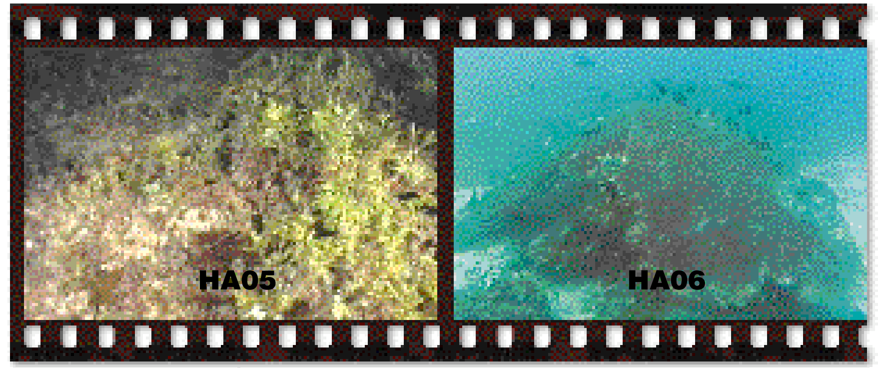
Figure 9. Histogram showing the major benthic categories of the *Halimeda*-type banks of the Big Bank Shoals.

was a purple, encrusting sponge (see film strip *HA04*) which in many cases was more abundant than the *Halimeda* itself. The sponges are able to grow over *Halimeda*, covering single segments and occasionally whole plants. The sponge is often held above the substrate and can filter water both above and below the *Halimeda* plants. This sponge was always found in association with extensive *Halimeda* beds and may be an example of algal-sponge commensalism (see Palumbi, 1985). The algal-sponge complex was augmented by soft and hard corals, which were a major, and in places dominant, component of the benthos (see *Individual bank descriptions,* page 33).

Both light dependent and independent soft corals (see the *Biology and ecology of soft corals,* page. *48)* were important components on the *Halimeda* banks, but there was great variation both within and between banks in species composition and abundance. Average cover ranged from 40 percent at Happy Bank to less than 2 percent at Bashful Bank, yet within Happy Bank, cover varied from 81 percent at the centre of the bank to less than 1 percent on the northern edge. Some of this extreme variation in abundance is due to the ability of soft corals to reproduce asexually by numerous means. This allows them to form dense populations of a single species, resulting in an extremely patchy distribution within individual banks. The most common soft coral found, *Xenia* spp., belongs to the Family Xeniidae and has extremely effective asexual reproduction (Lasker, 1984), (see film strip *HA03*). On a few banks, *Xenia* spp. has been able to establish itself in an area and, through vegetative reproduction, come to dominate that area. In other areas *Xenia* spp. has never gained a foothold. Other important soft corals found on the *Halimeda* banks include *Sarcophyton* spp. (e.g. Dopey and Grumpy Banks) and *Nephthea* spp. (e.g. Doc and Happy Banks).

Many of the *Halimeda* banks have areas or outcrops of hard coral (see film strip *HA06*). The western ends of both Big Bank and Grumpy Bank have areas of abundant and highly diverse coral cover, equivalent to that found on emergent coral reefs. The overall coral coverage of these areas is 2 and 17 percent, respectively. A total of 19 different genera of scleractinian coral were found on the *Halimeda* banks. The overall genera richness found on these banks is far less than reported from the emergent coral reefs to the west of the Big Bank Shoals (Figure 1). Ashmore Reef, for example, has at least 56 genera. The lower number of genera reported from the *Halimeda* banks of the Big Bank Shoals may be related to habitat diversity (see Hooper, 1994) and a smaller depth range on these banks. However, the difficulty of identifying species from video and the inability of the ROV to observe some areas (e.g. caves and overhangs) means that the true genera-richness of the banks has almost certainly been underestimated.





Pocilloporid corals, such as *Seriatopora* spp., were the most consistently encountered, although not necessarily the most abundant hard corals on the *Halimeda* banks. These corals can range in colour from pink to a very light cream. The colonies seen at the Big Bank Shoals were a bright pink. The fragile skeleton of *Seriatopora hystrix* is easily broken, and the fragments have the ability to survive and become new independent colonies (see *Biology and ecology of hard corals*, page 43). The other coral frequently found amongst the stands of *Halimeda* were the free-living mushroom corals of the family Fungiidae. These corals remain unattached to the substratum throughout their lives. Consequently, fungiids are commonly found on coarse, unconsolidated sediments to which other hard corals have difficulty attaching. Both *S. hystrix* and fungiids seem to be able to cope with coarse, unconsolidated substrata.

The ahermatypic soft corals, such as gorgonian sea fans, were found in very low numbers, being less than 1 percent overall cover, on all the *Halimeda* bank's plateaux. They were more noticeable on the bank slopes. Gorgonians and sea whips are susceptible to physical damage and periodic physical disturbances (e.g. storms or cyclones). Seasonal monsoonal weather on the *Halimeda* banks may preclude the survival of the fragile gorgonians and sea whips. It is also possible that the currents are not sufficiently strong or reliable on the top of the *Halimeda* banks to provide an adequate food supply. These corals are found in higher numbers in the deeper, and presumably

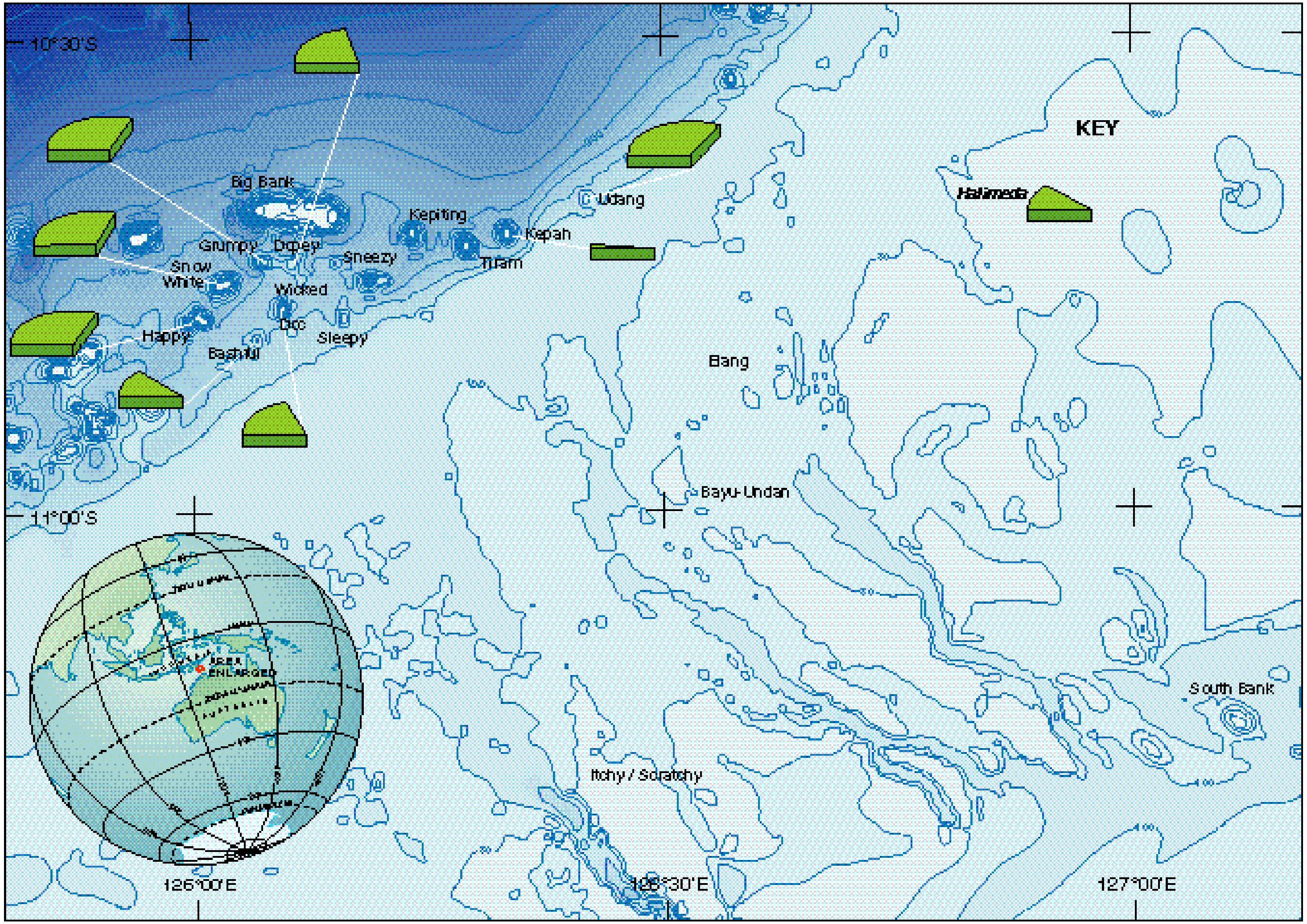


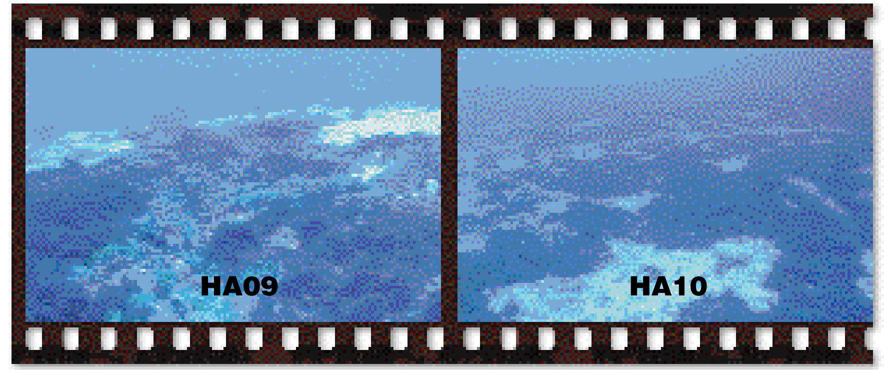
Figure 10. Map of the Big Bank Shoals showing the distribution of the calcareous algae, *Halimeda.* Note: *Halimeda* cover on Big Bank dropped markedly from 20 percent to almost zero between surveys in 1996 and 1997.

more predictable waters, of Sneezy and Wicked Banks (see *Biology and ecology of gorgonians*, page 60).

A number of detrital feeders were also observed (see film strips *HA07* and *HA08*), including holothurians (sea cucumbers) and asteroids (starfish). Large fish were rarely seen on the video (except around large coral outcrops), but many small hawkfish (Family Cirrhitidae) inhabited the thick beds of *Halimeda*. Hawkfish are mostly predators of benthic crustaceans and fish, using the *Halimeda* as a refuge against larger predators and as cover to ambush their prey.

Asexual reproduction - the dominant mode

Asexual reproduction is utilised by many marine organisms and is known to feature in the life histories of all the dominant benthic groups found on the *Halimeda* banks. *Halimeda* produces runners that form new plants, soft corals form stolons and fragments, and reproduce by splitting; many hard corals survive and multiply via fragmentation; and sponges use fragmentation or gemmules. These all have the effect of producing new daughter plants or colonies near the parent. Consequently, asexual reproduction allows these taxa to extend their local distribution and increase their abundance on individual banks. This type of propagation can give rise to patchy distribution, since daughter colonies (or plants) are budded near the parent. A single *Halimeda* plant may bud new, genetically



identical plants, thereby forming the dense meadows that are seen on these banks (see film strips *HA09* and *HA10*). *Xenia* spp. is the most abundant soft coral in terms of coverage on the *Halimeda* banks. It also uses asexual reproduction to cover large areas with colonies that are likely to be clones of a few founding individuals.

Bare patches of sediment, ranging in size from metres to several hundred metres, are common on the *Halimeda* banks. It seems likely that, for many types of organism, recruitment of sex-derived juveniles is rare on such terrain, in comparison to asexual propagation. Consequently, it is probable that the monospecific stands of *Halimeda*, soft corals and encrusting sponges represent an amplification, by asexual reproduction, of the limited success of previous sexual reproduction. The large, erect sponges and massive corals (e.g. *Porites* spp.) that do not undergo rapid and successful asexual reproduction are found as isolated individuals which are, most probably, the consequence of sexually produced larvae.

The role of disturbance

Disturbance has been found to be a major determinant of epibenthic cover in many tropical, marine ecosystems (Connell *et al.*, 1997; Pearson, 1981) and is likely to play a major role in determining the cover of the major taxa on the *Halimeda* banks of the Big Bank Shoals. Little information is available on the effects of disturbance on *Halimeda* communities. However,

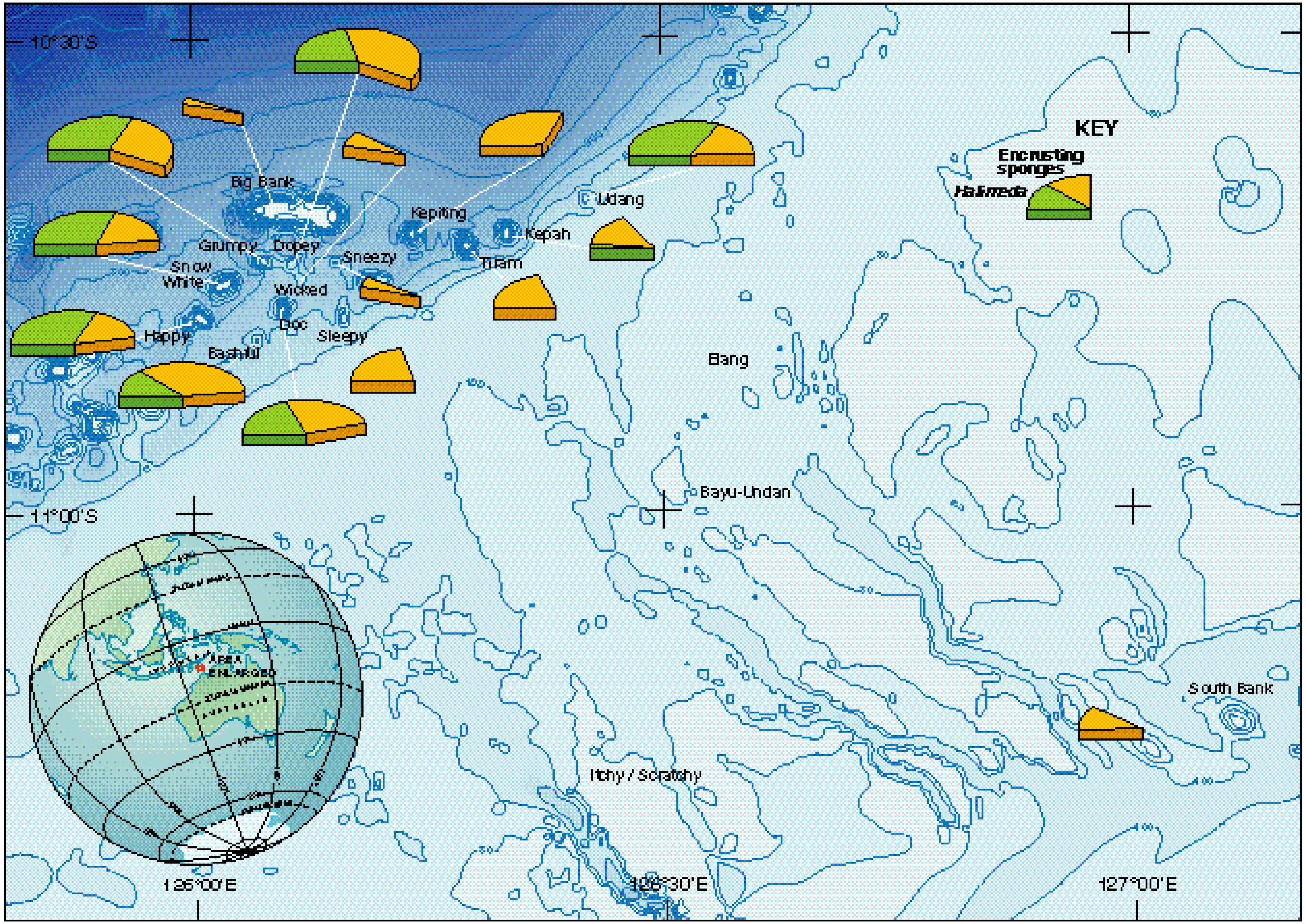
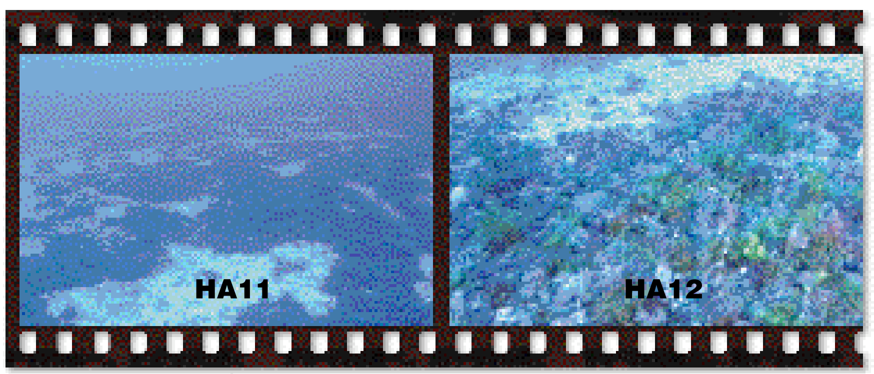


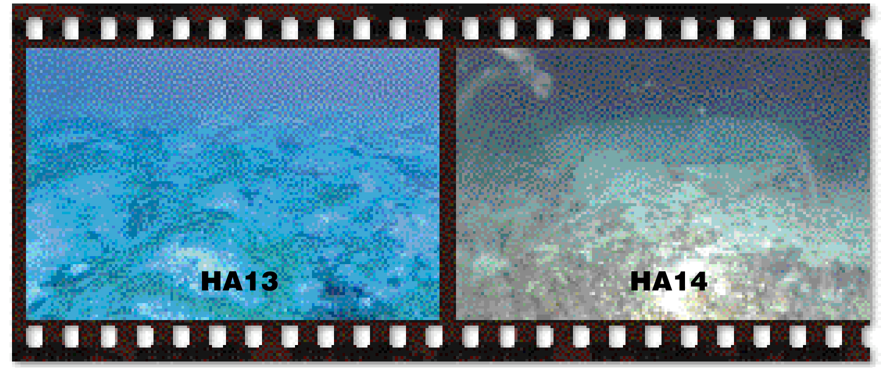
Figure 11. Map of the Big Bank Shoals showing the distribution of *Halimeda* and encrusting sponges.

our limited data suggest that natural physical disturbance could play a major role in determining overall *Halimeda* cover on these banks.

Big Bank, the largest bank of the Shoals, was surveyed at the same sites on three separate occasions over a 14 month period; February 1996, November 1996, and January 1997. The substratum on the top of Big Bank was flat in 1996 but had become, by 1997, highly sorted and shaped into wave-like patterns up to 20 cm high. The original beds of *Halimeda* and associated invertebrates were gone, either covered by sediment or washed from the bank. Cover of *Halimeda* dropped from 20 percent to less than 1 percent between November 1996 (see film strips *HA11 and HA12*) and January 1997 (see film strips *HA13* and *HA14*). Only occasional small *Halimeda* plants were observed. Turf algae, a fine, filamentous algae 5 mm high, had colonised much of the disturbed area of Big Bank.

The bank plateau is submerged 28 metres below the sea surface, yet the observed changes suggest exposure to strong wave action. Consequently, areas that were previously covered by *Halimeda* beds are now rubble zones. This disturbance was probably caused by extreme weather conditions redistributing the sediment. As perturbation occurs naturally and periodically it is likely that bank communities, particularly on the unconsolidated sediment areas, cycle between maximum coverage, cover reduction by wave action, then re-establishment through sexual recruitment and asexual propagation. The extensive hard coral community located at the western end of Big





Bank showed very few signs of disturbance other than a few upturned table corals (*Acropora sp.*). Obviously, hard corals are far more resilient to physical disturbance than *Halimeda*/sponge communities. The calcareous skeleton of hard corals makes movement difficult and the larger size of these corals reduces the likelihood of smothering by sediments.

A link between depth and frequency of major physical disturbances may play a role in shaping the nature of benthic communities on the Big Bank Shoals. The *Halimeda* bank plateaux lie within 28 and 45 metres of the surface, as do major *Halimeda* communities of other regions. Those of the Great Barrier Reef Lagoon are in approximately 30 metres, while *Halimeda* communities in the Java Sea are 25 metres deep at their shallowest point. In comparison, the coral-dominated banks of the Big Bank Shoals rise to within 15-25 metres of the surface. This may be related to coral reef structures being more resilient to physical disturbance than *Halimeda*-dominated communities.

Core and seismic data

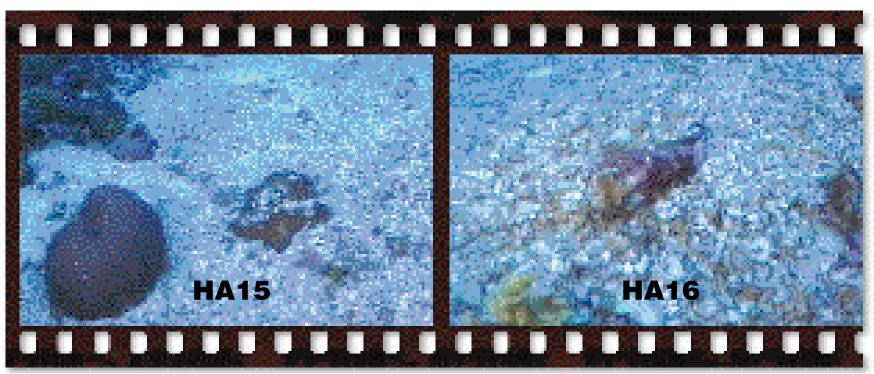
Much interest has been shown by the scientific community in the geological history of *Halimeda*-derived banks and bioherms of the Indo-Pacific region (e.g. Orme and Salama, 1988; Phipps and Roberts, 1988; Roberts *et al.*, 1987). Cores have been drilled into the surface layers of *Halimeda* bioherms in the Java Sea and the Great Barrier Reef Lagoon. These cores have been relatively shallow (up to 5 metres) and dominated by *Halimeda* rubble.

In the case of the GBR bioherms, a large percentage of the sediments were terrigenous. Deeper cores have been retrieved from Pacific Ocean atolls, down to depths of 100 metres. The lagoon sediments of these atolls are almost 100 percent *Halimeda*, 20 metres into the lagoon floor.

Three cores were retrieved from Big Bank in 1996, the largest bank in the Big Bank Shoals. These were situated approximately one kilometre apart. The cores reached depths of between 29 and 55 metres. These were logged on board the drilling ship, and later analysed for biogenic input.

The top 38 metres of Big Bank consisted of an unconsolidated, sandy gravel surface of bank (see film strips *HA15* and *HA16*). Below these sediments was a limestone which was composed almost entirely of calcite. *Halimeda* plates dominated the entire length of the cores (Figure 12), in some parts making up over 80 percent of the total sediments. Minor amounts of foraminifera, fragments of bryozoans, molluscs, hard coral, sponge and soft coral spicules were found throughout the cores (see Figure 13). It appears that the sand component of the cores is mostly degraded *Halimeda* segments.

The percentage of *Halimeda* rubble in the cores taken from Big Bank is extremely high when compared to other studies. The bioherms of the GBR are composed of approximately 40 percent *Halimeda* segments, with terrigenous sediments constituting 25 to 30 percent (Orme, 1985; Davies and Marshall, 1985). The Big Bank Shoals are approximately 300 km from



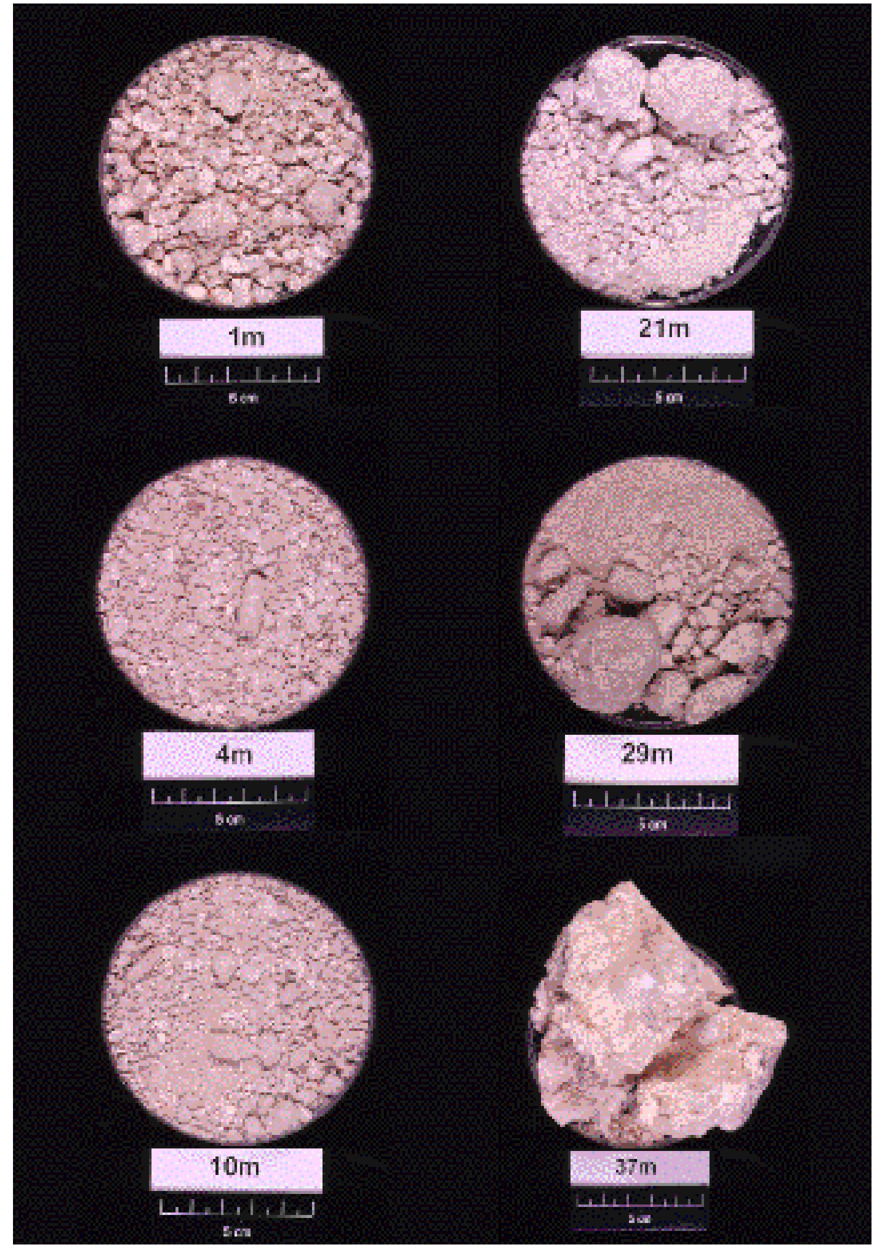


Figure 12. Core samples of sediment taken at Big Bank between 1 and 37 metres.

the Australian mainland and so have little terrigenous input. Studies undertaken in the Java Sea reveal *Halimeda* dominated sediments (>50 percent) with no terrigenous component (Roberts *et al.*, 1987). The sediments of Big Bank also lacked a terrigenous component. The high terrigenous input to sediments of the GBR bioherms is likely to be related to their proximity to the shore and its freshwater run off.

The samples from Big Bank Shoals represent the deepest cores drilled into a possibly *Halimeda*-derived structure. They show that these are definitely

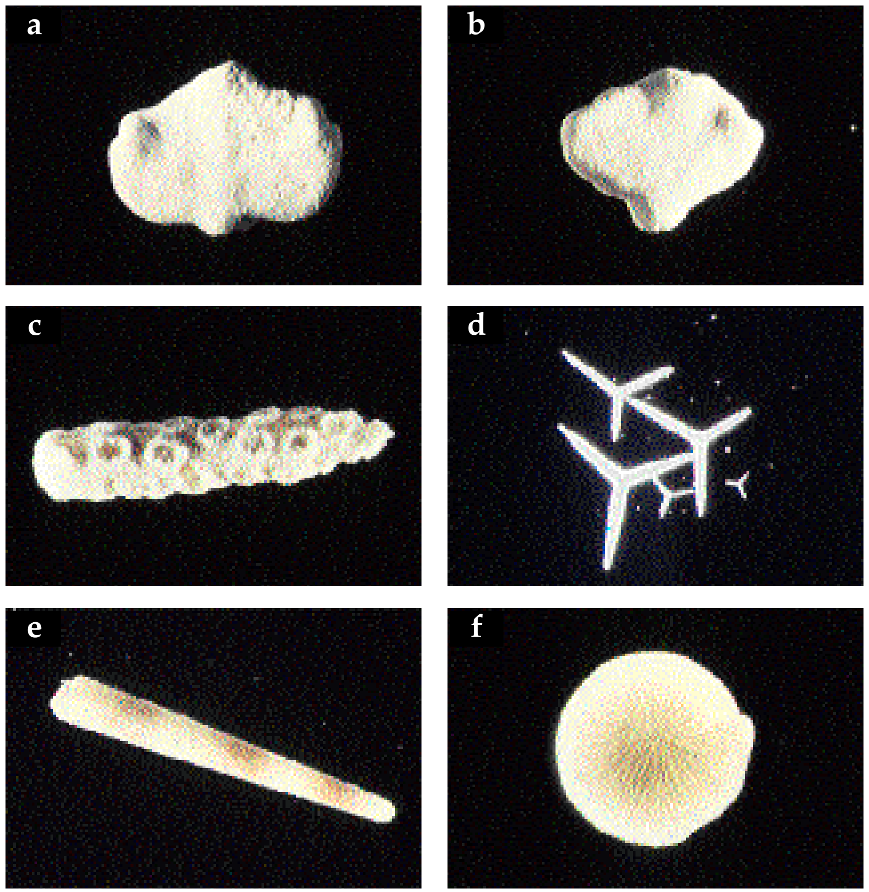


Figure 13. The sediments of Big Bank. a & b: *Halimeda* segments, c: coral fragment d: sponge spicule e: echinoderm spine f: foraminifera.

living banks that have grown towards the sea surface by *in situ* accumulation of dead *Halimeda* skeletons. Radiocarbon dating of these cores has yet to be undertaken, but initial investigation of the foraminiferan fauna suggest that the base of these cores was deposited in the Late Pleistocene (Rexilius, 1996). Consequently, the *Halimeda* banks of the Big Bank Shoals are not a mere veneer of *Halimeda* growing over remnant coral reefs of the recent past. A Late Pleistocene age at 50 metres deep would indicate that these structures are much older than *Halimeda* systems of the Java Sea or the GBR.

The top of Big Bank is relatively flat with little evidence of the mound-like bioherms found in the Java Sea and in the GBR lagoon. Bioherms form distinct hummocks that are usually small in size (less than 150 metres across). It is unknown whether the uniformity of Big Bank is because the mounds that may occur are periodically smoothed by storms or whether these systems are structured differently to previously described *Halimeda* bioherms.

Regional context

The majority of banks within the Big Bank Shoals complex were dominanted by *Halimeda* and encrusting sponges. These banks were Big, Bashful, Doc, Dopey, Grumpy, Happy, Snow White and Udang. Each bank is discussed in more detail below.

Halimeda banks were first discovered in the Timor Sea in 1993 by the Australian Geological Survey Organisation (AGSO), (Marshall *et al.*, 1994). Dredges and photos taken on the Sahul Banks (southwest of the Big Bank Shoals) revealed extensive *Halimeda* banks, as well as banks with large areas of seagrass. Our studies reveal that *Halimeda*-dominated communities are also prevalent further to the northeast, with coral-dominated reefs being the exception. This suggests that *Halimeda* banks are the dominant carbonate structures along the shelf edge of the Timor Sea.

Individual bank descriptions

Big Bank

Big Bank, the largest bank surveyed, rises from the Continental Slope to a plateau within 22 metres of the sea surface and extends 12 km by 3.5 km along an east-west main axis (Figure 14). A total of 81 ROV transects were undertaken at Big Bank, both on the slope and the top of the bank. Video data were collected on four separate survey expeditions between 1995 and 1997. A reconnaissance expedition was conducted on Big Bank in May 1995, with two sites investigated. In January 1996, 13 transects were filmed on the top of Big Bank. A further 26 sites were surveyed along the bank's slope during November 1996. These video transects were undertaken between depths of 250 metres and 40 metres and demonstrate how the communities change from deeper to shallower depths. Thirty-three sites on the top of Big Bank were surveyed in January 1997, with four being re-surveys of the 1996 sites. This larger number of sites permitted a much more detailed assessment of community structure on this bank, enabling us to identify particular types of benthic assemblages, or habitats, within the bank itself. In addition to the snapshot-in-time descriptions, which are comparable to our surveys of all the other banks, the re-survey of particular locations has allowed some limited assessment of temporal change on Big Bank. This aspect, and specifically the disturbance of Big Bank, that was observed between January 1996 and January 1997, are discussed elsewhere (see *The role of disturbance*, page 28). However, the slopes and plateau of the bank will be discussed here.

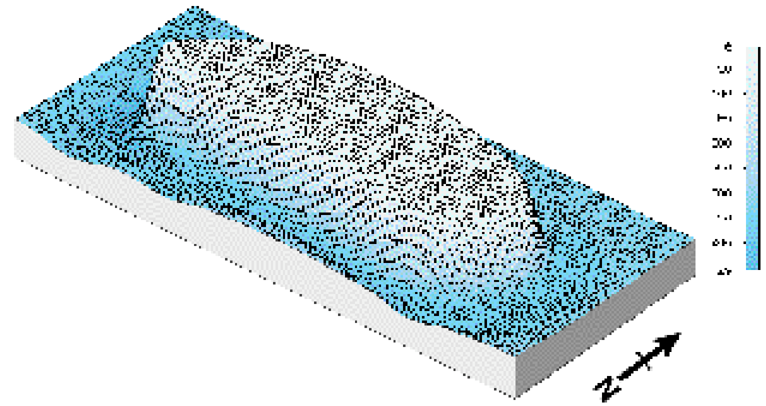


Figure 14. A three-dimensional bathymetry map of Big Bank (vertical exaggeration five times).

The slope of Big Bank

The base of Big Bank which lies between a depth of 200 and 300 metres, has a fine, sandy substratum which is highly rippled. Overall cover of sessile organisms was very low at these depths. Sponges and the galatheid or squat lobsters were encountered at these locations, however they covered less than 1 percent of the substratum. *Halimeda* rubble was found at the 250 metre depth sites, indicating that sediments do tumble down the sides of these banks from shallower areas. This observation is in agreement with the findings of Marshall (1994) which suggest that *Halimeda* derived rubble is likely to contribute greatly to the sediments of the surrounding deep water. Between 100 and 150 metres depth the slope becomes steeper (60 degree

angle) and the substratum appears more consolidated. Macro-invertebrates are still rare. Sponges and gorgonians dominate the epibenthic community at these depths, with overall live cover being less than 8 percent. A single, large rocky outcrop which exhibited a highly diverse invertebrate assemblage (including sponges, gorgonians, feather stars, sea whips) was discovered at site N2/11 (see Figure 15). Above 100 metres the slope of Big Bank becomes gentler (a 40 degree angle). Gorgonians and sponges remain the major groups and become much more abundant at the shallower depths. Furthermore, the diversity of the sponge community increases dramatically. At 80 metres, macroalgae and *Halimeda* are first seen and overall live cover increases to 15 percent. At 30 metres, the edge of the bank plateau is reached. Hard and soft corals, macroalgae and *Halimeda* become common and overall cover exceeds 25 percent.

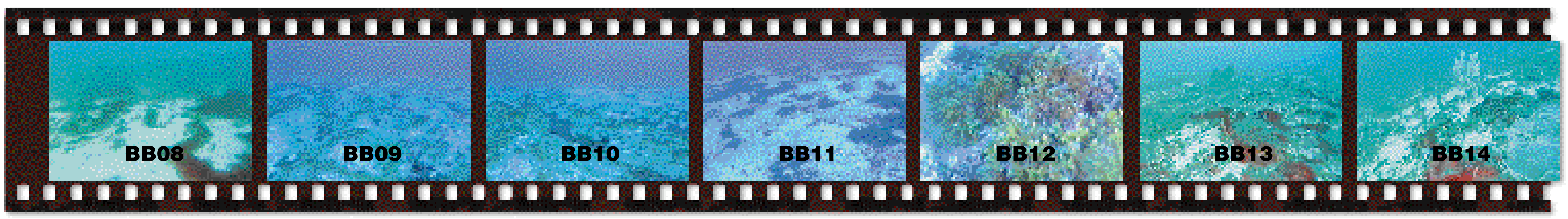
In summary, diversity and overall live cover increases from being very low at 250 metres to moderately high at 30 metres. Large, rocky outcrops, apparently made of limestone, were found around the base of Big Bank at 300 metres. These outcrops had a greater coverage of epibenthos than the surrounding sea floor at 300 metres. Flora and fauna that require light were found in water shallower than 100 metres.

The plateau of Big Bank

A total of 50 transects were recorded on the plateau of Big Bank, revealing great spatial variation in epibenthic community structure and cover. Previous work on this region of the bank (Woodside, 1995, using side-scan sonar and results of a 26 location epibenthic survey, led to development of a preliminary map of major biological features. Surveying undertaken by AIMS/BHPP has refined this map into habitats as of Janurary, 1997 (Figure 15).

A fine, brown macroalgae is the most spatially dominant organism found upon Big Bank, particularly over the middle of the bank (60 percent of the substratum at location N1/06), (see film strips *BB08 to BB11*). Over much of the northern end of Big Bank little is apparent (see film strip *BB07*). The brown macroalgae, seen on the southern transects, covers less than 10 percent of the substratum. The only other taxa observed at these sites were small encrusting sponges which covered less than 2 percent of the substrate. The late 1996 and 1997 surveys revealed only traces of live *Halimeda* (< 1%) in the northern section of Big Bank (early 1996, pre-disturbance, (see film strips *BB05*, *BB06* and *BB12*). Overall cover of this habitat is less than 15 percent (Figure 15).

Two regions of hard coral were recorded on Big Bank (see Figure 15). These were on the eastern and western ends of the bank, where areas of consolidated substrate occurred along the rim or edge regions of the bank (see film strips *BB13* and *BB14*). Overall coral cover at the western region is 21 percent and appears to be less diverse than communities found on Kepah and Tiram Banks (see *Coral ecosystems*, page 43). Acoporiids were the dominant coral taxa at the western end of the bank. The coral community at the eastern end of the bank is very different. The soft coral, *Nephthea* spp. dominates, forming large monospecific beds. *Montipora* sp., a foliaceous coral, has the highest coverage of any hard coral. Overall live cover in this area is approximately 55 percent. The full extent of this area of high coral abundance is yet to be established.



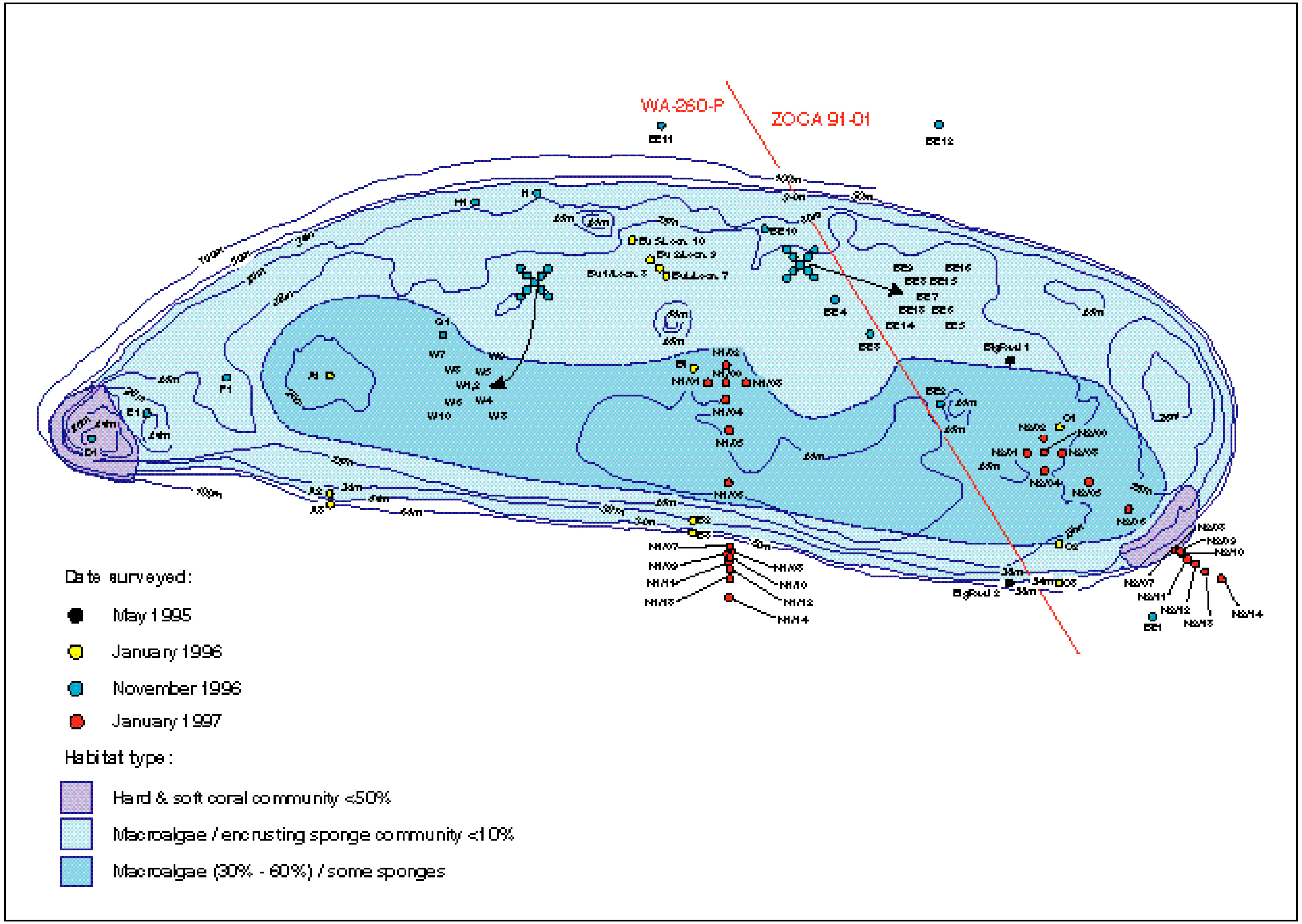


Figure 15. A habitat map of Big Bank showing the locations of surveys (95-97), modified after Woodside, 1995.

Bashful Bank

Bashful Bank is a pinnacle, rising steeply from the Continental Slope to a plateau 500 metres across and to within 36-40 metres of the surface. Two ROV video transects were recorded in both the direct centre and the north-western edge of the bank (Figure 16). Overall live cover was found to be 68 percent.

The two locations were very similar with all major benthic groups being represented. Dense patches of live *Halimeda* (12 percent mean cover) occurred amidst extensive areas of *Halimeda* rubble, which accounted for just over 30 percent of the substrate (see film strips *BA01* to *BA03* and *BA06*). Interspersed within and between the *Halimeda* beds were numerous sessile invertebrates; particularly sponges and hard and soft corals. The benthic community was dominated by very high cover associated with the *Halimeda* beds and rubble patches.

Hard corals, including *Palauastrea* sp., *Seriatopora* sp. and various Acroporiids, Faviids (see film strip *BA03*) and Fungiids (see film strip *BA04*) were present in amounts (15 percent cover) similar to *Halimeda*. Both light dependent (hermatypic) and light independent (ahermatypic) soft corals were rare on Bashful Banks. The depth of the bank may be marginal for hermatypic corals, such as *Sarcophyton* spp., *Lobophyton* spp. and Nephthiids, which were found on shallower banks (e.g. Tiram and Kepiting), but the paucity of filter-feeding ahermatypes is surprising. Filter-feeding crinoids or feather stars and stinging hydroids were observed on small coral outcrops raised above the surrounding substrate (see film strip *BA07*).

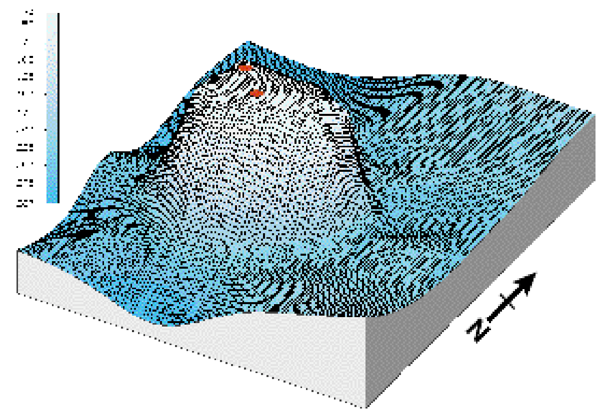
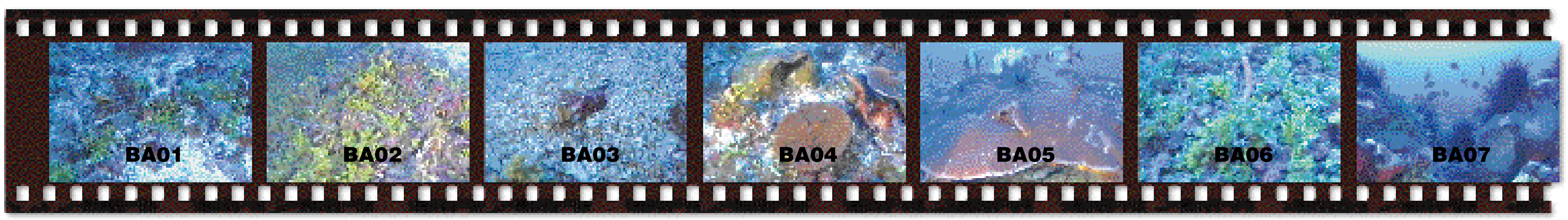


Figure 16. A three-dimensional bathymetry map of Bashful Bank (vertical exaggeration five times).

Relative to other banks in the *Halimeda* group, the overall abundance of live *Halimeda* is low on Bashful, approximately half that found at neighbouring Doc Bank and one-third the highest levels recorded at nearby Happy Bank. The low live cover, however, contrasts with the dominance of dead *Halimeda* skeletal material visible on the bank surface. It may be that productivity of the *Halimeda* beds is reduced, due to greater than average depths. No clear correlation has been found yet to confirm incremental decreases in abundance of *Halimeda* with increasing depths of the banks, but a clear demarcation does seem to occur at around 45-50 metres, below which the light dependent organisms, such as *Halimeda* and hermatypic corals, become rare or nonexistent.



Doc Bank

Doc Bank rises steeply from over 200 metres to a roughly circular plateau mostly 27-28 metres beneath the surface. Small regions of the plateau were only 20 metres deep. This bank has typical abrupt, pinnacle-like bathymetry, but the 2 km diameter is much larger than that of Bashful Bank. Four ROV video transects were undertaken (Figure 17). The survey of Doc Bank was undertaken in early 1996 and overall live coverage was found to be 52 percent.

All transects at Doc Bank were dominated by *Halimeda* and sponges, although their relative abundance varied between locations on the bank (see film strips *DC01 to DC06*). The contribution of sponges varied from 14 percent at the southwesterly transect to 38 percent at the southeasterly transect. Sponges predominate over *Halimeda* at both the northern and southeasterly transects, while *Halimeda* is the dominant organism at the southwesterly transect. At the central transect the cover of *Halimeda* and sponges was nearly equal. The sponges were almost exclusively encrusting types.

The *Halimeda* and sponge communities of Doc Bank were similar to those described at Bashful, but the general composition of the benthic community was distinct with regard to corals. Small amounts of soft corals were present at both the southeasterly (9 percent) and southwesterly (4 percent) transects, yet were absent from the other two transects. At both these transects the predominant soft coral was *Dendronephthea* spp., though there were small amounts of *Xenia* spp. Despite the shallower depths,

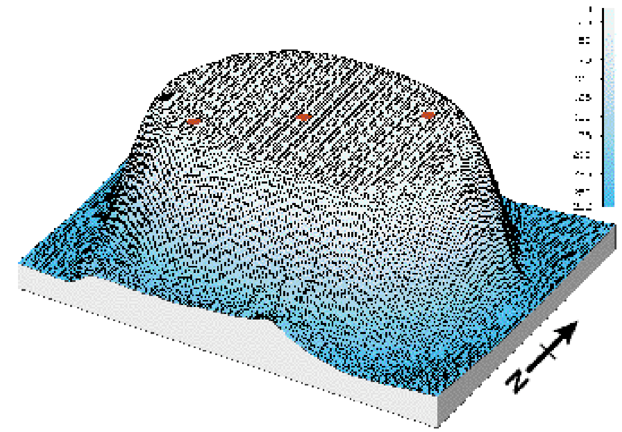


Figure 17. A three-dimensional bathymetry map of Doc Bank (vertical exaggeration five times).

hard corals were rare (approximately 1 percent cover) at all locations. Nonetheless, the coral taxa found on Doc Bank were similar to those observed on Bashful Bank. The lack of consolidated substrate that would support coral settlement and growth may be a factor limiting hard coral abundance.

On the Doc Bank plateau there were a number of relatively large, boulder-like structures, which may be old, dead coral colonies. These bommies appeared to provide 'islands' of elevated hard substrate amidst the 'sea' of loose *Halimeda*, sponges and rubble. Sponges, coralline algae, hard corals and numerous other encrusting organisms were found in large numbers on these bommies, together with high concentrations of fish (see film strip *DC07*).

Dopey Bank

Dopey Bank is a pinnacle rising steeply to a small plateau 500 metres in diameter and within 40 metres of the surface. It is one of the smaller banks in the Big Bank Shoals. Two ROV video transects were undertaken at this location, one in the centre of the bank and another on the western edge (Figure 18), revealing a high overall live cover of 78 percent.

The community was very similar to that observed on Doc Bank, being dominated by *Halimeda* and small, encrusting sponges that grow upon the *Halimeda* (see film strips *DP01 to DP04*). There were large differences in relative abundance of *Halimeda*, encrusting sponges and soft corals between the two transects, but sampling was too limited to assess the true level of hetrogeneity. The bank edge transect had *Halimeda* cover of 33 percent compared to only 9 percent in the centre. The patchiness of *Halimeda* may be related to competition, as overall live benthic cover in the centre of the bank reached almost 85 percent. Numerous small colonies of the soft coral *Sarcophyton* sp. accounted for 19 percent of the epibenthos in the centre of the bank and the majority of the remaining space (50 percent) was occupied by sponges (i.e. fan sponge, see film strip *DP06*). Similar to the other *Halimeda*-dominated banks, the sediment was mostly *Halimeda* rubble. Hard corals were very rare on Dopey Bank. Only the occasional solitary fungiid (*Fungia* spp.) or pocilloporiid coral was observed. The depth of this bank should not be a significant factor in limiting hard coral growth, as banks of similar depth exhibit extensive areas of hard coral (e.g. Bashful and Sleepy Banks). The size and unconsolidated nature of

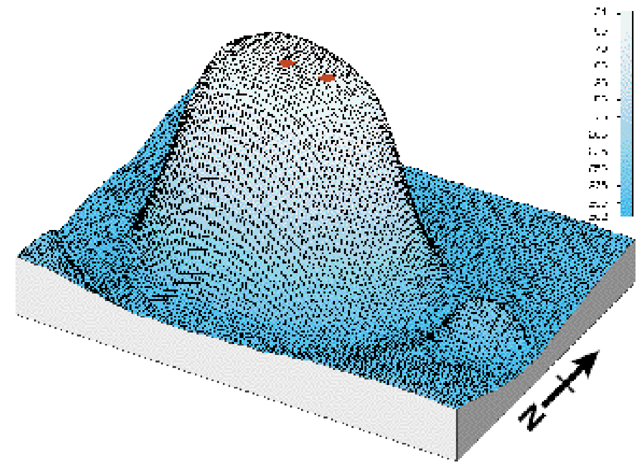


Figure 18. A three-dimensional bathymetry map of Dopey Bank (vertical exaggeration five times).

Halimeda rubble, together with competition from existing organisms may prevent the settlement and subsequent survival of hard coral larvae.

The ability of soft corals to reproduce asexually can result in localised, high density patches, where numerous colonies have arisen from one or a few original settlers. On Dopey Bank, large, monospecific beds of soft corals were found in some areas, while being completely absent in others. The large gorgonians and sea whips found on some deeper banks (see *Filter-feeding ecosystems,* page 60*)* were rarely seen. Numerous cushion stars were observed upon Dopey Bank (see film strip *DP07*).

Grumpy Bank

Grumpy Bank has typical bathymetry found on these banks, rising steeply from 250 metres on the Continental Slope and tapering to a plateau 30 metres below the surface. It is a pinnacle in shape, but the plateau is roughly rectangular with a 1.5 km long northeast-southwest axis and a width of approximately 600 metres. Four ROV video transects were undertaken at depths of approximately 35 metres (Figure 19), revealing a high average live cover of 75 percent.

The most defining characteristic on all transects was moderate (15-20 percent) to high (30-35 percent) levels of both sponges and *Halimeda*, in equivalent amounts (see film strips *GR01* to *GR03*). The sponges were mostly low, encrusting species closely associated with the *Halimeda* beds and rubble patches, as seen on Bashful and Doc Banks. Benthic cover was consistent for these dominant groups but of variable composition for other organisms, depending on location. A variety of invertebrate filter-feeders, such as crinoids, hydroids and ascidians, were found in low numbers on all sites. Hard corals, however, were generally rare but dominated the area of the single transect located on the southern edge of the plateau. A diverse coral reef habitat was encountered on gently undulating terrain. Foliaceous hard corals, particularly *Montipora* sp., covered large patches on the first half of the survey transect (see film strips *GR06* and *GR07*), while branching and small, massive forms were more common on the latter half. In this location hard corals (17 percent), sponges (19 percent) and *Halimeda* (15 percent) were found. The hard coral taxa represented were very similar to those

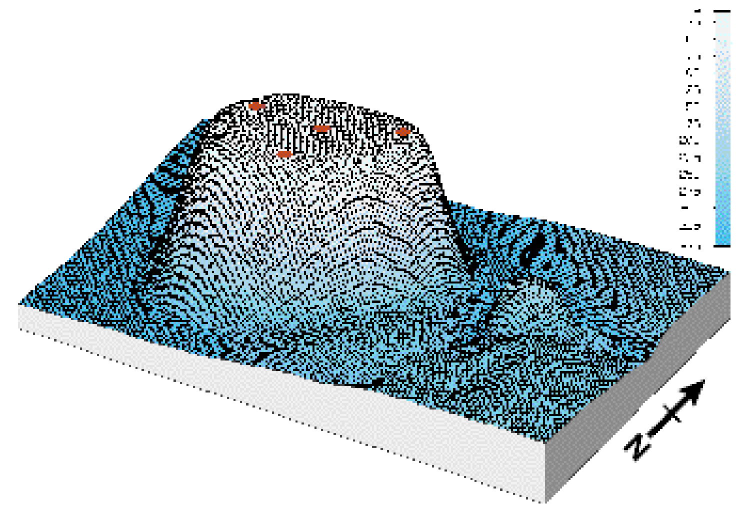
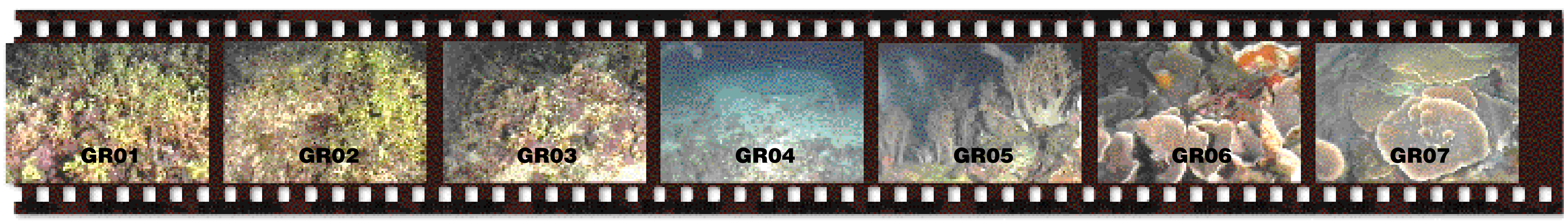


Figure 19. A three-dimensional bathymetry map of Grumpy Bank (vertical exaggeration five times).

observed on Bashful Bank, while the soft corals were a mixture of hermatypic (*Sarcophyton* spp. and *Sinularia* spp.), (see film strip *GR05*) and ahermatypic (*Dendronephthea* spp.) species.

The substrate on the edge of the bank plateau was almost completely covered with live organisms. The reduction in live cover measured on the other three transects reflected the absence of hard and soft corals, which were rare or nonexistent, although live *Halimeda* and sponge cover was higher. In all three locations, areas of bare *Halimeda* rubble substrate (23-36 percent) were an important feature of the benthos.



Happy Bank

Happy Bank rises steeply from the Continental Slope (approximately 280 metres deep) to within 30 metres of the surface. It is a larger sized bank, with a plateau measuring approximately 2.5 km by 4.5 km. Four ROV transects were undertaken at this location (Figure 20). Average overall live epibenthic cover of Happy Bank exceeded 90 percent, making it the highest cover of all the *Halimeda* banks.

While Happy Bank had significant beds of *Halimeda* and associated encrusting sponges, typical in this group of banks (see film strips *HP01* to *HP05*), a more pronounced feature was the extremely high cover achieved by soft corals, particularly in the central and southern areas. A species of *Xenia* (see film strip *HP06*), which formed large, monospecific beds, occupied between 18 and 78 percent of the benthos. It is hypothesised that this species has the ability to proliferate asexually, by sending out runners and budding new colonies. This type of extensive *Xenia* proliferation was not recorded elsewhere. However, a 1995 investigation of Big Krill Bank to the east-northeast of Happy, found a similar situation. On Krill, *Xenia* was estimated to cover 40 percent of the substrate (Woodside, 1995), although different methodologies were adopted to those in the current surveys.

The distribution and abundance of *Halimeda* and *Xenia* were somewhat inversely related. *Halimeda* was most abundant (49 percent cover) at the northern end of Happy Bank, where there was no soft coral but where it decreased in proportion to increasing amounts of *Xenia* at the other three locations. On the centre of the bank, for example, *Xenia* occupied 78 percent and *Halimeda* only 8 percent.

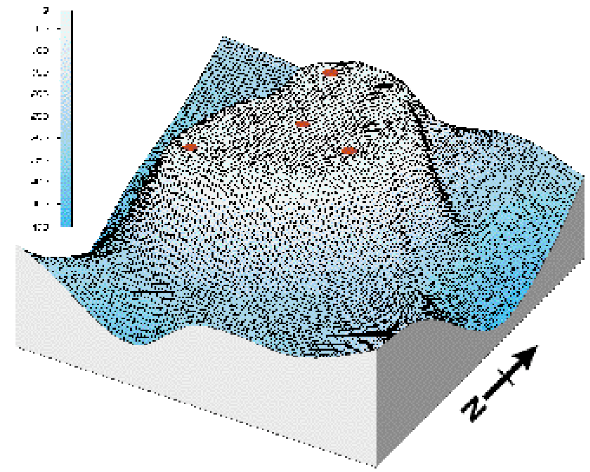
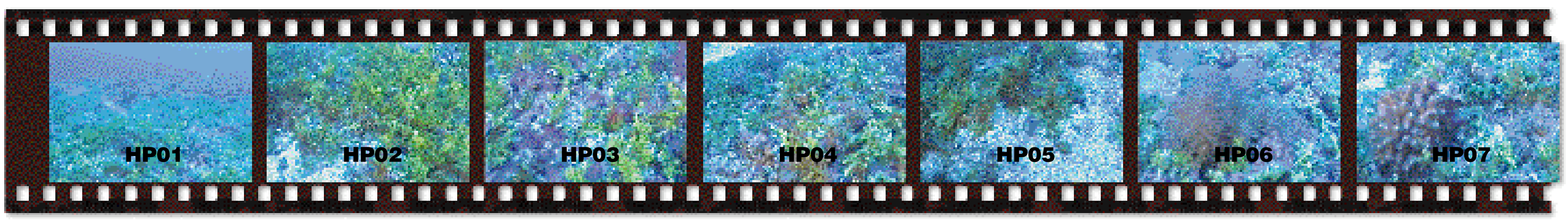


Figure 20. A three dimensional bathymetry map of Happy Bank (vertical exaggeration five times).

Numerous sponge species were encountered (6-24 percent cover). These were mostly the purple, encrusting type found on other banks. The only hard corals observed were small, scattered colonies, including the solitary coral, *Fungia* sp. and *Seriatopora* spp. (see film strip *HP07*) and *Acropora* spp., which were common but in low abundance (7 percent) on the northern edge of the bank and completely absent elsewhere. Like the rest of the *Halimeda* banks of the Big Bank Shoals, *Halimeda* rubble covered the top of the bank in unoccupied spaces.



Snow White Bank

Snow White Bank rises steeply from the Continental Slope (approximately 280 metres deep) to within 30 metres of the surface. It is an elongate bank, with the plateau measuring approximately 3.5 km by 1.5 km. Five ROV transects were undertaken (Figure 21). Live cover of the bank averaged a moderately high 54 percent. Cover around the edges of the bank was a low 25 percent however on the rest of the bank to 52-73 percent.

A *Halimeda* and encrusting sponge assemblage, as seen on other banks in the *Halimeda* group, characterised the top of Snow White (see film strips *SW01* to *SW04*). The *Halimeda* was particularly lush, up to 30 cm high, and formed extensive beds with the small, purple encrusting sponge growing upon them. The *Halimeda* was often more abundant than the sponges, in contrast to banks such as Bashful, where sponges were dominant, or Grumpy where each were equally abundant. With the exception of the soft coral, *Xenia* (10 percent cover), other invertebrates on Snow White were only minor contributors to overall live cover (see film strips *SW06* and *SW07*).

Halimeda cover was moderate to high over the top of Snow White Bank (20-42 percent), except for the southern transect which was substantially lower (6 percent). Bioturbation or physical disturbance could have contributed to the patchy distribution of *Halimeda*. Many concave depressions (diameter of 1.5-2.5 metres) were observed on the southern transect. Triggerfish, which dig deep nests into the sediment, may be responsible for this bioturbation. The loss of *Halimeda* cover has resulted in encrusting

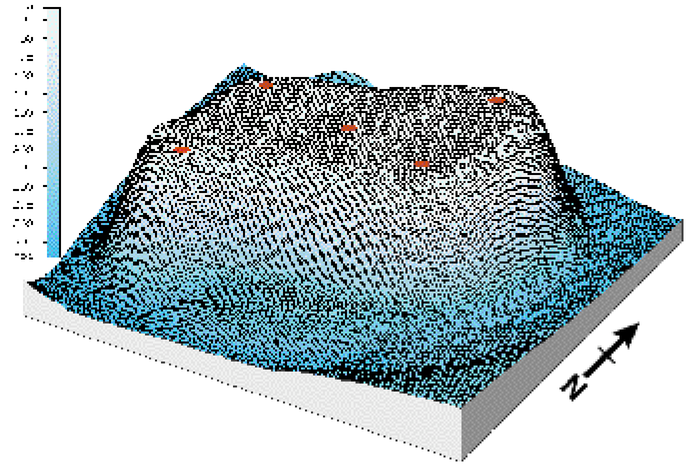


Figure 21. A three dimensional bathymetry map of Snow White Bank (vertical exaggeration five times).

sponges losing the framework upon which they grow. Consequently, the coverage of sponges was also substantially reduced in the southern sector of the bank.

Unlike most other *Halimeda* banks of the Shoals, no large hard or soft corals were observed. Other than the *Xenia* patch on the western transect, hard and soft corals were uncommon, with small coral colonies being interspersed amongst the *Halimeda*/sponge beds. The main hard coral species observed at this location were the same species observed on other *Halimeda* banks of the region, (*Seriatopora* spp., *Fungia* sp. and *Favia* spp. (see film strip *SW05*), but on average they accounted for less than 1 percent of overall cover.

Udang Bank

Udang Bank rises steeply from the Continental Slope (approximately 180 metres deep) to a circular plateau, measuring 1.4 km by 1.3 km, within 42 metres of the surface. Two sites were surveyed (Figure 22), revealing very different epibenthic communities. Average live cover was 60 percent, however the difference in organism abundance between the two transect sites was extreme (90 percent and 30 percent).

The plateau surface has little vertical complexity and Udang is dominated by the same *Halimeda* and sponge assemblage seen on other *Halimeda* banks (see film strips *UD01* and *UD02*). The two transects were both at the same depth (42 metres) on the plateau, but had very different overall cover and relative abundance of the major groups. One site had moderate live cover (30 percent), which was mostly encrusting sponges (22 percent) interspersed with minor amounts of bryozoans, ascidians and live *Halimeda* (<4 percent) growing upon *Halimeda* rubble (see film strips *UD06* and *UD07*). In contrast, the other area surveyed was almost completely covered in live *Halimeda*, encrusting sponges and hard corals. *Halimeda* formed thick beds that covered 60 percent of the area. The beds provided a structurally complex habitat allowing a more diverse group of invertebrates to colonise this location. In addition, many more fish, including an herbivorous surgeonfish (*Acanthurus auranticavus*) were seen (see film strip *UD03*). These surgeonfish are likely to be feeding upon the abundant *Halimeda* meadows of the area. Fish were much less frequently seen at the location with little live cover.

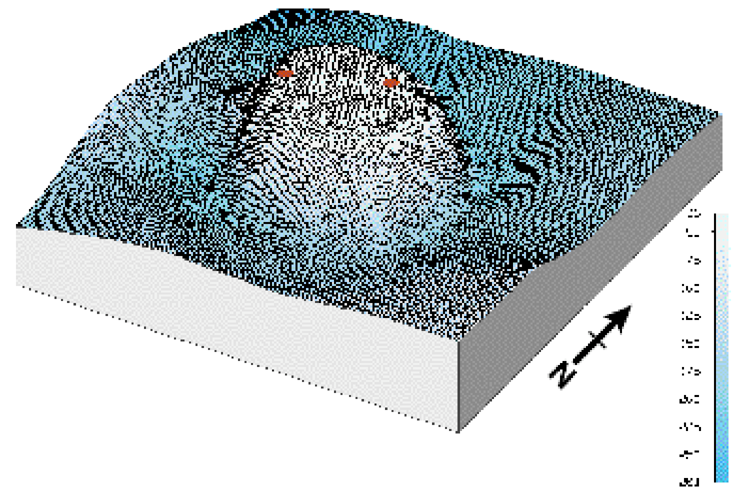


Figure 22. A three dimensional bathymetry map of Udang Bank (vertical exaggeration five times).

Soft corals were rare and only a single species of hard coral was observed. Hard corals are completely absent at the eastern site, but numerous brown, foliaceous *Montipora* spp. were found at the western site (see film strip *UD05*). These corals (Family Acroporidae) were found scattered throughout the *Halimeda* beds. They were rarely attached to the substratum and appeared to have been extensively broken up.

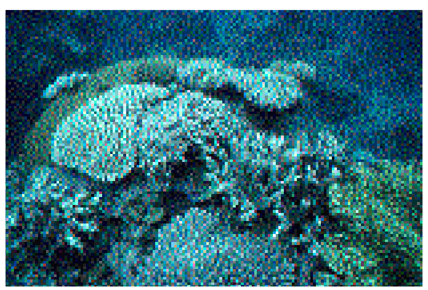
The epibenthic communities found at Udang Bank were extremely varied. The *Halimeda* cover varied from the highest yet seen on any transect undertaken on the Big Bank Shoals, to one of the lowest.

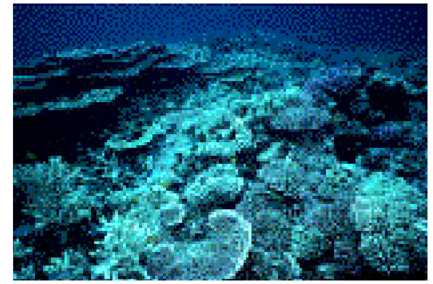
Coral ecosystems

Documenting and researching Australia's coral communities has focused on the most recognisable and accessible locations, such as fringing reefs, barrier reefs and emergent atolls. Submerged areas between such shallow water features have received relatively little attention from coral reef biologists. The discovery in the Timor Sea that corals are the dominant organisms on the plateaux of four submerged banks, and are also present to a lesser degree on most others, is a major finding of the Institute's current research. It raises questions about the true extent of Australia's coral reef associated biological resources, which at present may be underestimated.

Understanding the structure and function of these Timor Sea coral communities provides innumerable challenges for marine science. A great deal, nonetheless, can be inferred from our knowledge of corals elsewhere. This section provides a background of coral biology and ecology, together with detailed descriptions of the research findings from the four coral-dominant banks: Kepah, Kepiting, Tiram and Sleepy.

Populations of many coral species can be important components of the benthic fauna over a wide latitudinal range, even in the subtropics and into temperate zones. In cooler waters, however, the corals tend to grow as isolated colonies or form a single layer on the sea floor substrate. Warmer waters and abundant sunlight in the tropics favour more various growth. Shallow waters, which rarely drop below a winter minimum of 18°C, generally permit a diverse range of coral species to build their stony skeletons at a rate fast enough to form reef frameworks. These in turn support a wide range of other organisms. The resulting three-dimensional structures can be large and extremely diverse biological entities, as typified by the numerous reefs rising to the sea surface along the length of the Great Barrier Reef.


A highly diverse ecosystem: a coral reef (T. Done).


A coral reef (E. Lovell).

Various forms of calcium carbonate, a type of limestone, provide a ubiquitous building material for the skeletons of stony corals and many other marine organisms. This skeletal material remains and may slowly accumulate after the organism dies. Hard coral skeletons, the calcareous red and green algae and the shells of foraminifera, are the major contributors to reef-building. The sclerites of soft corals, the spicules of sponges and the hard parts of echinoderms, crustaceans, molluscs and others generally make lesser, but still important, contributions to reef-building.

Coral reef communities are estimated to occupy about 600,000 km^2 of the tropical seas. They are among the most diverse living assemblages in the world, supporting thousands of species and representing most of the living phyla. Their occurrence in nutrient deficient, tropical waters has fascinated biologists for decades. An explanation for this revolves around the evolution of symbiotic associations between algae and corals (both soft and hard). In addition to providing both structure and habitat for other reef organisms, corals are vital to the flow of energy through the reef community. Symbiosis and other aspects of the biology and ecology of corals are considered in the following sections.

Biology and ecology of hard corals

Corals tend to be modular or colonial organisms, with each coral colony composed of numerous repeated components. The basic component is the polyp, which has the form of a small sea anemone. In hard corals, the polyp tissues secrete limestone skeletal material which provides the colony with a distinct shape. Their physical shape provides vital structure to the reef and refuge, and surfaces for attachment for the varied organisms associated with coral reefs (see *Associated fauna*, page 86). This is a fundamental structural feature common to the hard corals, classified as Scleractinia, an order of the Subclass Zoantharia (or Hexacorallia). They are a diverse group and comprise several hundred distinct species (see Figure 23).

Symbiosis

Most common corals live in a mutually beneficial (symbiotic) relationship with numerous zooxanthellae (single-cell algae), living within their tissues. The zooxanthellae use light to produce organic carbon compounds but, like all plants, can only do this when they are supplied with nutrients. The nutrients they need are provided by the waste products of the coral polyps. While many corals are able to capture food with their tentacles, they obtain a large proportion of their energy needs from the zooxanthellae. Of all organic carbon produced by the symbiotic algae, over 94 percent is used as a food source by the coral polyp. The photosynthesis driven productivity of the algae allow coral to secrete their limestone skeletons two to three times faster than would be the case without light.

Coral growth

A coral polyp is an animal essentially consisting of a mouth surrounded by tentacles and a simple body cavity (Figure 24). The polyp can be thought of as the building block of a colony. The physiological link between coral and alga, resulting in exchange of metabolic products, ensures that rapid coral skeleton building is dependent upon light. A coral colony begins when a single polyp grows by budding or cloning new and identical polyps. The colonial nature of corals means that the size and life span of individual polyps are not limiting factors of ultimate colony size and age. Theoretically this may be unlimited, but in practice some species tend to grow larger and live longer than others. Many coral species can produce colonies with life spans of decades, but only a few are confirmed to

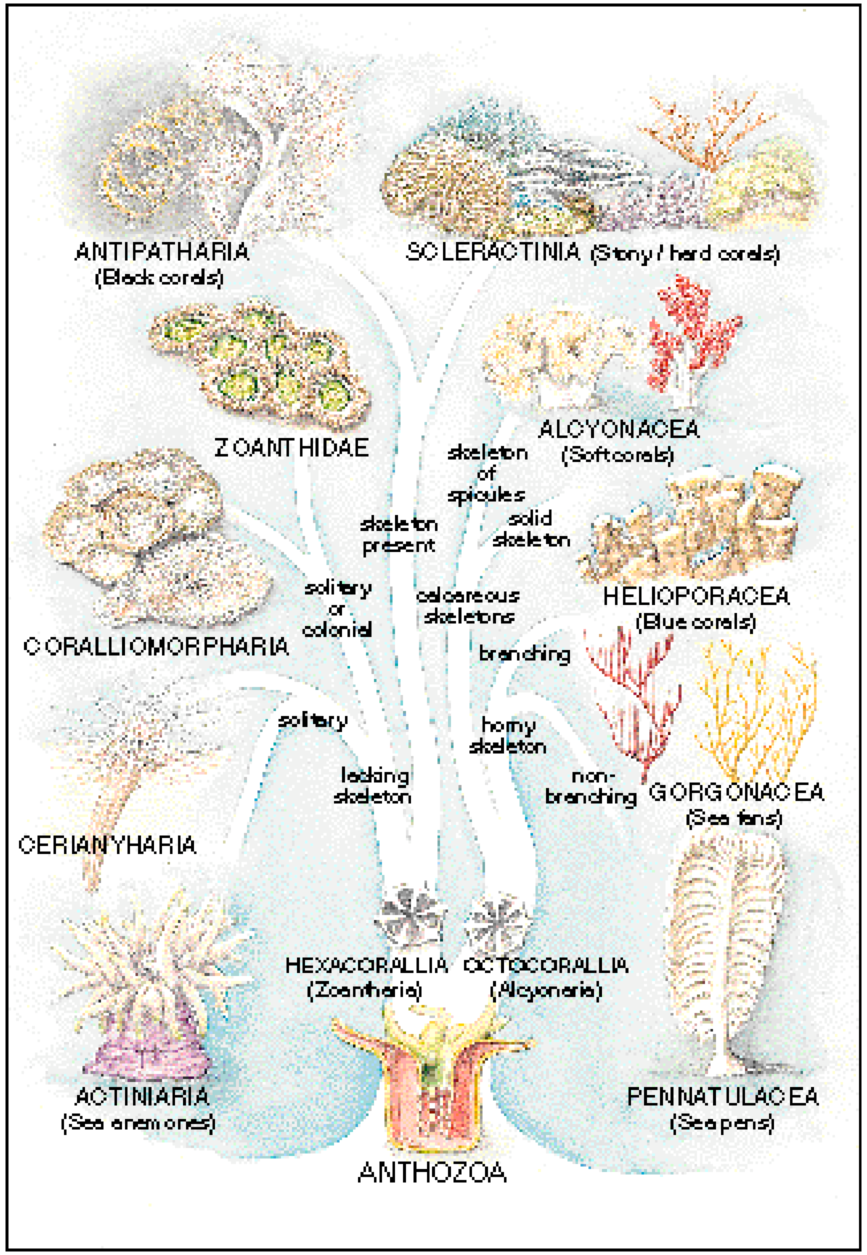
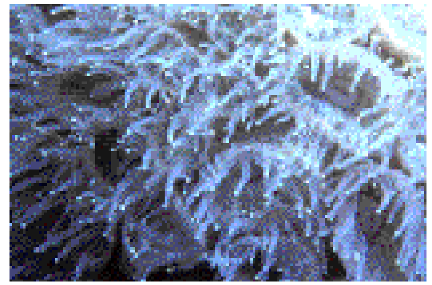


Figure 23. Relationships within the Class Anthozoa.

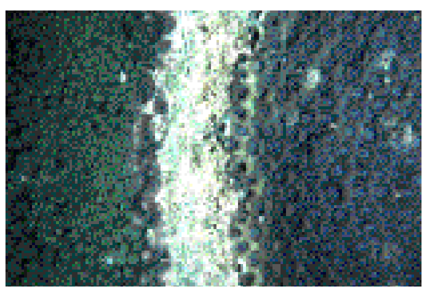
be able to live for multiple centuries as intact colonies. Each polyp secretes a skeletal cup of calcium carbonate beneath the external veneer of living tissues, into which the polyps (of most species) can withdraw for protection. Growth involves the formation of new skeletal cups on top of the old ones, as well as the adjacent budding of new polyps.

Colony growth rates are highly variable between different species and the growth forms within species. In the larger branching corals (*Acropora* spp.), growth is achieved by specialised, axial polyps which bud radial polyps in a precise pattern, forming intricate structures. These corals have the highest linear growth, with branch extension rates reported of up to 15 cm a year. At the other end of the range, massive *Porites* bommies, that can reach sizes in excess of 9 metres in height, may achieve radial colony increments as low as 8 mm per year. The majority of species, however, grow at intermediate rates, with many massive forms achieving radial increments of 1-2 cm per year and plate type and branching corals somewhat more.



A group of coral polyps feeding at night (GBRMPA).

Competition



Competition between two corals (E. Lovell).

Inevitably, colony growth leads to potential overlap with neighbours. Some species possess sweeper tentacles which can reach out and inhibit the growth of an adjacent competitor, although a variety of more subtle strategies have been noted. Like plants, corals can outgrow a competitor and shade them from the light. At a superficial level it may appear that fast growing species should be able to outcompete ones that grow more slowly. However, the structure of branching corals makes them more susceptible to physical damage and predation and so their high growth rates do not ensure competitive success.

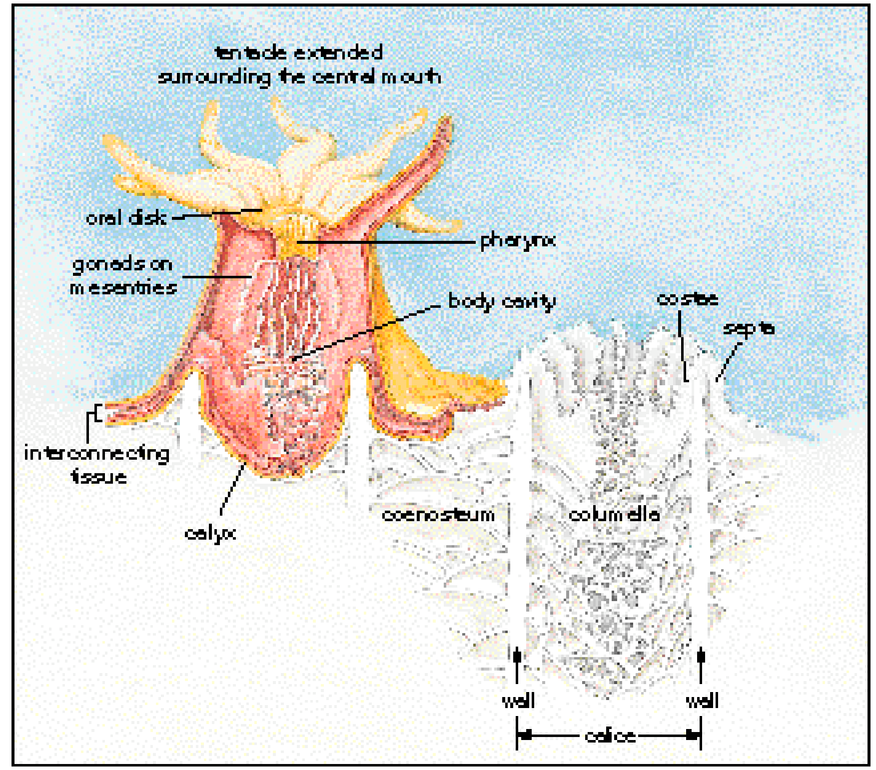


Figure 24. Major features of a coral polyp.

Competitive success can also be viewed in terms of the relative abilities of species to occupy space by asexual reproduction of clones. Asexual reproduction allows corals to rapidly produce copies of themselves that settle close to the parent. A coral may outcompete its neighbours by filling all available substrate with these genetically identical copies of itself. In this way one set of genes (a genotype) may compete against another genotype of the same species, or a soft coral may outcompete a hard coral.

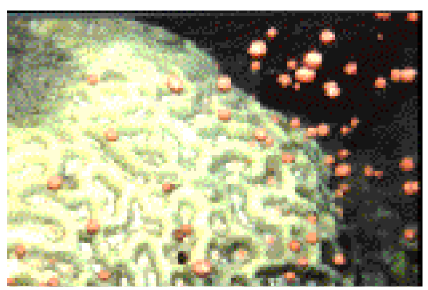
Consequently, coral reefs are held in a series of complex interactions that allow no single species to completely dominate. The result is a highly diverse community of invertebrates competing for light, food and space.

Reproduction

Corals propagate themselves by a variety of methods, and many species can be considered analogous to plants in this respect. Both asexual and sexual modes of reproduction rapidly produce copies of a colony on the reef of origin, while sexual reproduction increases genetic diversity and provides a mechanism to disperse offspring further afield.

The arrival of new juvenile corals to renew populations is an essential process for the long-term viability of diverse coral reef communities. Sexual reproduction leading to the production of small, free-swimming planula larvae, which subsequently attach to the substrate and form new colonies, is the typical reproductive pattern (Figure 25). However, vegetative or asexual propagation is also common and can be particularly important for local proliferation in selected species.

A significant ecological dichotomy amongst corals is apparent in the reproductive pathways leading to production of planulae larvae. Planulae may be produced via external fertilisation or brooding. Brooding corals fertilise their eggs within their body cavity, where they develop into planula larvae before being released. It has been shown that some brooded larvae are capable of settling almost immediately upon release, while others can survive for prolonged periods



Spawning of a hard coral (J. Oliver).

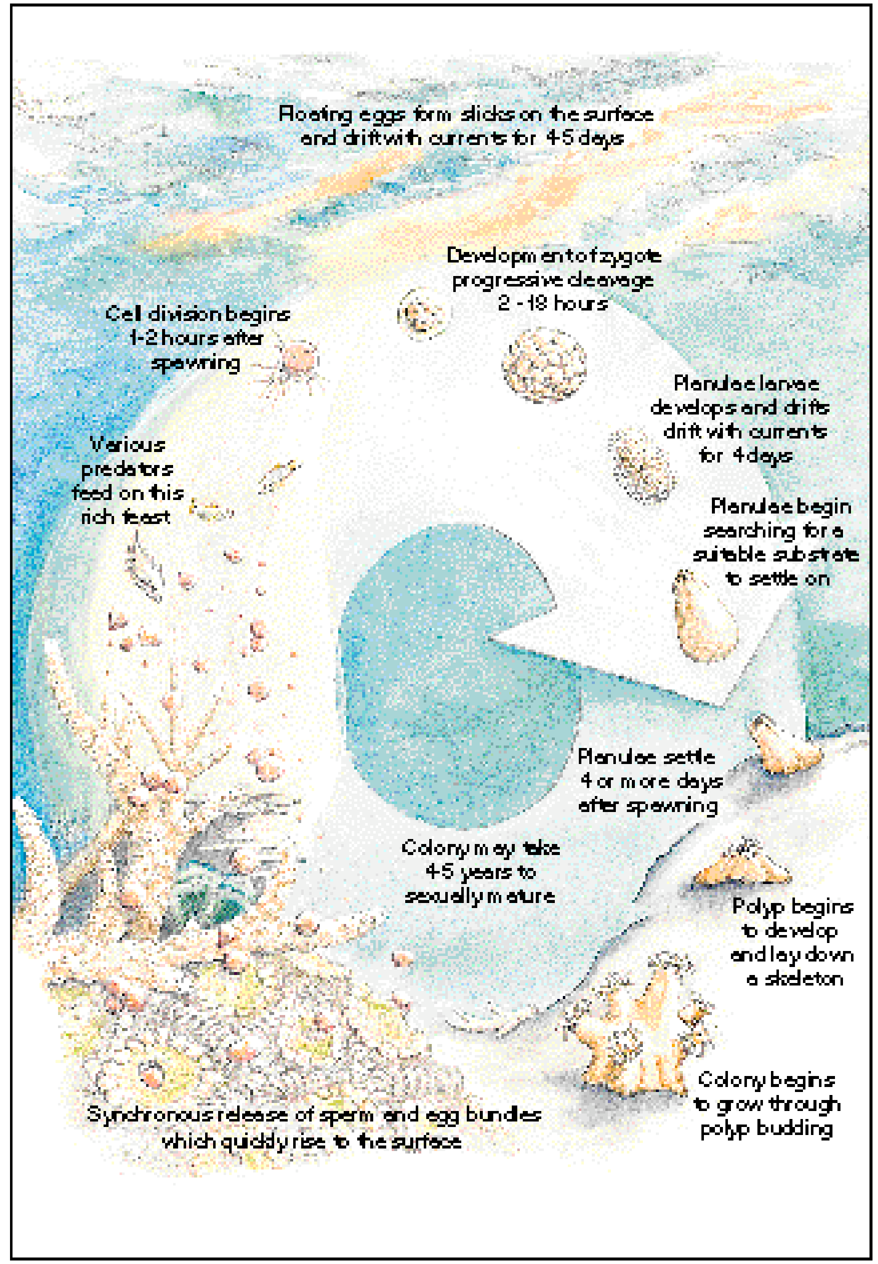


Figure 25. The generalised life cycle of a broadcast spawning hard coral.

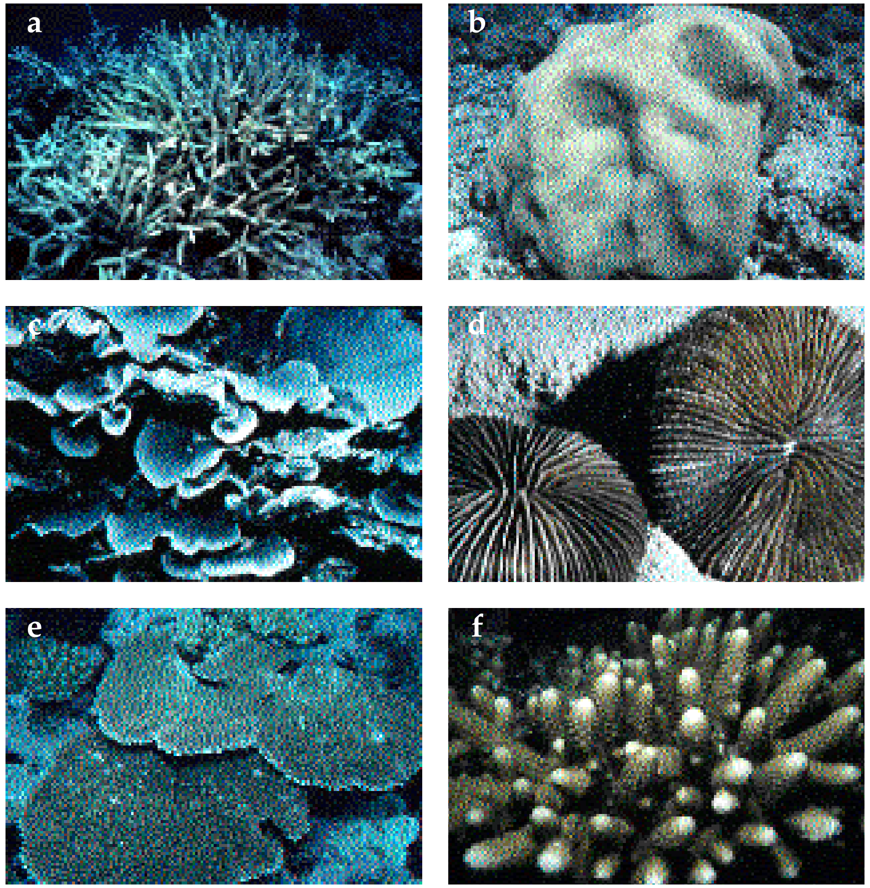
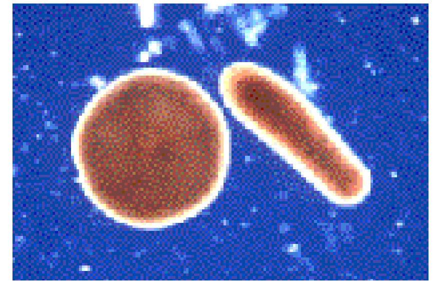


Figure 26. Hard coral morphologies. a: digitate *Acropora* sp., b: massive *Goniastrea* sp., c: foliaceous *Leptoria* sp., d: solitary *Fungia* sp., e: table *Acropora* sp., f: corymbose *Acropora* sp. (AIMS).

and disperse widely. Symbiotic zooxanthellae, inherited from the parent colony, are thought to help sustain these larvae. Some very important and ubiquitous species in several of the dominant coral families rely on brooded planulae. The majority of corals, however, release eggs and sperm into the water and depend on external fertilisation and development of their larvae (see *Mass spawning of corals*, page 48). Coral eggs released using this method of spawning are rich in fatty yolk. This provides energy reserves during larval development and also makes the eggs highly buoyant.



A planula larva (P. Harrison).

Fertilised eggs gradually develop into planula larvae over the next 24-36 hours. Laboratory studies suggest that these larvae will continue to drift in currents for at least 3 days before being fully developed and able to settle onto reefs (see Figure 25). Planula larvae can settle onto a variety of substrates, but recent research suggests that certain chemicals found in reef environments can actively promote attachment of the larvae and stimulate metamorphosis into single coral polyps. Once firmly attached to the substrate the primary polyp builds a skeleton of calcium carbonate then begins to form a growing colony by budding new polyps. The age or size at which sexual maturity is reached varies between each species, but many of the common, reef-building species require 3-5 years before reproducing for the first time.

In addition to sexual planula production, five different modes of asexual reproduction have been identified in hard corals. All of these result in the creation of new colonies that share exactly the same genotype as the parent colony. While several unusual forms of asexual planula and polyp production have been recorded, two types of colony fission are probably much more significant. Fragmentation, common in branching and plate-like colonies, is one of the more significant. When pieces of the colony are broken off they may re-cement themselves to the reef surface and grow to produce a new colony. Similar but controlled whole colony fission (splitting) occurs in some species (among them the unattached, fungiid species) in the early stages of development. This process may explain large fields of fungiids found on some reefs.

A newly settled coral (C. Wallace).

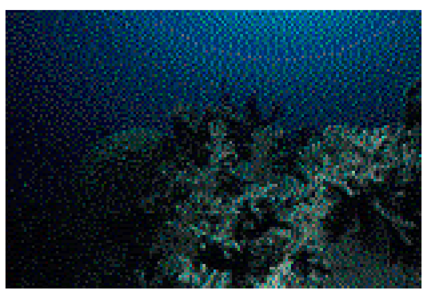
Biology and ecology of soft corals

Soft corals (Order Alcyonacea)are the second most abundant benthic animal in coral reef communities of the Indo-Pacific. They are closely related to the dominant scleractinian corals (Figure 23) but lack the rigid, stony skeleton. They are classified within the Octocorallia goup, a subclass of the Class Anthozoa. The Order Alcyonacea, (species that are commonly called soft corals) and the Order Gorgonacea (gorgonian sea fans and sea whips) are the groups that contain the majority of the octocoral species. Here we consider the general biology of the Octocorallia and focus on features of the Alcyonacea, which were most commonly found in association with hard corals on the banks plateaux. The Gorgonacea are dealt with in the section on deep water, *Filter-feeding ecosystems* (page 60).

General biology

Like the hard corals, soft corals are colonial organisms made up of numerous polyp units. Colonies are usually cemented to a hard surface and remain attached (sedentary) for the whole of their life span. However, some species are capable of moving. The colony can creep slowly around the reef by extending the tissues of its base in the direction of travel.

A principal architectural difference between hard and soft coral polyps is the number of tentacles present. While the stony corals have polyps with six tentacles and mesenteries (or multiples of) soft coral, polyps have eight tentacles. The tentacles are subdivided so that two rows of fine, comb-like pinnules fringe the length of each one and the polyps are arranged so that they lie side by side, with their mouths and tentacles facing out to the surrounding water. A common

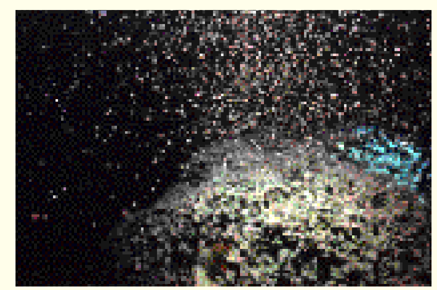


The soft coral, *Nephthea* sp. (AIMS).

Mass spawning of corals

Until the 1980's corals were generally thought to reproduce via the production of brooded planula. However, a group of scientists working on the Great Barrier Reef began to observe certain species broadcast spawning their gametes. The species list grew rapidly and by 1986 more than 100 hard coral species and numerous soft corals had been discovered to spawn in this way. To ensure successful reproduction, colonies of the same species must synchronise their spawning, using cues, such as water temperature and moon-phase. Each geographical location around the world may have different timing for coral spawning, but on any given reef and most notably on Australian coral reefs, the spawning time for numerous species coincides. This has resulted in one of the most spectacular biological phenomena, known as the coral mass spawning. Multiple species of coral spawn over one or two nights, releasing their gametes almost simultaneously. Millions of eggs and sperm are released following the full moons in either late spring (GBR) or early autumn (WA).

Spawning is predominantly a night-time event, frequently occurring between sunset and midnight. Prior to releasing their gametes the polyps in the colony can often be observed going through a preparation phase where the gametes are gathered together prior to being ejected through the polyp mouth. The most common hard corals are hermaphroditic, containing both eggs and sperm in their polyps, and the preparation phase enables both types of gametes to be packaged together into highly buoyant bundles. The often brightly coloured (red, pink or orange) packages can be seen clearly at this point. Within the next hour the gametes are released, rising slowly to the sea surface. These join eggs and sperm released from hundreds of other colonies (Photographs by P. Harrison and G. Bull).



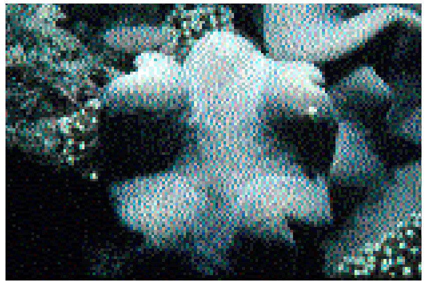
mass of tissue, called the coenchyme, surrounds and joins the polyps to form the colony.

Octocoral tissues are supported by numerous, small pieces of calcium carbonate, called sclerites, which are found throughout the coenchyme. These stiffen the soft tissues and in some species are fused to form a stiff support. The sclerites may project externally, in bundles that encircle the polyps. The spiky bunches of sclerites discourage predators, and in some cases may facilitate more efficient filter-feeding by supporting the polyp tentacles in swift water currents (Fabricius, 1995).

Polyps of the soft coral, *Nephthea* sp. (K.Fabricius)

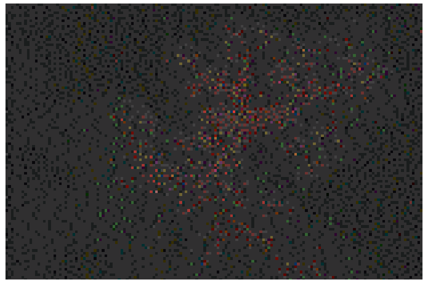
Nutrition

The relationship between the soft coral colony and its zooxanthellae is essentially the same as for hard coral. Many soft corals harbour symbiotic zooxanthellae and rely on them for essential photosynthetically derived products. These species are limited to depths where there is sufficient light for photosynthesis. They often utilise a combination of approaches to obtain adequate nutrition and even in shallow water, where there appears to be abundant light, many soft corals have a requirement for filter-feeding to supplement their energy supplies (Fabricius, 1995). Soft corals living in deep water tend to lack symbiotic algae and rely exclusively on harvesting their food from the surrounding waters.



The soft coral, *Sarcophyton* sp. (AIMS).

Filter-feeding involves the removal of plankton from water flowing around the colony. Recent data on soft corals indicates that they successfully feed on very small planktonic particles, such as unicellular algae (Fabricius, 1995), rather than larger zooplankton, as has been generally presumed. In order to harvest small particles, such as these algae, soft corals use the fine gaps between the feather-like pinnules on the tentacles to achieve effective filtration.

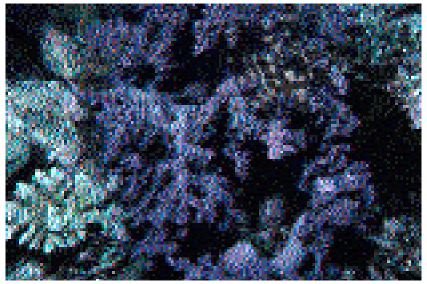


An ahermatypic, *Dendronephthya* sp. (AIMS).

Reproduction

Populations of soft corals are maintained by both sexual and asexual reproduction. The relative importance of each varies within the three major Families of the Alcyonacea (Xeniidae, Nephtheidae and Alcyoniidae). Vegetative or asexual reproduction, via colony fission, can be important for increases in population size of soft corals. As with hard corals, specialised and unspecialised modes of colony fission have been recorded.

The trigger that starts asexual reproduction usually comes from within the colony and may occur almost constantly. Mature colonies of *Dendronephthya hemprichi* (Nephtheidae) release fragments nearly every day (Fabricius, 1995). Deliberate fragmentation is the result of the colony producing small buds that detach and fall near the parent. Similarly, high rates of asexual reproduction have been reported for several species of the Xeniidae, as well as the Nephtheidae. The Family Xeniidae have a unique mode of reproduction whereby colonies produce elongate runners or stolons which extend along the bottom. Another colony forms on the end, in time the connection withers, resulting in two separate colonies. A few species are capable of longitudinal fission where the parent colony splits down its length and two discrete colonies result.



A brightly coloured soft coral (L. De Vantier).

Sexual reproduction in soft corals is very similar to that of hard corals, leading to the production of planula larvae. Both broadcasting and brooding species exist and similar processes of larval dispersal apply as with hard corals. All three families contain species that are predominantly dioecious (some colonies are male and others are female) in contrast to the high frequency of hermaphroditism found in hard corals. The majority of the Family Alcyoniidae are broadcast spawners and the release of gametes can coincide with the mass spawning events of hard corals (see *Mass spawning of corals,* page 48). The general coral life cycle (see Figure 25) applies, with the important modification that many soft corals mature their eggs prior to release over two spawning cycles. This is in contrast to the annual gametogenic cycle observed in most broadcast spawning hard corals.

Predation and defence

The sessile nature of soft corals, along with their soft bodies, would appear to make them obvious targets for predation. However, surveys reveal that the level of predation is surprisingly low (Sammarco and Coll, 1992). The corals have a variety of effective means to discourage attack. Some species merely withdraw their polyps into the colony whereas others rely on the spiky nature of their sclerites. A large number of species defend themselves by producing noxious chemicals called terpenes. This class of chemicals is also used by terrestrial plants (such as pines and eucalypts) to render them distasteful to grazing animals.

Coll and Sammarco (1986) found that almost 90 percent of soft corals tested contained terpenes that made their tissues unpalatable to predators. Fifty percent of the soft corals contained compounds that were toxic to fish. Soft corals that have defences, like sharp sclerites or the ability to retract their polyps, are less likely to be toxic to fish. However none of these precautions guarantee immunity from predation. There is a select group of coral reef animals that have evolved specific adaptations, allowing them to exploit the abundance of soft corals. For example, the egg cowry (*Ovula ovum*) and a butterflyfish (*Chaetodon melannotus*) feed on toxic soft corals with impunity.

Coral banks of the Big Bank Shoals

A number of previous coral surveys have been undertaken on reefs in and around the Timor Sea. In October 1978, members of the Western Australian Museum surveyed Ashmore Reef aboard the Soviet vessel *R.V. Professor Bogorov*. Collections of corals, molluscs and echinoderms were made (these are included in Berry, 1993). In 1986 an extensive survey was undertaken of Ashmore and Cartier Reefs(see Figure 1), where samples of corals were collected. A total of 56 genera, represented by 255 species, were recorded (Berry, 1993). These figures represented the highest richness of coral species for any area within Western Australian waters. Surveys along the Kimberley coastline over a number of years, have revealed 102 species from 45 genera. However, these figures probably significantly under-represent the true numbers because of the limited samples taken during the survey and the great extent of the area surveyed (Veron and Marsh, 1988). A further survey and report was undertaken by the Northern Territory Museum in May 1992 (Russell and Hanley, 1992).

The Australian Institute of Marine Science has undertaken coral community surveys from 1993 onwards, of the emergent Scott and Seringapatam Reefs, south of Ashmore Reef (Done *et al.*, 1994 and Heyward *et al.*, 1997). Taxonomic surveys were undertaken on these reefs during initial visits and in 1994 long-term monitoring was initiated to study spatial and temporal changes in the coral communities of these reefs. Coral and fish recruitment data has been collected by AIMS from Scott Reef and Rowley Shoals since 1996, to elucidate the seasonal recruitment peaks and underpin future research into regional connectivity (Smith, Heyward and Halford, unpubl. data).

The Sahul Banks and the Big Bank Shoals were surveyed by the Australian Geological Survey Organisation (AGSO) in 1993. Surface sediments were sampled and dredges were undertaken at a number of banks. Numerous dead and live fragments were retrieved, including genera such as *Goniastrea*, *Pocillopora*, *Seriatopora*, *Porites*, *Goniopora* and *Fungia*. While the AGSO survey indicated the presence of at least six genera, it was inferred that extant coral communities were generally insignificant and little more was discovered in regard to coral distribution and abundance.

Hard corals of the coral banks

The current ROV video surveys on the epibenthic communities of submerged Timor Sea shoals have been undertaken by BHP Petroleum in consultation with AIMS. Scientists at the Institute have analysed the video, using the resultant data to describe the distribution and abundance of major benthic groups rather than attempting to construct extensive coral species lists. While previous surveys by AGSO (Marshall *et.al.* 1994) revealed extensive *Halimeda* banks that were interspersed with small hard corals (fungiids and pocilloporiids), the present investigations indicate that some banks of the region are coral-dominated systems, with what appears to be a reefal structure (Figure 27 and 28). Kepiting, Kepah, Sleepy and Tiram Banks were found to be dominated by hard and soft corals (see film strips *CC01* to *CC12*) rather than the calcareous algae, *Halimeda*, which frequently dominated other banks. Overall live cover was very high compared to the *Halimeda* banks of the Big Bank Shoals, ranging between 95 percent at Kepiting to 75 percent at Tiram (Figures 27). In comparison, *Halimeda* banks averaged approximately 40 percent overall live cover of the substratum.

Sixteen genera of scleractinian corals were noted from the ROV video tapes recorded at the coral-dominated banks. Such sampling techniques underestimate total genera richness because of an inability to detect small

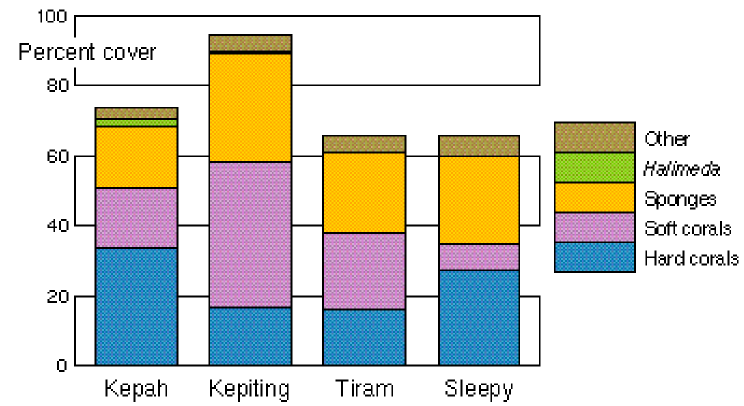


Figure 27. Histogram showing the major benthic categories of the coral-dominated banks of the Big Bank Shoals.

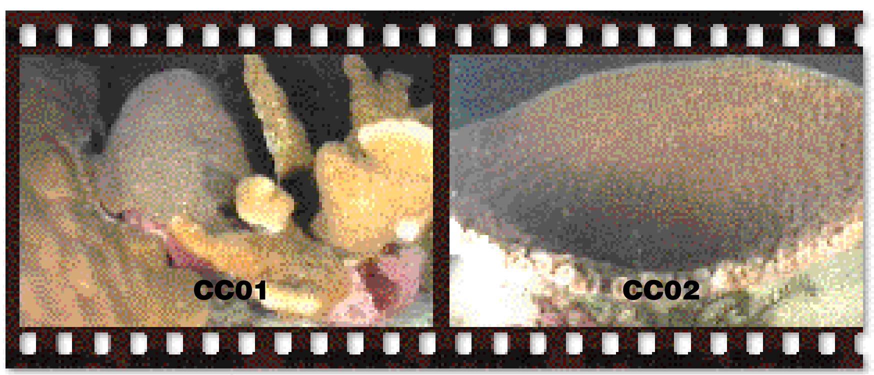
or cryptic species. The most abundant hard coral (with the exception of Sleepy Bank) was the massive coral *Porites* sp. (see film strip *CC03*). These corals can be extremely old and attain huge sizes. On the coral banks of the Big Bank Shoals they rise up to 4 metres above the substratum and are scattered between 10 metres and 20 metres apart on individual banks. When small sections of these corals die the dead skeleton provides a hard surface upon which other invertebrate larvae settle. Consequently, many other animals, such as gorgonians, sponges and other coral species (both hard and soft), were found growing on these coral colonies (see film strips *CC03*, *CC05*, and *CC08*).

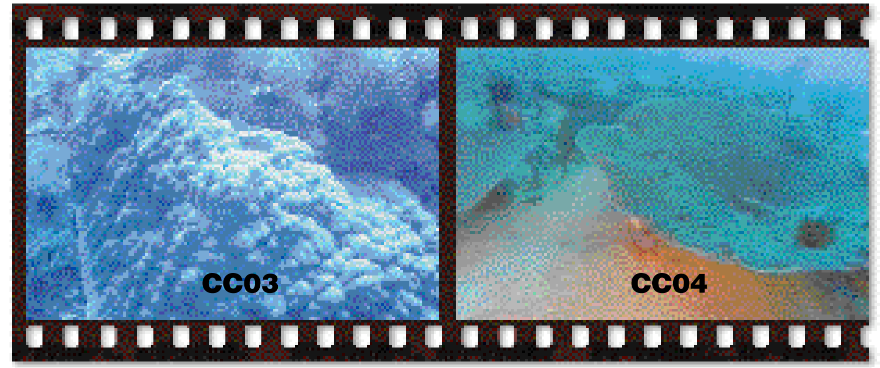
The branching corals, *Acropora* spp. are also common. The species of this genus exhibit a range of growth morphologies including tabulate, staghorn and encrusting. Branching species were the most common, sometimes forming thickets between large *Porites* colonies. Kepah Bank harbours the most vivid examples of monospecific stands of *Acropora* spp.

The community structure of the hard coral ecosystems (except for Sleepy Bank) is very similar to the composition of moderately sheltered, shallow communities at Scott Reef. For example, the east “hook” of South Scott is

12 percent poritids, 12.8 percent acroporiids, 3 percent pocilloporiids and 7 percent other coral families (Heyward *et al.*, 1995). In comparison, Kepah Bank is 9.5 percent, 13.5 percent, 1 percent and 9 percent for these family groups, respectively. Both have large, old *Porites* surrounded by branching acroporiids and other relatively small corals. Interestingly, the Scott Reef community is in far shallower water (9-12 metres) than the coral ecosystems of the Big Bank Shoals (15-50 metres).

Sleepy Bank is very different to the other three coral banks. Its coral community is dominated by foliaceous corals, like *Pachyseris* spp. and *Montipora* spp. (see film strips *CC02 and CC04).* On Sleepy Bank thin sheets are produced by these corals, forming whorls or plate-like colonies. Differences in the composition of the coral communities between Sleepy Bank and the other banks can be explained mostly by depth. Most corals are hermatypic, requiring light to produce energy (see page 44). The quality of light changes rapidly with depth, both in intensity and composition. Consequently, many hermatypic corals have a limited distribution. The tops of Kepiting, Kepah and Tiram Banks are in depths of between 15 metres and 26 metres. In contrast, Sleepy Bank is much deeper, being approximately 50 metres below the surface. While the corals there are still hermatypic they are species which are able to cope with lower light regimes. Differences between the coral communities of Sleepy Bank and the other banks may also be related to the effect of depth on water temperature and water currents. Interestingly the deeper banks, Sneezy (80 metres) and Wicked (70 metres), have almost no hard coral on them (Figure 38, page 67. These data suggest that coral growth is limited by depth below approximately 50 metres in the Big Bank Shoals region.

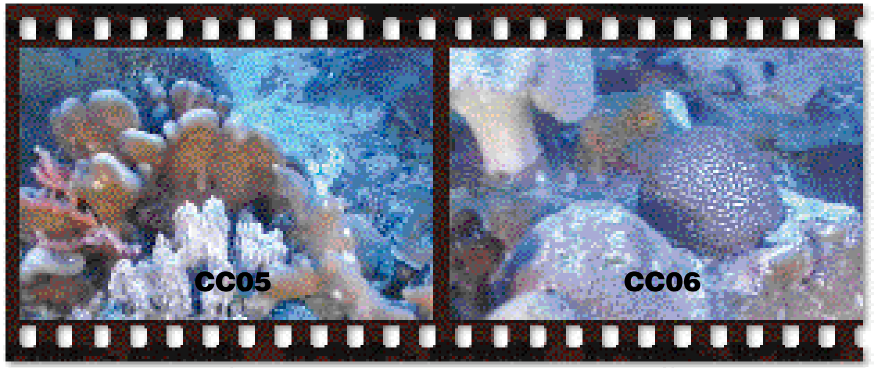




Soft corals of the coral banks

On the four coral-dominated banks, overall cover of soft corals ranges from 7 percent at Sleepy to 41 percent at Kepiting, with an all-transects average of 22 percent (Figure 27). While comparable soft coral abundance was recorded on the *Halimeda* banks of the Shoals (see section below) the two systems have very different soft coral species composition (Figure 28). *Halimeda* banks are dominated by soft corals of the Family Xeniidae. In contrast, on the coral banks the families Nephtheiidae and Alcyoniidae have the highest cover (see film strips *CC09 to CC11*).

Differences in the soft coral assemblages between the *Halimeda* banks and the coral banks are not easily explained. One possible explanation, however, may be the differences in substratum type on the two groups of banks. *Halimeda* rubble dominates the sediments of the *Halimeda* banks, and sand, coral rubble and the skeletons of hard corals make up the substratum on the coral banks. *Xenia,* the dominant soft coral of the *Halimeda* banks has the ability to grow over the unconsolidated rubble by means of stolons, which spread laterally through the sediment, thereby providing support. The soft corals from the Nephthidae and Alcyoniidae families, which are



found in high numbers on the coral banks, though not on the *Halimeda* banks, are unable to grow on the unconsolidated rubble. They require a harder substrate, which is provided by the coral rubble and dead coral skeletons.

Sponges of the coral banks

The coral banks of the Big Bank Shoals, like the *Halimeda* banks, support an extensive and diverse array of sponges (see film strip *CC12*). The coral banks, however, do appear to have a far higher diversity. Hard substratum, formed by the growth and death of hard corals, creates space for other invertebrates to colonise. Sponges are likely to quickly settle on these areas. While sponge species are impossible to discern from video, the coral-dominated reef habitats have sponge species representative of all major morphological groupings.

Halimeda and coral communities provide very different habitats and structures upon which other invertebrates can live. Consequently, the invertebrate groups observed at each bank type are distinct. *Halimeda* ecosystems are dominated by encrusting species (especially *Haliciona* sp.) that are able to grow upon the *Halimeda* plants, whereas more complex sponge morphologies (e.g. branching, vase and tubular) are found upon coral outcrops of the coral ecosystems.

Sponges are an important component in these coral reef communities. Kepiting Bank has the highest overall cover and Kepah Bank the lowest, being 30 percent and 17 percent, respectively. Overall cover of sponges is very high compared to emergent coral reefs of the Timor Sea region (those that break the water surface). For example, comparable areas (in terms of coral community, see page 52) at Scott Reef have a far lower coverage of sponges, at less than 3 percent (Heyward *et al.*, 1995) than any bank of the Big Bank Shoals. The reasons for this difference are unknown, and while noting high sponge diversity in the region, Hooper (1994) dismisses the concept of 'ubiquitous coral reef sponge fauna' as too simplistic. For further information on the sponges of the Big Bank Shoals, see *Filter-feeding ecosystems*, page 60.

Banks as living structures

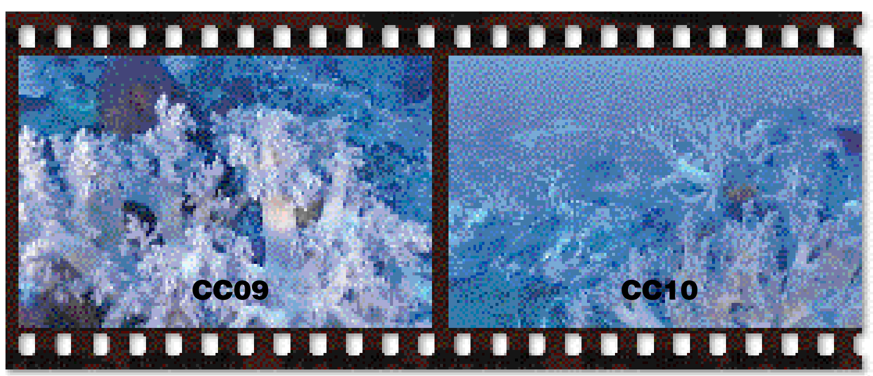
Coral reefs can be thought of as living carbonate structures that are able to grow towards and sometimes reach the sea surface. Cartier and Ashmore Reefs, located on the North-West Shelf, are both examples of this type of reef. The banks of the Big Bank Shoals are submerged and situated on a subducting margin of the Australian tectonic plate. It is not clear why some of these banks are coral-dominated while others are *Halimeda*-dominated. However, depth and light attenuation seem to play key roles. The three shallowest banks of the area exhibit coral-dominated communities. On other banks, areas of coral cover tend to be restricted to the bank rims, which are more elevated than much of the bank plateau. For

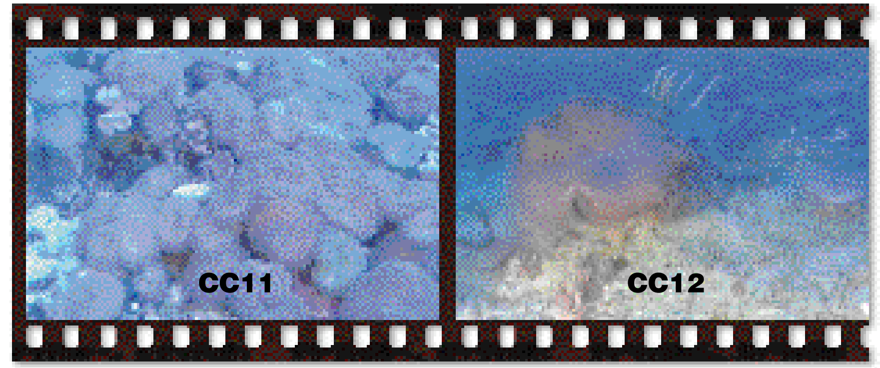
example, Big Bank has a large hard coral community on the western end of the bank, which is 4 metres shallower than the rest of the bank plateau. While depth may be significant in these bank rim areas, local currents, sediment regimes and substrate consolidation are all likely to play a role in determining coral distribution.

Regional context of the coral-dominated banks

The finding that abundant and diverse coral communities occur on some of the banks demands reconsideration of the bioregional character of the Timor Sea. In previous studies, a functional or conceptual distinction appears to have been made between the reef complexes of the three emergent reefs to the southwest: Ashmore, Cartier and Hibernia, and the coral communities of the Sahul Shelf Shoals (see, for example Marshall, 1994). This may not be the most reasonable view.

The abrupt bathymetry of the banks and the presence of diverse and abundant coral communities, particularly on the shallowest banks, are features shared with the emergent reef systems to the southwest. Dredge sample data (Marshall, 1994) also indicates that at an earlier stage of development, the banks had substantial reef growth around their perimeters. The Sahul Shelf is a recently drowned extension of the Australian platform and seismic data indicates that the Shoals have had periods of subaerial exposure. Therefore, we believe that it is reasonable to include the corals of





the Big Bank Shoal system within a regional association of shelf edge communities that occupy the outer edges of the Sahul Shelf. Both the submerged banks and three emergent reefs are located far from terrigenous inputs and are constructed from locally derived carbonate sediments. The high diversity of fauna occurring on the emergent reefs have similarities to both the Australian coastal and Indonesian Archipelago marine communities and many coral species are shared with Australia's east coast (see Veron, 1993 and Berry, 1986, 1993). This regional grouping encompasses a broad and loose association of widely dispersed coral communities, including the Rowley Shoals, the Scott Reef and Ashmore Reef areas and extending east beyond the banks of the Sahul Shoals to the Van Diemen Rise.

Individual banks

Of the banks surveyed by AIMS, Kepah, Kepiting, Tiram and Sleepy were those banks most dominated by corals. Both hard and soft corals made significant contributions to the epibenthic communities found on these plateaux. Each bank is described in more detail below.

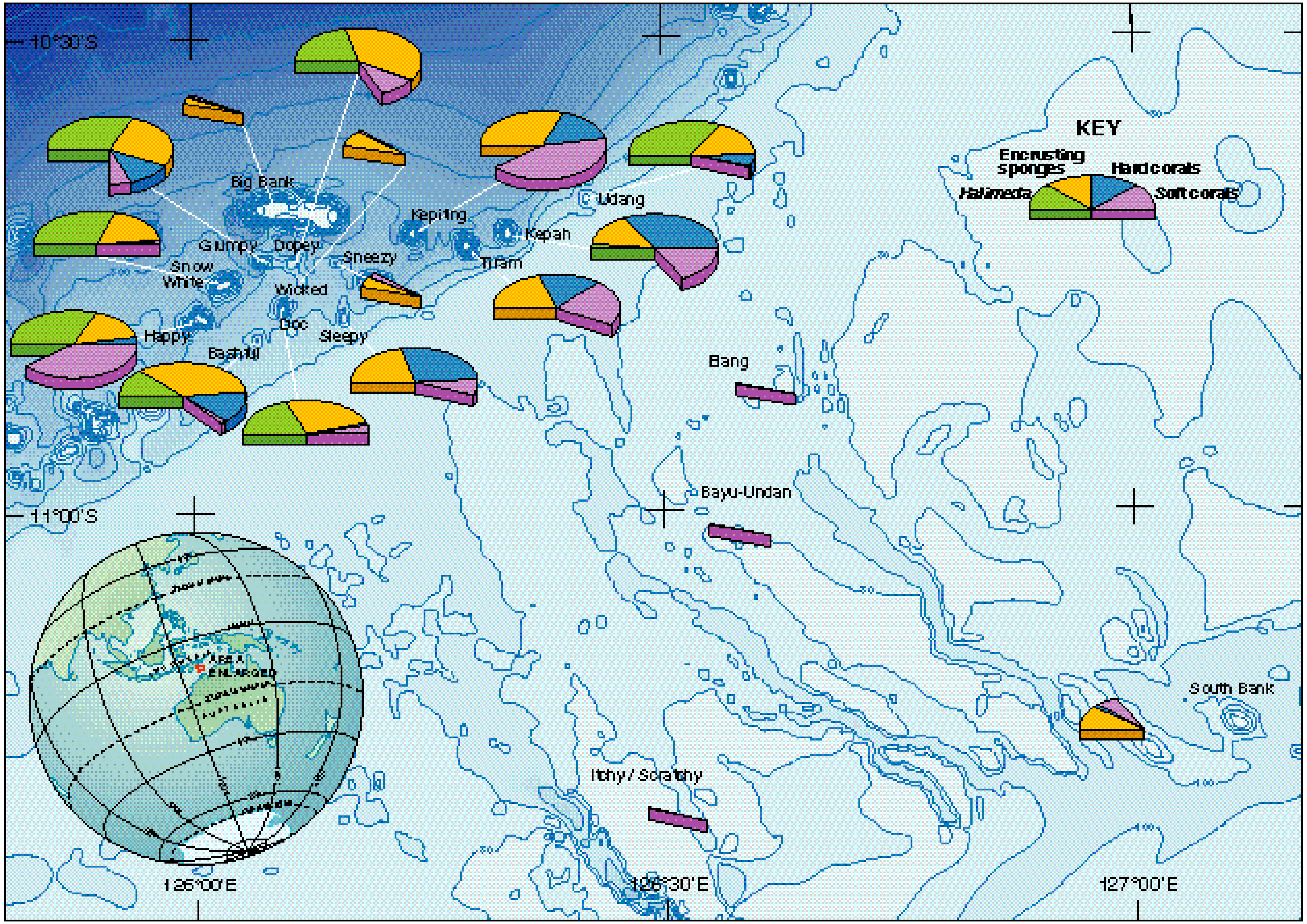


Figure 28: Map of the Big Bank Shoals showing the distribution of *Halimeda,* encrusting sponges, hard corals and soft corals.

Kepah Bank

Kepah Bank was found to have a rich invertebrate community, although, with the exception of hard coral, the relative abundance of each major group varied between the two transect locations. The area covered by hard coral exceeded 30 percent on both transects and was the highest recorded for any of the surveyed banks. Soft coral abundance was much less consistent, differing greatly between the two transects, as did total live cover. Moderate cover of encrusting sponges was a feature of both locations. Only minor amounts of calcareous algae, *Halimeda*, were seen on Kepah Bank.

The first transect was at a depth of 19 metres (see northern site, Figure 29) and the video revealed that 98 percent of the area was covered with live invertebrates, living on a rubble substrate (see film strips *KH01* to *KH03*). The total cover of hard coral was 34 percent, with at least three hard coral families, Acroporidae, Fungiidae, and Poritidae, being present. The Acroporidae and Poritidae were the most important hard coral families, covering 16 percent and 10 percent of the benthic area, respectively. *Nephthea* spp., was the dominant soft coral, providing 21 percent cover, while lesser contributions were made by *Sarcophyton* spp. (4 percent) and *Sinularia* spp. (3 percent). Encrusting sponges were less abundant than on other banks, but still provided 13 percent of the benthic cover.

The second transect was videoed at a depth of 26 metres (see southern site, Figure 29) and was found to have less live cover, although at nearly 65 percent, it was still high (see film strips *KH04* to *KH07*). Hard coral accounted for 31 percent of the total live cover. Acroporidae and Poritidae were the most abundant hard coral families at 10 percent and 8 percent, respectively. Sponges were well-represented. Encrusting sponges were found to cover 16 percent of the transect, while massive sponges occupied 3 percent, and branching forms were calculated to cover 1 percent. Soft corals (4 percent) were notably less conspicuous on this transect, with *Xenia* spp. and *Nephthea* spp. contributing 1 percent and 2 percent, respectively. The differences in the observed benthic communities at the two locations may be related to substratum changes. The area of the second transect was mostly sand-dominated, as opposed to predominantly calcareous rubble on the first transect.

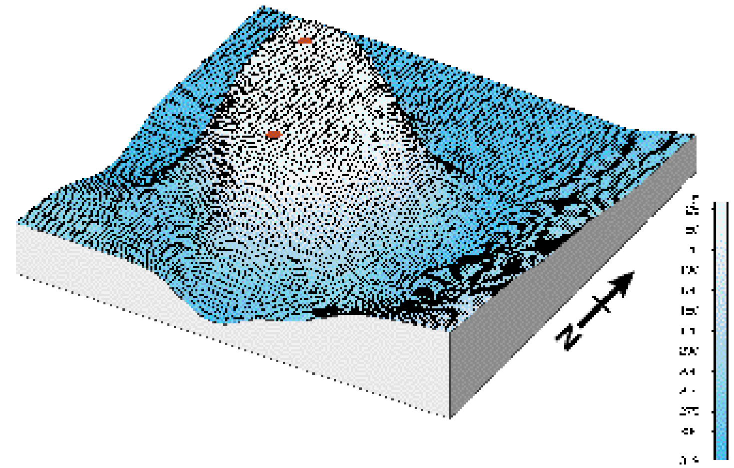


Figure 29. A three-dimensional bathymetry map of Kepah Bank (vertical exaggeration five times).

Kepiting Bank

The top of this bank is very shallow in comparison to the other banks (Figure 30). At a depth of 15 metres, the first transect was completely covered (100 percent) by live fauna. Observed assemblages were dominated by soft and hard corals and encrusting sponges were attached to a substrate that ranged from sand to rubble. The bank was characterised by a single species of soft coral. The nature of these soft coral beds and the fact that this species was not generally observed on other banks gave the impression that *in situ* asexual propagation may have been responsible for the abundance of this organism on Kepiting Bank alone. The two transect locations were very similar, with regard to these stands of soft coral, but somewhat more patchy distributions were noted for the other major benthic groups.

The community was dominated (36 percent cover) by an unidentified soft coral that resembles *Siphonogorgia* spp. (see film strips *KG01* and *KG02*). A further 4 percent of the total live cover was contributed by other soft coral species, from three families. Encrusting sponges made up an additional 36 percent, and hard corals (of at least three families), 12 percent. Poritidae were the dominant hard coral family (6 percent) composed of both branching (*Porites cylindrica*, 2 percent) and massive (*Porites* spp., 3 percent) forms (see film strips *KG03* to *KG07*).

The second transect sampled an equally diverse and abundant benthic community. The total live cover was 90 percent, with soft and hard corals dominating the transect. Extensive areas (40 percent) were occupied by the

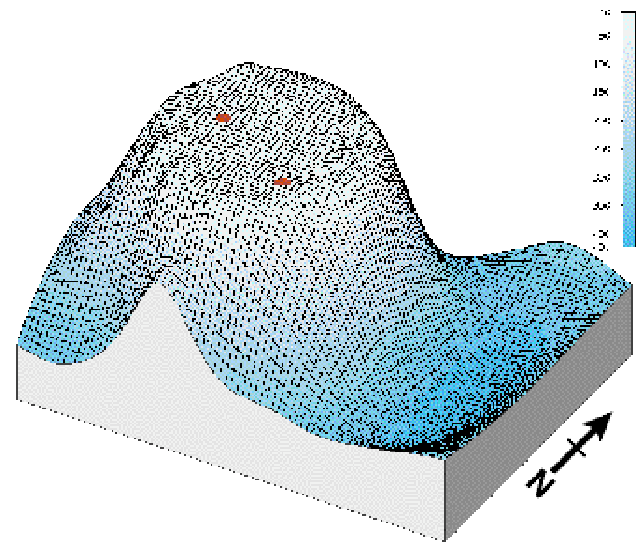
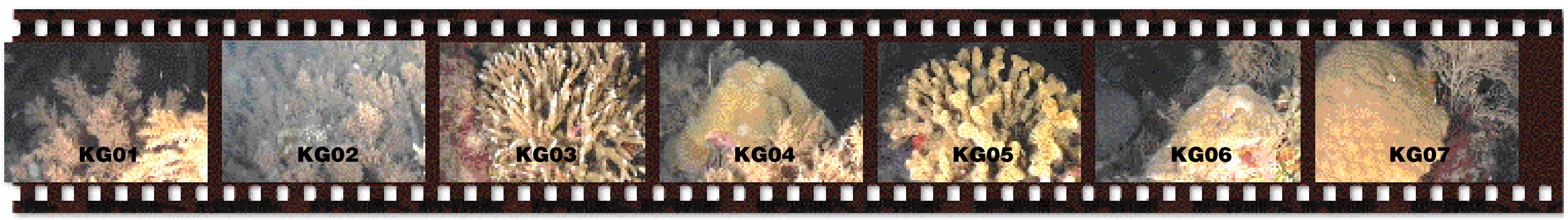


Figure 30 A three-dimensional map of Kepiting Bank (vertical exaggeration five times).

same unidentified soft coral noted above. Other soft coral species accounted for only 2 percent of the total coverage; primarily *Sinularia s p p .*, with occasional colonies of *Sarcophyton* spp., *Xenia* spp. and gorgonian fans. Hard corals held 19 percent of the occupied area, with at least three families present, in the following proportions: Poritidae 9 percent, Acroporidae 6 percent, Faviidae 2 percent, and other hard corals 3 percent. Encrusting sponges were also prolific, covering 24 percent. *Halimeda* was observed but was a very minor component of the benthos at this location. The substratum consisted mostly of calcareous sediments and sand.



Sleepy Bank

At Sleepy Bank, live cover was high, principally a mixture of hard corals and sponges, but the relative abundance of the major benthic groups varied markedly with location on the bank plateau. The spatial variation observed in relative composition and total live epibenthic cover was higher on this bank than any other adjacent bank.

The mean epibenthic cover at Sleepy Bank is approximately 64 percent, interspersed with patches of rubble substrate. When averaged across survey sites the benthic community at Sleepy Bank is dominated by hard corals (27 percent) and sponges (25 percent), with low to moderate amounts of soft coral (7 percent), (see film strips *SL01* to *SL07*). These statistics tend to hide the marked spatial variations which were observed. For example, hard coral cover exceeded 50 percent on the west transect yet was less than 7 percent on the southern site. Sponges were well-represented at all sites and were the most consistent component observed. The majority were encrusting species, although blade sponges were common. The proportion of living *Halimeda* on Sleepy Bank was also low, at less than 1 percent.

Of the three transects surveyed on Sleepy Bank the southern transect is quite distinct (Figure 31). Sleepy south had a coral abundance dominated by soft corals (18 percent), with only 6.7 percent accounted for by hard coral species. The other transects of Sleepy Bank revealed hard coral coverage of 20 percent and 54 percent. The latter statistic was calculated for Sleepy west, which had a unusual assemblage of hard coral species. The massive, large polyped *Lobophyllia* (see film strip *SL04*) was very common on this transect, accounting for 19 percent of the total live cover. Such a high concentration of this species was not seen on any other transect conducted in this survey. In shallow water reef systems, colonies of *Lobophyllia* have been observed to easily fragment into physically separate, viable polyp clusters. The localised high abundance of this species on Sleepy Bank could be due to a combination of sexual recruitment followed by local clonal propagation. Many echinoderms were observed on Sleepy Bank (see film strips *SL02* and *SL07*).

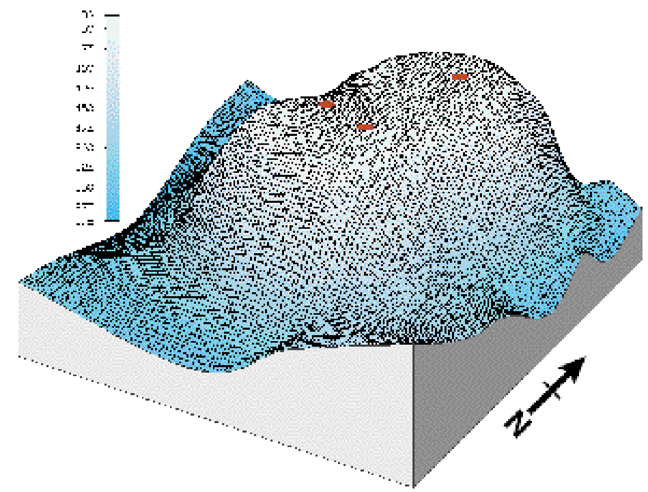


Figure 31. A three-dimensional bathymetry map of Sleepy Bank (vertical exaggeration five times).

Tiram Bank

This bank supports a prolific benthic communitylife. Differences in the relative abundance of hard and soft corals were noted at the two survey sites (see Figure 32), while sponges were well-represented at both. The relative proportions of hard and soft corals varied between transects. The first of two transects, conducted at a depth of 23 metres, revealed that 98 percent of the area was covered with live invertebrates living on a rubbly substrate. Here, the community contained a high proportion of soft corals. The Family Nephtheidae covered 21 percent of the substratum, while other soft corals, such as *Sarcophyton* spp., (5 percent) and *Sinularia* spp., (3 percent) made smaller contributions. In comparison, hard coral species were present in low numbers, represented by the families Acroporidae, Faviidae, Fungiidae and Poritidae, but occupied only 8 percent of the habitat. Of these, the Acroporidae were most common. Various sponge morphologies were observed, but encrusting sponges were the most abundant, accounting for 20 percent cover. Minor amounts of the algae *Halimeda* were found at this transect location.

The second transect was in slightly deeper water, at 26 metres, and had considerably less live cover than the first. However, at 60 percent, this is still high compared with reefs of the Great Barrier Reef (see Oliver *et al.*, 1995). The dominant benthic group was hard coral, accounting for 23 percent of total cover, while soft coral contributed only 7 percent cover (see fim strips *TM01 to TM07*). The Poritidae and Acroporidae were the most abundant hard coral families, recording 12 percent and 5 percent,

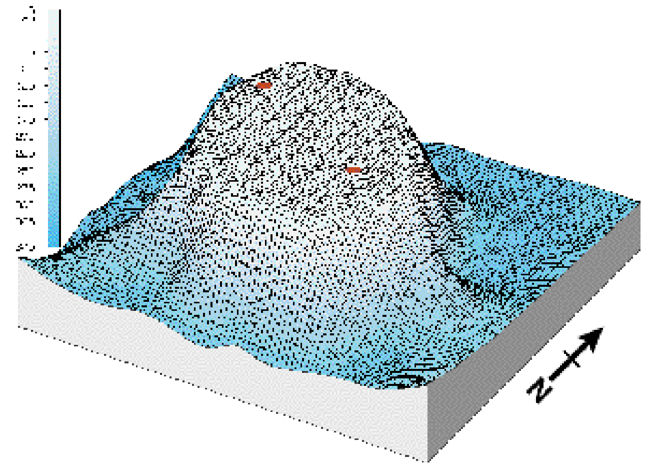
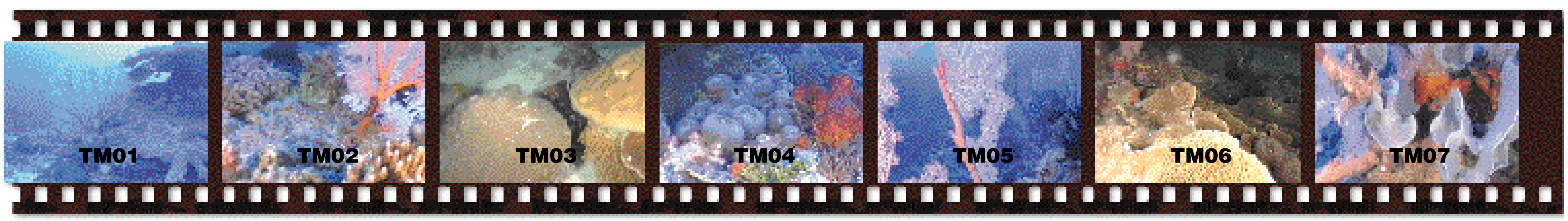


Figure 32: A three dimensional bathymetry map of Tiram Bank (vertical exaggeration five times).

respectively. Sea fans, from the soft coral Family Gorgonacea, were found here in greater numbers than in any other coral community of the Big Bank Shoals (see film strips *TM01* and *TM05*). They represented 5 percent of the total live cover. The only other record of them, amongst coral communities, was at a level of 0.4 percent on the northern part of Kepiting Bank. Despite the rather different proportions of other benthic groups, between this and the previous transect the encrusting sponges were comparable, at 22 percent cover.



Filter-feeding ecosystems

Three of the banks, Wicked, Sneezy and South, were shown to form a group which is quite distinct from the light dependent *Halimeda* and coral dominated communities common to other banks of the Big Bank Shoals. Wicked and Sneezy are surrounded by *Halimeda* dominated banks close to the edge of the Timor Trough. However, their plateaux are too deep for photosynthesis dependent organisms, such as *Halimeda* and hard corals, to thrive. South Bank, the third member of this group, is a large bank located approximately 100 km landward on the shallower Continental Shelf. Although water depths are shallow enough to sustain light dependent corals, and the bank is dominated by macro-algae, *Halimeda* is absent. Although the lack of *Halimeda* is a common feature of these three banks, it is the similarities in the structure and function of their benthic fauna that form the primary linking factor between them.

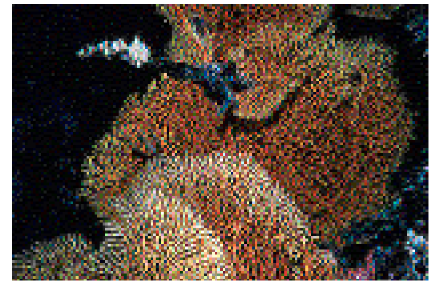
South Bank is distinctly larger and has a more complex benthic ecosystem than Wicked or Sneezy. The common link between this and the other two banks is a benthic fauna dominated by a diverse assemblage of filter-feeders. These fauna are heterotrophic and extract their food from the surrounding waters. A mixture of sponges and soft corals, such as gorgonians, were observed on these banks.

The following section outlines the general biology and ecology of these key filter-feeding groups, followed by the survey results from the three banks, which share them as a common feature.

Biology and ecology of gorgonians

Sea fans and sea whips are part of the group called gorgonians and are classified as Gorgonacea, an order of the subclass Octocorallia (=Alcyonaria). They are close relatives of soft corals (Order Alcyonacea) on the evolutionary tree (see Figure 23. *Relationships within the Class Anthozoa,* page 44). Soft corals are the most conspicuous and abundant octocorals of the Indo-Pacific region. In contrast to th eCaribbean where the Gorgonacea dominate with about 1,200 species of gorgonian known.

General biology



Gorgonian sea fan (L. De Vantier).

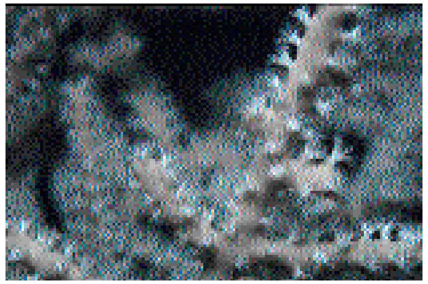
The general biology, polyp morphology and defensive chemistry of gorgonians is similar to that of soft corals (see page 48). The growth form of gorgonian colonies is, however, quite distinctive. The colony is supported by an axial skeleton from which side branches arise. These contain the polyps. The skeleton may be made of sclerites, like other octocorals, but is frequently a combination of sclerite pieces and a horny but flexible core of protein called gorgonin. The tendons of vertebrates are composed of a similar protein called collagen but the axes of gorgonians have been shown to have twice the tensile strength of tendons (Jeyasuria and Lewis, 1987). In sea whips the branches are minute and the colony has the appearance of a single rod, whereas sea fans are highly branched and often interconnected, forming colonies that are bushy or grow in a single plane to form a fan shape (Figure 33).

Feeding

Gorgonians inhabit a wide variety of depths, but the majority are found in deep water. A few shallow water species possess symbiotic zooxanthellae and benefit from their photosynthetic production of energetic compounds, in the same manner as soft and hard corals. However, the most important mode of feeding amongst the gorgonians is through filtering plankton from the surrounding water.

Gorgonians are commonly found in benthic habitats that are subject to persistent currents. To sieve enough food in a given time, filter-feeding animals require a large volume of water to pass through their tentacles. Gorgonian colonies, particularly the sea fan types, thrive in positions that are swept by relatively vigorous currents.

Colonies may vary their growth form and orientation depending upon the type and direction of local currents. When currents are turbulent and come from variable directions, the growth form is typically bushy. A region that is subject to strong and highly uni-directional currents will tend to support colonies with concave fans. The fans are positioned so that the 'dish' faces towards the oncoming current. The flat fan, characteristic of the majority of gorgonians, is often found where the currents uni- or bi-directional. Different morphologies have developed to maximise the amount of plankton entering the sieves of the polyps. This is achieved by reducing the amount in which one part of the colony 'shades' another part of the colony from the current.



Gorgonian polyps feeding. (K. Fabricius).

Gorgonians must avoid being damaged by currents but, at the same time, must remain erect in order to feed effectively. These two requirements have produced a compromise between rigidity and flexibility, with colonies typically having the elasticity of stiff rubber. When currents threaten to damage a colony, the colonies have the ability to bend and then spring back into their original position.

Reproduction

Asexual propagation is frequently the dominant reproductive mode. This serves to produce large populations from a single, founding colony as a result of the settling and growing of sexually produced larvae. Sexual reproduction follows the pattern characteristic of all anthozoans, with both internal and external larval development having been recorded (for sexual reproduction of hard coral and soft coral, page 46). The fertilised egg develops into a planula larvae which settles and differentiates to produce a polyp. This then multiplies into a colony. Subsequent asexual reproduction can be a very successful means of rapidly establishing numerous colonies.

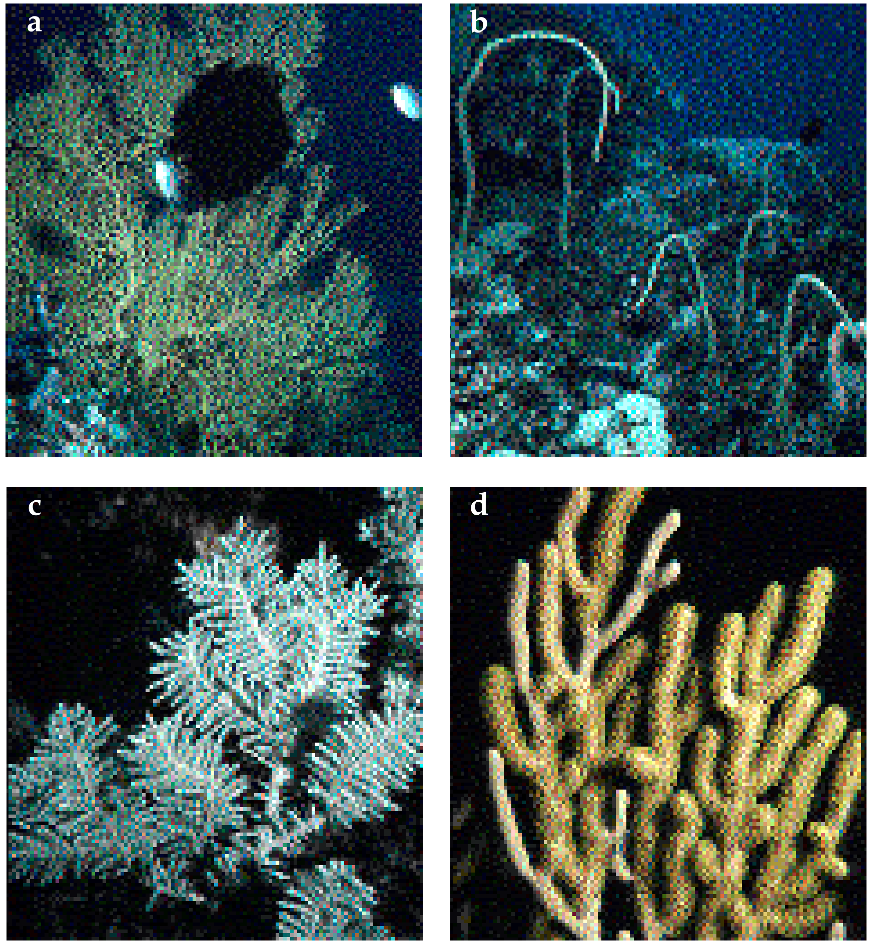


Figure 33. Examples of the Order Gorgonacea. a: gorgonian fan (Melithaeidae), b: sea whip (*Juncella* sp.), c: *Plexaura* sp., d: sea fan, *Isis* sp. (K. Fabricius).

At a site in the Caribbean, 94 percent of gorgonian colonies were found to be the result of asexual reproduction from fragments. These had broken from existing colonies and reattached and grown (Lasker, 1984). It was concluded that constrictions of the branches from the colonies had developed and increased the likelihood of breaking and fragmentation. The sea whip *Junceella fragilis* takes fragment formation one step further. The polyps and coenchyme tissue are reabsorbed at a point near the tip of the colony. Eventually, the gorgonin core breaks and a fragment falls to the bottom. These daughter colonies reattach and grow (Walker and Bull, 1983).

Biology and ecology of sponges

General biology

Sponges are sedentary, filter-feeding organisms which most commonly live on the sea floor attached to rock, shell, coral, algae and other hard surfaces (Figure 35). They compose the Phylum Porifera, and are relatively simple multicellular animals. They have no head, anterior end, mouth or gut cavity and the body is immobile. Each sponge is a loose aggregation of several types of cells, which do not form tissues. The cells are arranged to form an outer layer of covering cells and an inner layer of flagellated cells which move water through the animal (Figure 36).

In spite of their simplicity, sponges have been extremely successful. They are widely distributed and are present in all types of aquatic environments, including fresh and salt water and ranging from intertidal waters to the deepest ocean trenches and from polar to tropical seas. However sponges are predominately found in the marine environment, with over 5000 species identified to date.

Structure

The outer surface of the sponge is covered in tough, flattened cells called pinacocytes. The inner surface is covered in a lining of flagellated collar

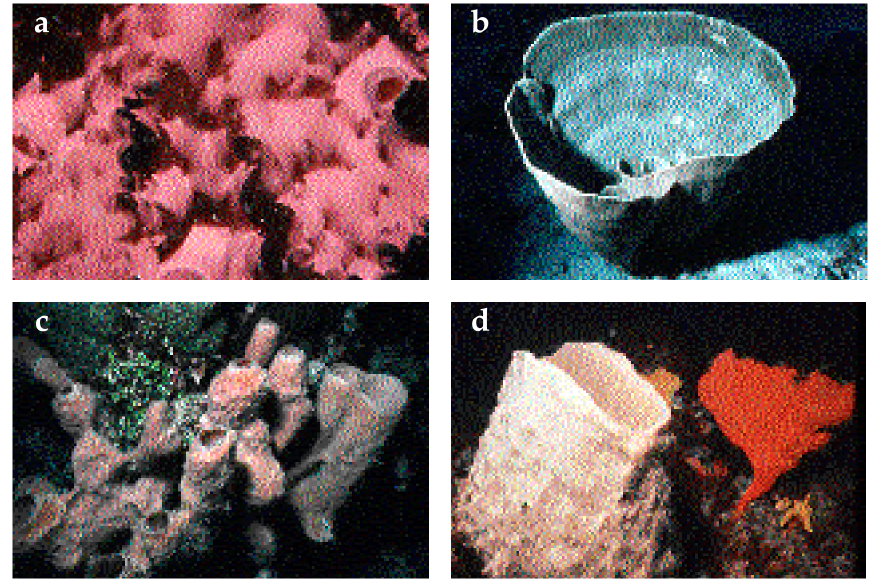


Figure 34. The highly varied sponge morphologies. a: encrusting, b: vase, c: columnar, d: bowl (C. Wolff and L. De Vantier).

cells or choanocytes. Between these two layers is a gelatinous mesochyme which contains several types of free-moving cells, or amoebocytes, and various spicules which provide reinforcement and stiffening. The minute spicules which form the skeletal framework can be crystalline or organic fibres. Crystalline spicules are either calcium carbonate ($CaCO_3$) or siliceous material (chiefly $H_2Si_3O_7$). Spicules are of many types, shapes and sizes and are used as a diagnostic tool in the classification of sponges. For example, some deep-sea glass sponges (Hexactinellida) are characterised by spicules which become fused together in a framework. Bath sponges, and some other horny sponges, are examples of sponges which display fine, interconnected and irregular fibres of spongin, which are composed of collagen.

The body of a sponge is perforated with numerous pores, each of which form a canal through a tubular cell called a porocyte. Water is circulated through these openings by the beating of the choanocytes' flagellae (Figure 35). Water flows into an internal cavity, the spongocoel, where waterborne food is trapped by the choanocytes and is then extracted by feeding cells called archaeocytes. The water then exits through a large, excurrent pore, the osculum.

Sponge spicules (AIMS).

The simplest type of sponges are those which are vase-shaped. These simple structures are called asconoid sponges and are small, no more than a few centimetres high. The asconoid architecture imposes limitations on the size that the sponge can attain. If the sponge becomes too big it would contain more water than its collar cells could efficiently move. This problem has been solved by the evolution of sponges that have repeated infoldings of the flagellated layer to increase surface area. These are called syconoid sponges (Figure 35).

The majority of sponges have further increased the surface area of the flagellated layer through the formation of many small chambers within which the collar cells are located. These are called leuconoid sponges and are characterised by a system of canals which carry water to the flagellated chambers. The water leaves the sponge through converging excurrent canals opening to the exterior osculum. These sponges do not possess a spongocoel, like the asconoid and syconoid sponges. These modifications, have allowed sponges to attain much greater sizes and numerous, different morphologies (Figure 34).

Reproduction

Sponges have a variety of sexual and asexual reproductive modes, but are renowned for truly remarkable regenerative powers. This is well-illustrated by the classic experiment of forcing a piece of sponge through silk, which dissociates the cells. Within a short period of time the dissociated cells reaggregate into the proper relationship, although this cannot be achieved with all species.

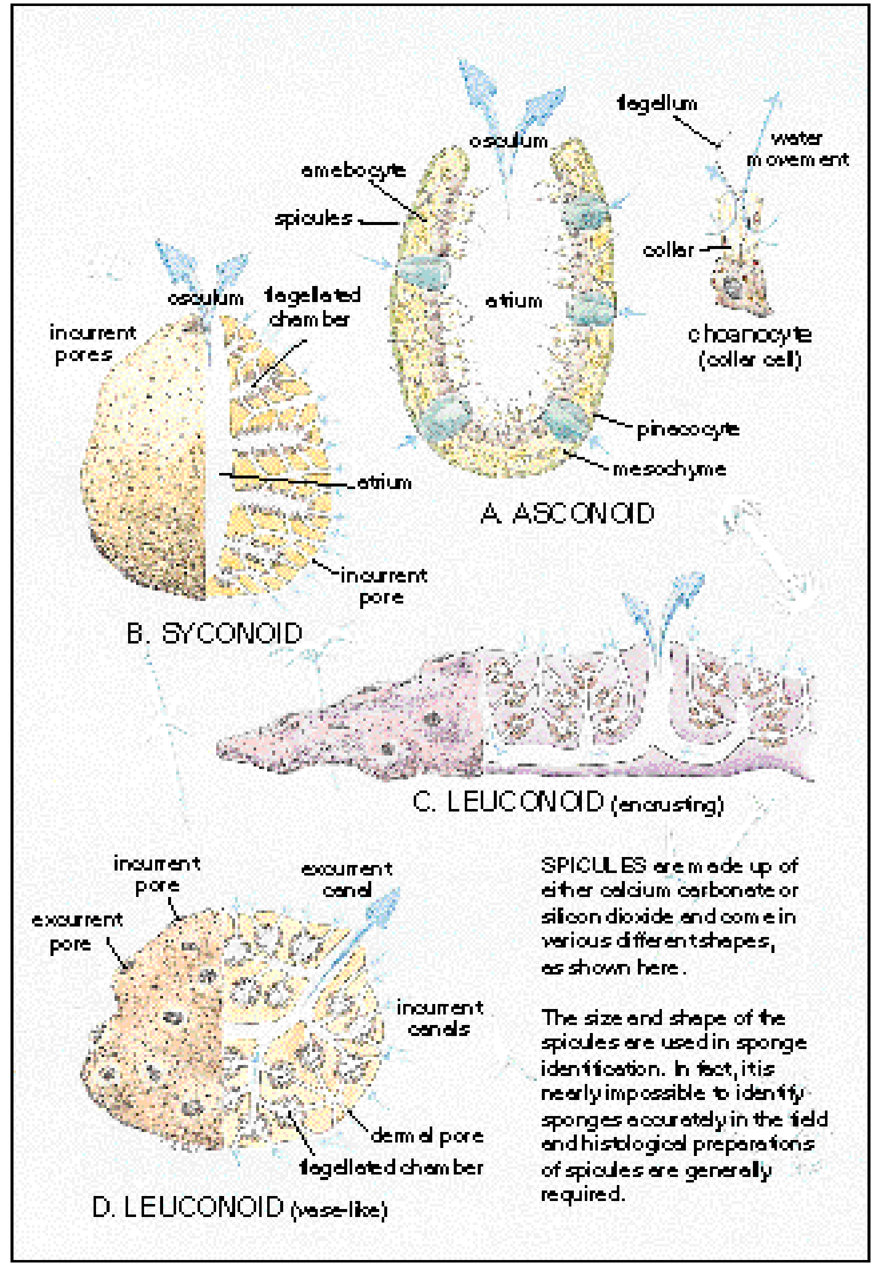


Figure 35. The differing structures of sponges showing the direction of water flow.

The ability to regenerate is closely correlated with asexual reproduction. A bud or small fragment broken from the parent sponge can generate a new sponge. Some sponges produce special, asexual reproductive bodies called gemmules. These consist of an aggregate of essential cells; food-filled archeocytes and amoebocytes, which are capable of giving rise to any other type of cell. They are all protected by a sheath of protective spongocytes. Gemmules remain viable for extended periods of time. Some types are even resistant to freezing and desiccation. When suitable conditions are found a gemmule can grow to form a new sponge, genetically identical to the parent. Gemmules provide a means of dispersal and are a way of maintaining local distribution and abundance. They allow the genotype of an individual sponge to persist through extreme environmental conditions.

The majority of sponges are hermaphroditic, and therefore capable of producing both sperm and eggs, though generally at different times. Because sponges do not have cells organised into tissues or organs, sperm and eggs are produced by the amoebocytes and choanocytes. Mature sperm are shed into the water column, where they are carried into the water canals of neighbouring sponges and where they fertilise their eggs. Fertilised eggs are then either carried into the water column where they undergo further development in the sea or, as is the case with most sponges, they are brooded and develop within the body of the parent sponge. Embryonic development leads to free-swimming larvae, a stage that is important for species dispersion in sessile animals. After a brief free-swimming existence, the larvae settle to the bottom and develop into adult sponges.

Ecology of sponges

The sedentary life style of sponges precludes them from actively evading predators themselves. The main predators of marine sponges are nudibranchs commonly called sea slugs. Although fish, turtles and other invertebrates also feed on them. Sponges appear to evade high levels of predation by incorporating an array of noxious chemicals as a defence mechanism (see also the section on *Halimeda* defence, pages 23-24).

These biologically active compounds are also known to be used offensively in the competition for space with other benthic invertebrates. This sort of competition is not, however, universally applied. Commensal and symbiotic relationships involving sponges are extremely common.

Shrimp, crabs, holothurians, worms, molluscs and other animals are known to habituate the interior cavities of many sponges. In fact, 17,128 animals have been counted in a sponge the size of a washtub. These mainly comprised a single variety of shrimp, although a considerable variety of other species were also found in this sponge including a number of slender fish. At the microscopic level, many species of bacteria can live within sponges and may, in fact, be the origin of the toxic chemicals used by the sponge for defence.

Filter-feeding banks of the Big Bank Shoals

Previous work on filter-feeding communities in the region

Little scientific research has been undertaken on the gorgonians of Indo-Pacific waters. Sampling of these assemblages is difficult, since most epibenthic communities dominated by these filter-feeders are in deeper water. Furthermore, the paucity of specialists in these taxa has tended to limit the collection effort for gorgonians by the Northern Territory (Russell and Hanley, 1992) and the Western Australian Museums (Berry, 1986; 1993) in northwestern Australia.

Collections of sponges have been relatively extensive in the Timor Sea region (compared to gorgonia), (van Soest, 1989; Hooper, 1994). Large collections have been made in both shallow coastal waters and areas on the Continental Shelf and Slope (see Hooper, 1994). Most results of these studies have remained unpublished. Sponge collections, documenting 138 species, have been undertaken on the emergent reefs (Ashmore, Cartier and Hibernia) in the Timor Sea (Hooper, 1994). The assemblages varied

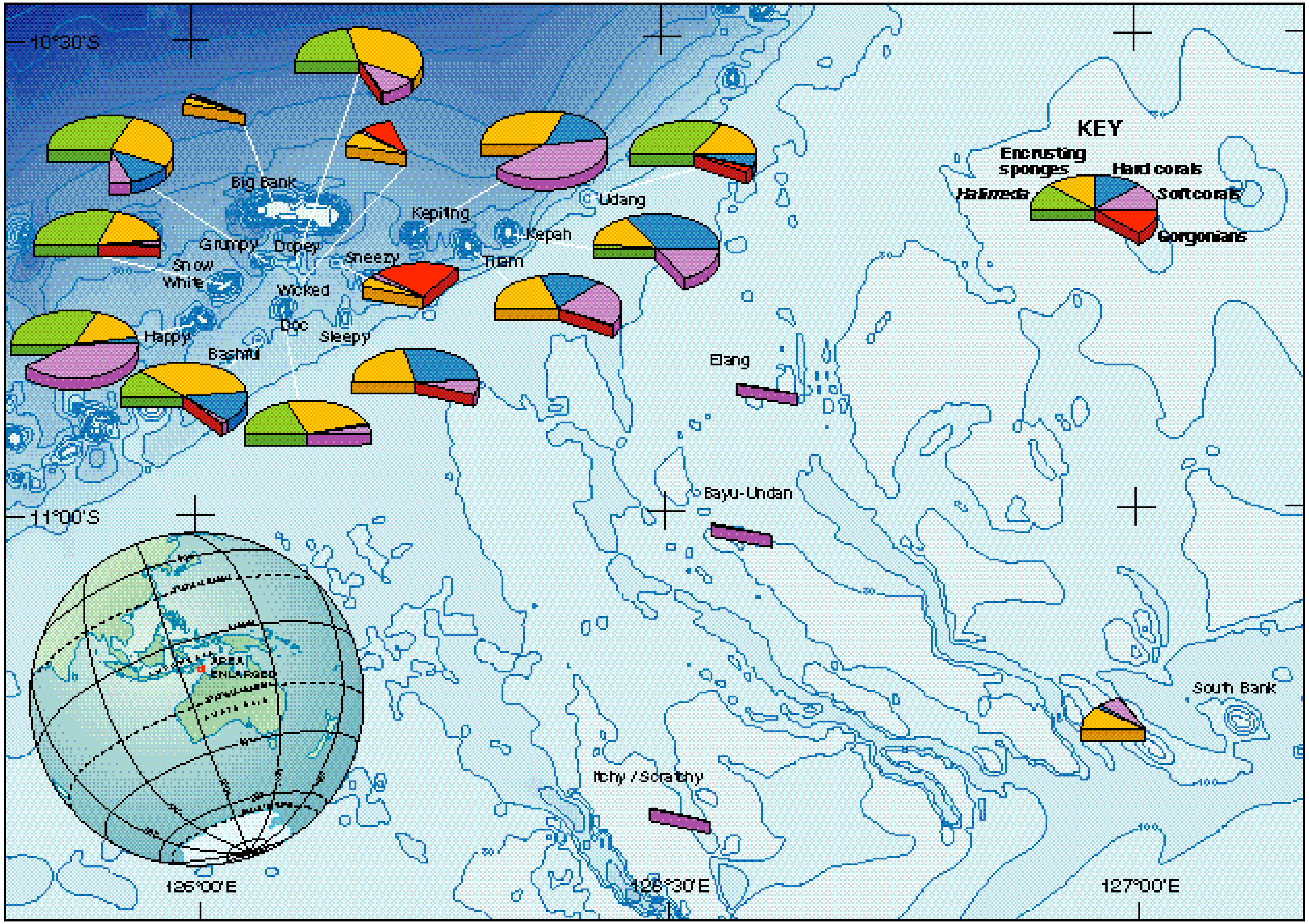


Figure 36: Map of the Big Bank Shoals showing the distribution of *Halimeda*, encrusting sponges, hard and soft corals, and gorgonians.

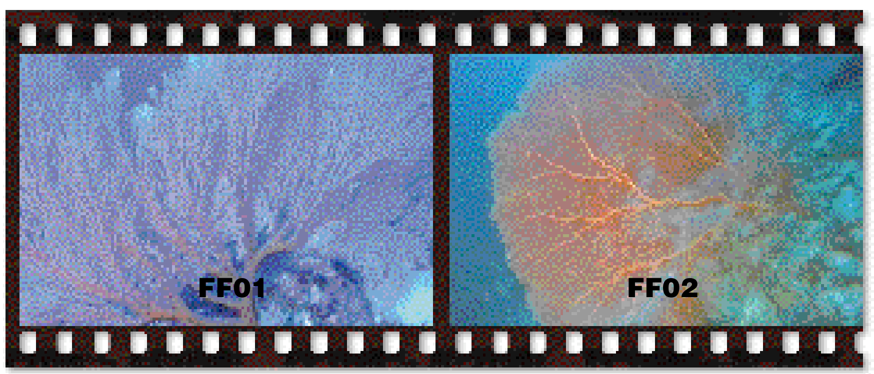
remarkably between reefs. For example, Hooper (1994) found that only 13 percent of species were common between Hibernia and Ashmore Reefs (35 km apart).

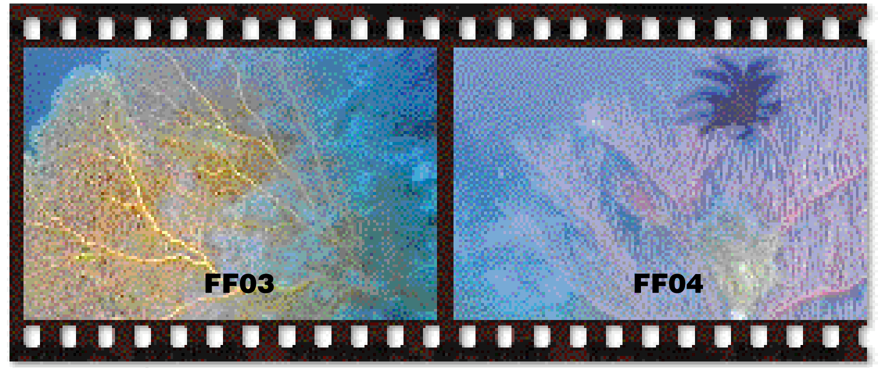
General aspects of these filter-feeding communities

The benthos of Sneezy, Wicked and South Banks are likely to be light-limited to varying degrees. Reef building *Halimeda* and hard corals that have been found to dominate most banks of the Shoals are rare or absent on these banks (Figure 38). Given the depth of Sneezy and Wicked Banks, and the lack of reef-building taxa, it seems that these are banks are drowned reefs that have been unable to keep pace with rising sea levels since the last ice age.

South Bank has a distinctly larger and more complex benthic ecosystem than Wicked or Sneezy, but is linked to the other two banks by a benthic fauna dominated by a diverse assemblage of filter-feeders. These fauna are heterotrophic and extract their food from the surrounding waters. In particular, a mixture of sponge types (Figure 36) and soft corals (Figure 37), such as gorgonians, were common features on these three banks.

Whereas most hard corals require light to produce energy, gorgonians and many soft corals filter plankton from the water column. Consequently these taxa can flourish in deeper, darker waters such as that found at Sneezy and Wicked Banks. Gorgonians are highly prevalent on these banks





while hermatypic corals and macro-algae are rare (Figure 38). For example, Sneezy Bank, a submerged pinnacle that plateaus to 100 metres beneath the sea surface, is covered in gorgonians (up to 30 percent of the substratum), (see film strips *FF01* to *FF04*) while scleractinian corals are absent.

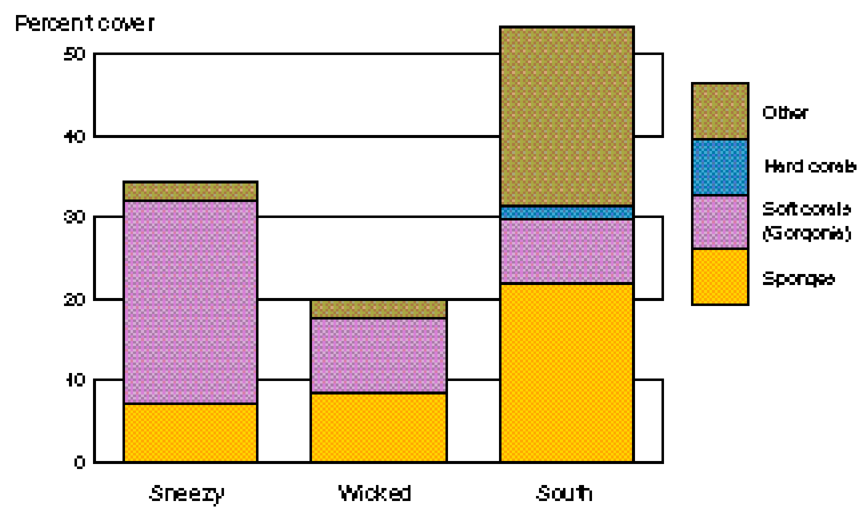


Figure 37. The percent coverage of the major benthic categories of the filter-feeding banks.

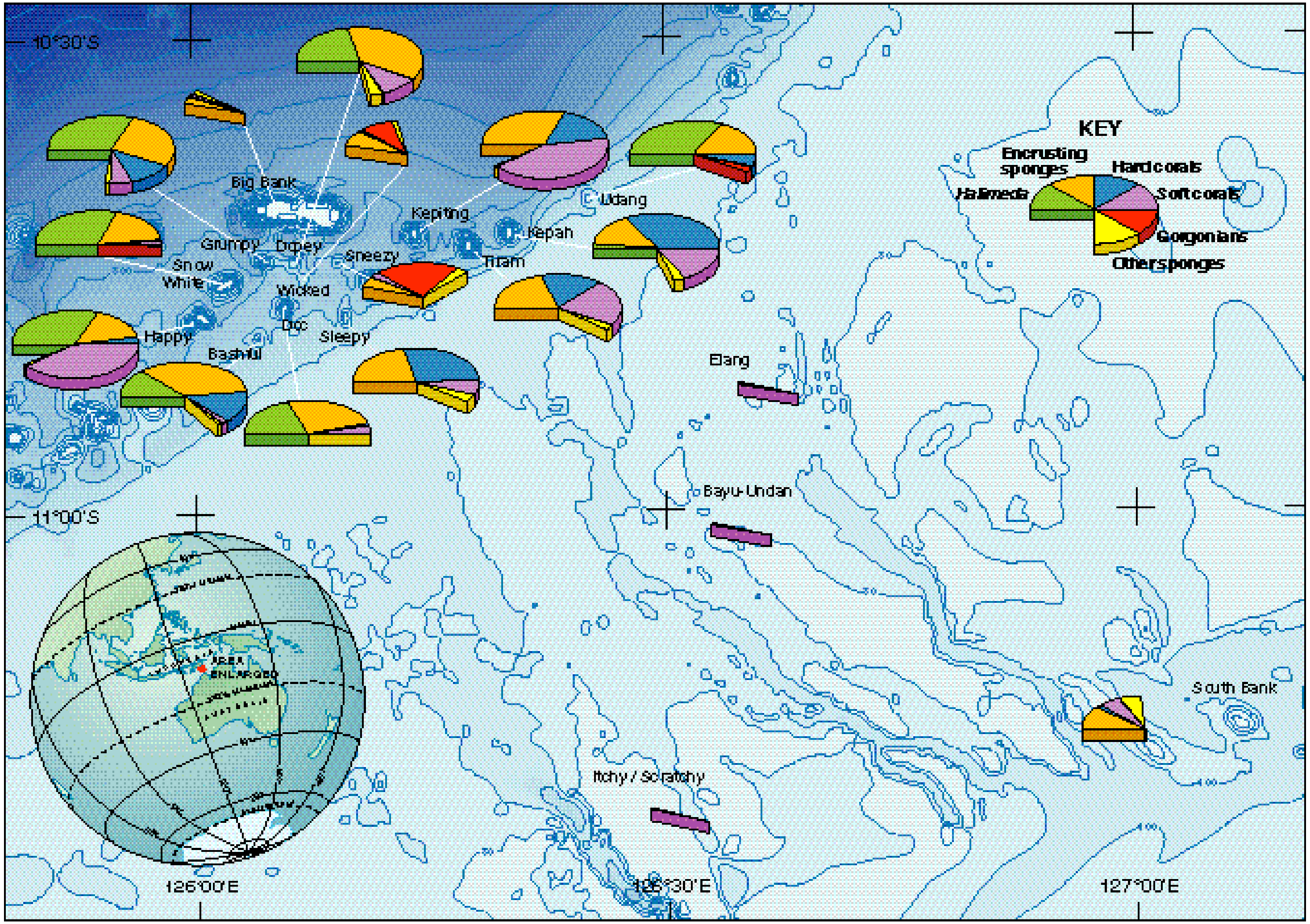
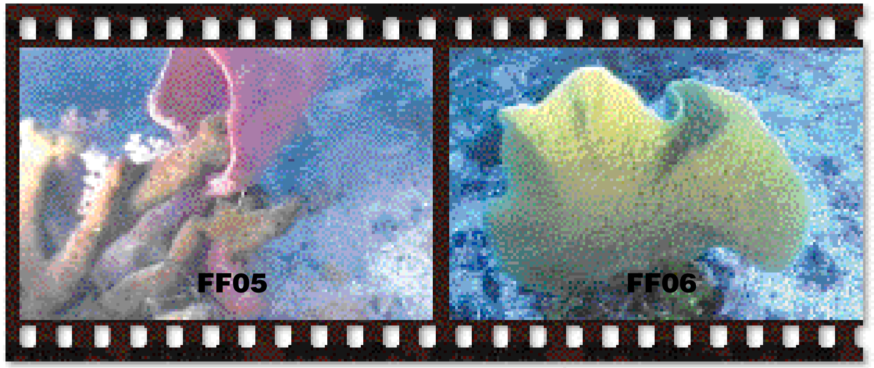


Figure 38: Map of the Big Bank Shoals showing the distribution of all major benthic groups.



Filter-feeders dominate the deep water, light-limited habitats on Sneezy and Wicked. Overall cover of these deep water banks is relatively low compared to the shallower banks of the area. Wicked Bank has an overall live cover of 20 percent, while the *Halimeda* banks generally have an epibenthic coverage greater than 50 percent (see *Halimeda ecosystems*, page 20). The dominant invertebrates are sea fans and whips, the soft coral *Dendronephthea* sp. and a range of sponges. The gorgonian fans can reach heights of up to two metres on these banks. Many have filter-feeding feather stars or crinoids living upon them. Interspersed amongst these fans are areas of numerous sea whips (*Junceella* sp.) and small colourful sponges (see film strips *FF05* and *FF06*). Some very large vase-shaped sponges were also observed at both banks.

While overall cover is relatively low at Sneezy and Wicked, the sampling method is likely to underestimate the true cover of gorgonians. The ROV videos the substratum (and the epibenthic community growing upon it). However, gorgonians grow as fans or whips perpendicular to this substratum. For example, Sneezy Bank has an overall coverage of gorgonians of 25 percent, however large fans (greater than 1 metre in diameter) were observed at approximately 1 metre intervals, indicating that these communities are very rich in terms of overall abundance.

Gorgonians, being sessile filter-feeders, require the currents to bring plankton to them and are consequently found in sites which have higher water movement. Since the fans orientate perpendicular to the prevailing current, the direction of the current at Sneezy and Wicked Banks can be implied. Fans growing upon these banks face towards the south-southwest, indicating that the water is from this direction. Interestingly, shallow water currents recorded at other locations around the Big Bank Shoals seem to run in an east-northeast direction (see *Currents*, page 13). However, complex localised water eddies may cause currents to be different compared to the region as a whole.

Individual banks

Among the banks surveyed, Sneezy, South and Wicked Banks were dominated by filter-feeders. Both sponges and gorgonians made significant contributions to the epibenthic communities found on these plateaux. They are described in more detail below.

Sneezy Bank

Sneezy Bank is a small, cone-shaped pinnacle which rises steeply from over 230 metres and tapers to a rounded knoll. The apex, which is within about 60 metres of the sea surface, is only 100 metres in diameter (Figure 39). Two ROV video transects were recorded at depths of 80 metres and 110 metres, revealing moderately high live cover (36 percent average) on a flat sandy substrate (64 percent).

Both survey transects revealed very similar organisms, typical of deep water benthic environments (see film strips *SN01* to *SN07*). The same major filter-feeding groups were encountered at each location, with slightly different levels of abundance. Soft corals were the most common, with gorgonian and *Plexaurid* species occupying 19-30 percent of the substrate (25 percent average). Gorgonians accounted for 90 percent of the soft coral community at both locations (see film strips *SN05* to *SNO7*). Sponges were next in order of abundance, with average cover of approximately 8 percent (see film strip *SN03*). Encrusting sponges were equally abundant (4-5 percent) at both locations and were the only type recorded from the northwestern site, at a depth of 80 metres.

The deeper (110 metres) southeastern location had higher sponge cover (10 percent), with foliaceous (3.4 percent) and massive species (1.7 percent) contributing to a much more diverse sponge community. Other macroscopic fauna were rare, although other filter-feeding organisms, such as crinoids, were sporadically encountered. Despite the considerable

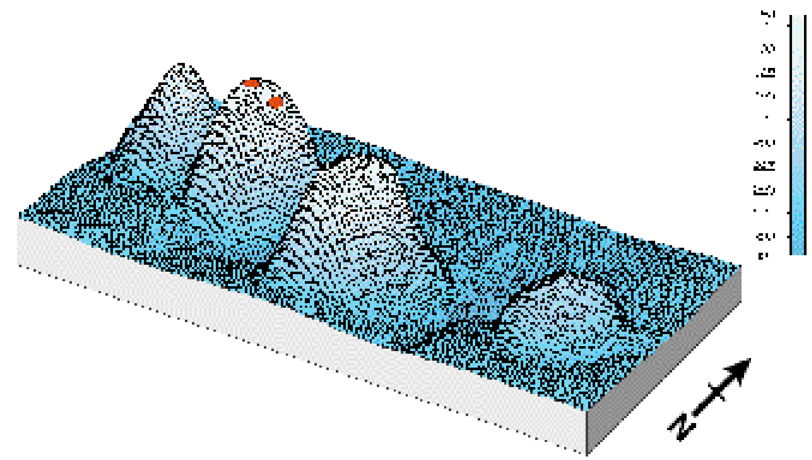


Figure 39. A three-dimensional bathymetry map of Sneezy Bank (vertical exaggeration five times).

depths, both transects revealed low, but consistent (3 percent), amounts of turf- and macro-algae.

The most common species of soft coral and sponge found on Sneezy Bank are different to those encountered on the *Halimeda* and coral-dominated banks. However, overall abundance was quite similar to the shallower banks when the two major groups of soft corals and sponges were compared.

Wicked Bank

Wicked Bank is adjacent to Sneezy and has a very similar shape and bathymetry. It is a small, cone-shaped pinnacle which rises steeply from over 250 metres in depth and tapers to a rounded knoll. The apex reaches to within approximately 70 metres of the sea surface, at which point the bank is only 150 metres in diameter (Figure 40).

Two video transects were recorded, one close to the apex and a second 200 metres away to the southeast (see Figure 40). These transects, at depths of 70 metres and 97 metres respectively, revealed moderate live cover (21 percent average) on a flat substrate of sand and rubble. The substrate in the centre of the bank was predominantly rubble (52 percent rubble, 27 percent sand) while the deeper location to the southeast was almost entirely sand (4 percent rubble, 77 percent sand), (see film strips *WK06* and *WK07*).

Both transects showed a similar composition and abundance of benthic communities. Soft corals and sponges were equally common with comparable levels of abundance at both transects. The soft corals (9.2 percent average cover) were predominantly gorgonians (8.4 percent average cover), although a more diverse soft coral assemblage was recorded on the shallower site in the centre of the bank (see film strips *WK01* to *WK05*). Sponges, mostly encrusting forms, provided an average cover of approximately 8.5 percent. The deeper (97 metres) southeast survey site had less encrusting forms, but slightly higher total sponge cover

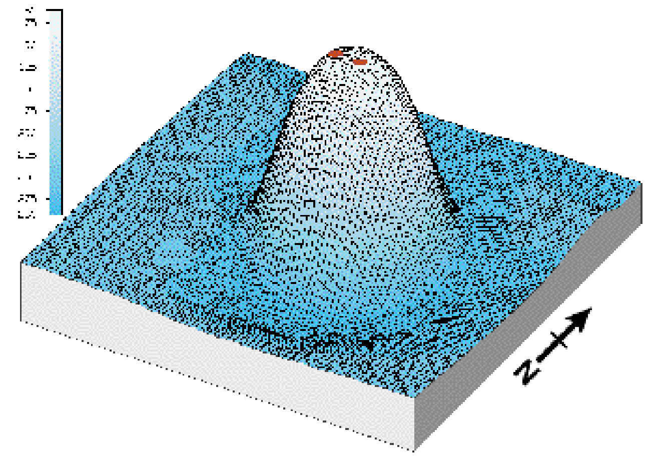
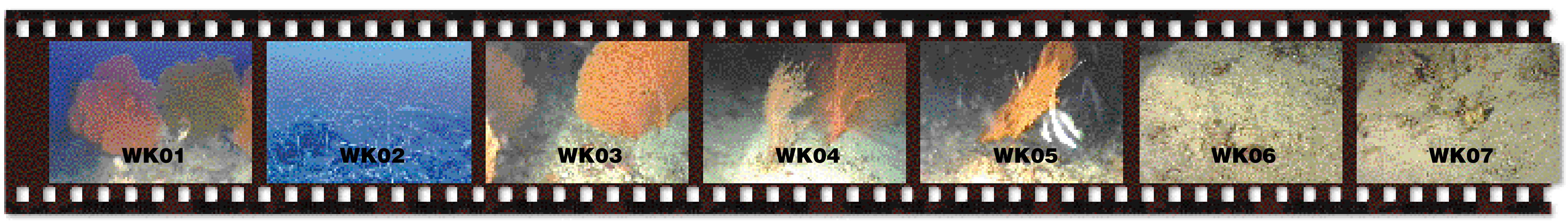


Figure 40. A three-dimensional bathymetry map of Wicked Bank (vertical exaggeration of five).

(8.8 percent), with branching (1.3 percent) and massive species (0.4 percent) contributing to a more diverse sponge community.

Minor amounts of turf and macro-algae were seen on both transects. The shallower central site had colonies of the hard corals *Montipora* sp. and *Porites* sp.. The presence of these light-dependent organisms at such a depth is indicative of the prevalence of clear water conditions. Other macroscopic fauna were rare, although filter-feeding organisms, such as corallimorpharians and hydroids were sporadically encountered. The most noticeable difference between the benthic communities on Wicked and Sneezy Banks was in abundance rather than species diversity. Gorgonians were much less common on Wicked Bank



South Bank

South Bank consists of a single, submerged platform, rising from a depth of approximately 80 metres to a more or less flat plateau, 34 metres below the sea surface (Figure 41). The plateau is relatively large, approximately 3.2 by 2.2 kilometres, which is similar in size to Happy Bank. There is a slight tilt of the plateau plane downwards to the north. The steepest slopes occur along the eastern and southern rims, with a markedly gentler slope from the northern rim of the plateaux at a 40 metre depth down to the 80 metre contour. Thirty transects were recorded at South Bank during the first half of 1996. All but two were situated on the plateau rim and top, at depths ranging between 42 metres and 34 metres below the sea surface. This larger number of sites permitted a much more detailed assessment of community structure on this bank. It enabled the identification of particular types of benthic assemblages, or habitats, within the bank itself (see Figure 42).

The South Bank plateau has a mixture of sediment types, with extensive areas of rubble and sand frequently covered with turf algae. This is interspersed with patches of consolidated, rocky substrate covered in sponges, soft and hard corals and macro-algae (see film strips *SB01* to *SB14*). These patches of consolidated substrate and larger organisms are usually found around the rim of the plateau, with more rubble and sand towards the central areas. The percentage coverage of the plateau with biota was moderate to very high. However, significant spatial variation was found. Algae and sponges were the dominant benthic groups at all locations, with a variety of soft coral species also common in some areas. The

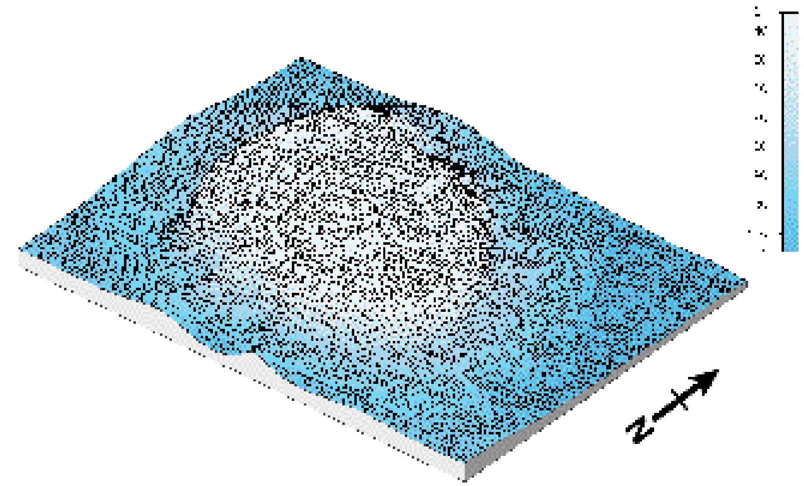
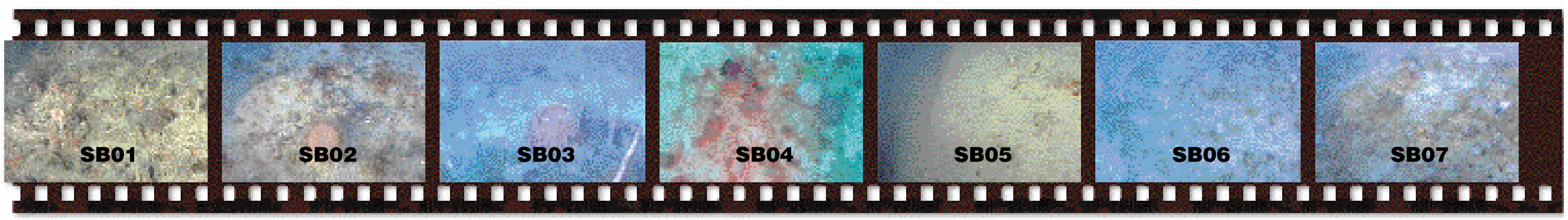


Figure 41. A three-dimensional bathymetry map of South Bank (vertical exaggeration of five).

macro-algae observed was generally brown in appearance and rarely the green calcareous *Halimeda*. Hard corals typically contributed less than 5 percent and generally averaged 2 percent or less of the benthic cover.

The abundance and biodiversity data from all the South Bank transects were compared, using cluster analysis, and ranked in order of similarities between transects. On the basis of the cluster analysis, each survey site was assigned to one of four nominal groups, representing notional habitat types with characteristic community structure. The transects were grouped as follows - Habitats A, B, C and D (Figure 42).



The distribution of these habitat types on the South Bank plateau was mapped (Figure 42), revealing a pattern of broad areas of continuous habitat type. Classification of the bank into these habitat types suggests that the plateau consists of five areas, each with characteristic abundance and diversity of major benthic organisms. The Eastern Rim (Habitat A) has the highest benthic cover, with encrusting sponges dominating (see film strips *SB01* to *SB04*). Significant amounts of macro-algae are also a major feature of this area. This sponge/algal-dominated community also contains notable amounts of soft corals and other sponge types, reflecting the presence of raised, reef-like areas of consolidated substrate.

The correlation between the structural complexity of the bottom and high cover was noted on transects at the Western and Southern Rims (Habitat D). In these regions of the plateau, overall live cover was still very high with macro-algae the major component. The contribution of each major organism group was much more evenly distributed compared to other areas. Habitat D areas contain a complex community of almost equally dominant major faunal groups, together with high levels of algae. Patches of high structural complexity are interspersed with loose rubble and sediment (see film strips *SB12* to *SB14*).

Habitat C represents a single, continuous region on the northeast side of the plateau located adjacent to the Eastern Rim, Habitat A area. It is a habitat with high levels of live cover, but without the equitable abundance of most benthic groups typified by Habitat D. This area is overwhelmingly characterised by the dominant presence of macro-algae, with sponges the next most common group (see film strips *SB08* to *SB11*). This algal/sponge habitat type has a much less three-dimensional structural complexity than Habitats A and D, as its substrate consists largely of silt, sand and rubble.

Habitat B characterises the largest area of the plateau and covers the majority of the western half, with the exception of a small area of Habitat D on the very edge of the Western Rim. Live cover in this habitat region is moderate (30 percent) and markedly the lowest of all the areas surveyed (see film strips *SB05* to *SB07*). The community structure in this area is somewhat similar to Habitat A, being dominated by sponges and algae, but at much lower levels of abundance. A silty, sandy substratum was characteristic of all survey transects in the Habitat B area. This unstable sediment may be the primary reason for the low abundance of biota.

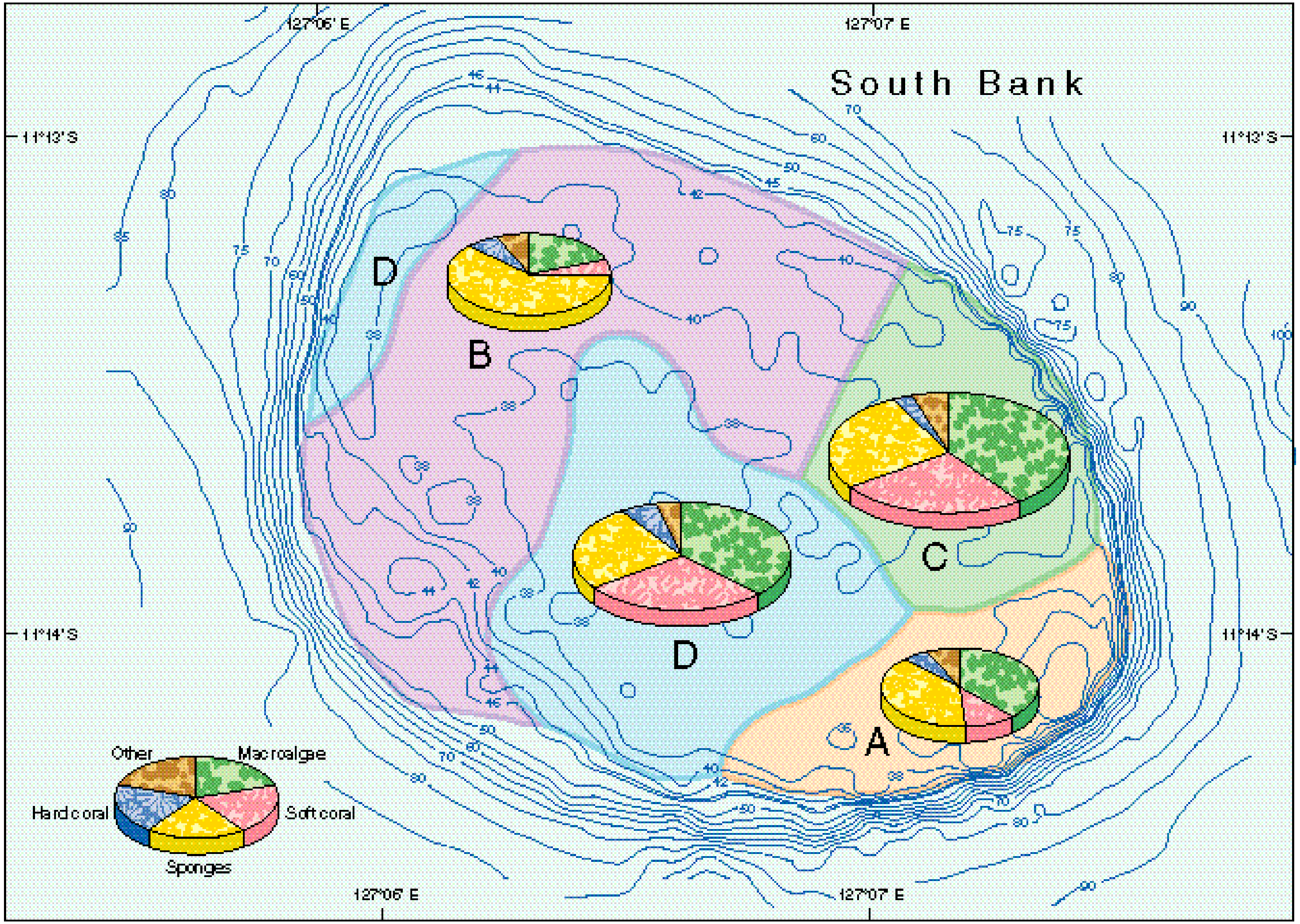


Figure 42. Habitat map of South Bank showing the four different assemblages.

Continental Shelf epi-benthic ecosystems

The Australian Continental Shelf is an underwater extension of the continental landmass. In these areas the ocean is relatively shallow, sloping gently from the shore to a depth of about 200 metres, where there is an abrupt drop off to the Continental Slope. The Continental Slope descends precipitously to depths of between 3 and 5 km. At these depths, the bottom becomes a flat, extensive, sediment-covered abyssal plain. Continental shelves form only 7-8 percent of the total ocean area. However, coastal waters host some of the most diverse and complex marine habitats, which include shallow water communities that rely on photosynthesis, such as coral reefs, kelp forests and seagrass beds. However, further from the shore, where water-depths increase and the quality of light decreases, there is a sharp decrease in abundance and diversity.

Many tropical continental shelves are wide and shallow and therefore are less constant and show more variability, especially where large rivers discharge massive amounts of fresh water. Light penetration is reduced in these regions, in contrast to the open ocean, due to the sedimentary input from rivers and resuspension of bottom sediments by wave action.

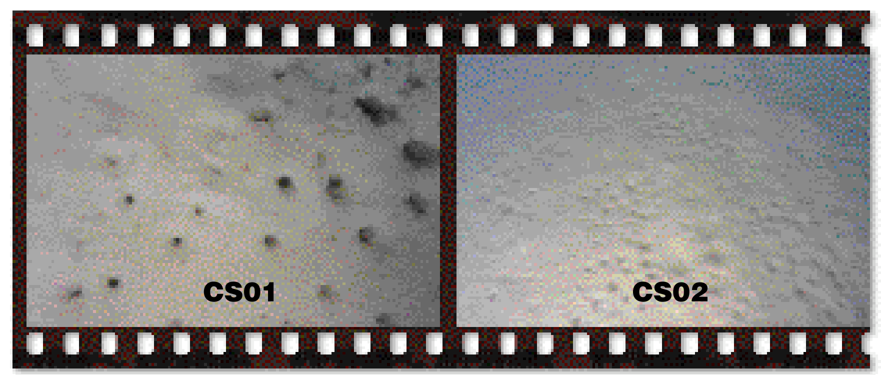
A large portion of the Continental Shelf is composed of soft sediment with little topographic relief, resulting in vast expanses of monotonous benthos. Often the only apparent difference from one place to another is that of sediment grain size. The lack of relief generally means fewer different habitats or niches for animals to occupy. Filter-feeding hetrotrophs, such as sponges, soft corals, gorgonians and detritus-feeding crustaceans and echinoderms are the dominant epibenthic organisms of these habitats.

Epibenthos of the Continental Shelf

In addition to South Bank (see page 69), three sites on the Continental Shelf adjacent to the Big Bank Shoals were surveyed using ROV video to determine the epibenthic communities on the Shelf. The sites sampled were Elang, Bayu-Undan and Itchy and Scratchy (Figure 43).

All three sites were very similar in character. Soft, easily resuspended sediments predominated, making up more than 97 percent of the benthos (Figure 43), (see film strips *CS01* and *CS02*). Epibenthic coverage was extremely low, with a maximum of 2.4 percent at the Itchy and Scratchy site. The predominant organisms found here were sponges, gorgonians and soft corals. The animals found at this depth do not have symbiotic algae within their tissues and are completely reliant upon food filtered from the water column.

The most obvious source of variation in biota is likely to be due to substrate type, that is, differences in particle size and degree of consolidation. Many filter-feeding organisms require some form of hard substrate for attachment. This may include rock or another organism like a hard coral. The soft, easily resuspended sediments found on the in these areas would not provide the stable substrate required by the settling larvae of the filter-feeding organisms. Surveys noted that whenever there was some form of hard substrate protruding through the sediment it was generally heavily populated with encrusting and filter-feeding organisms. These organisms, in turn, provide substrate for other organisms. Generally these outcrops were relatively small, being less than 50 cm across.



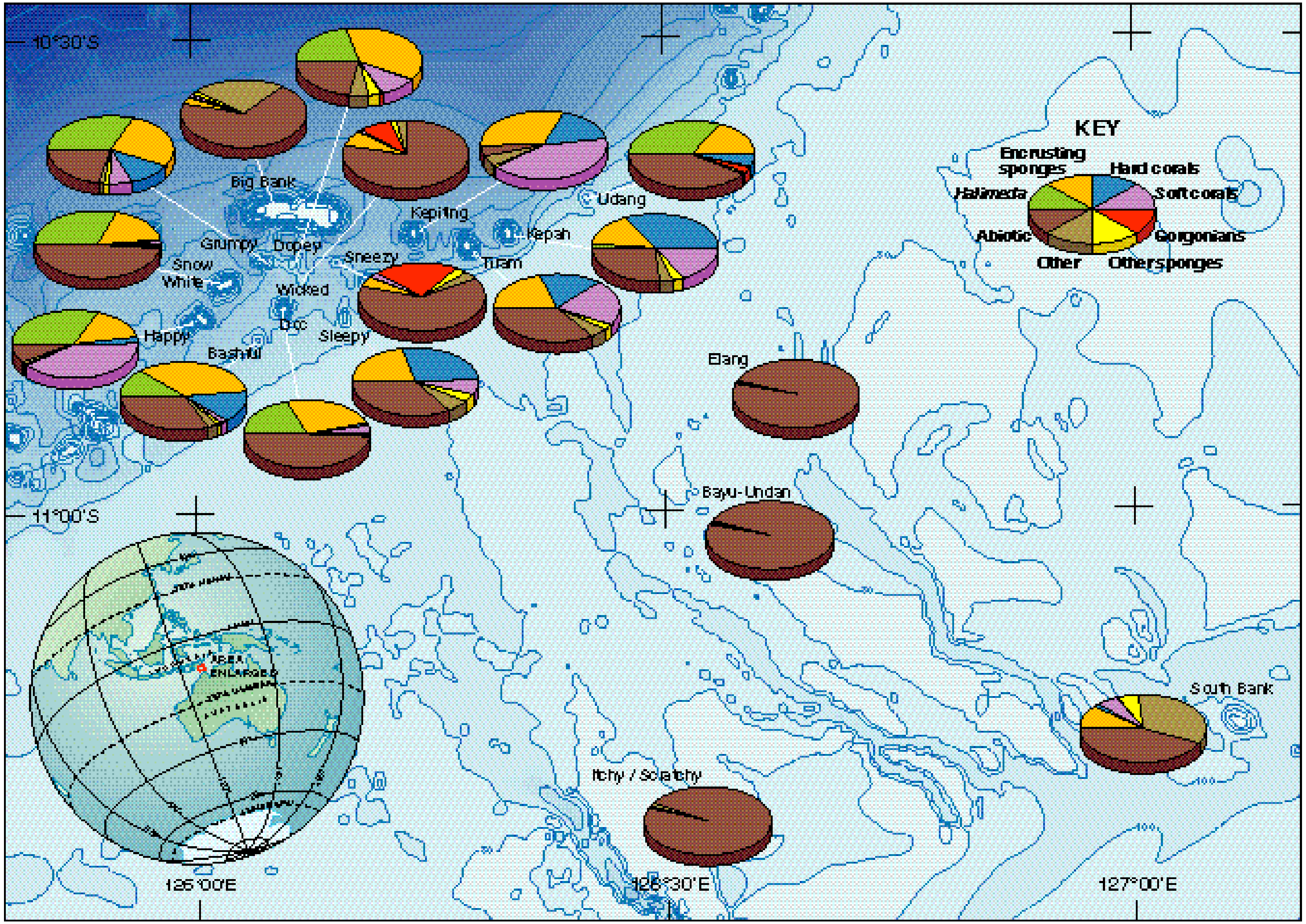


Figure 43. Map of the Big Bank Shoals showing overall make-up of the substratum.

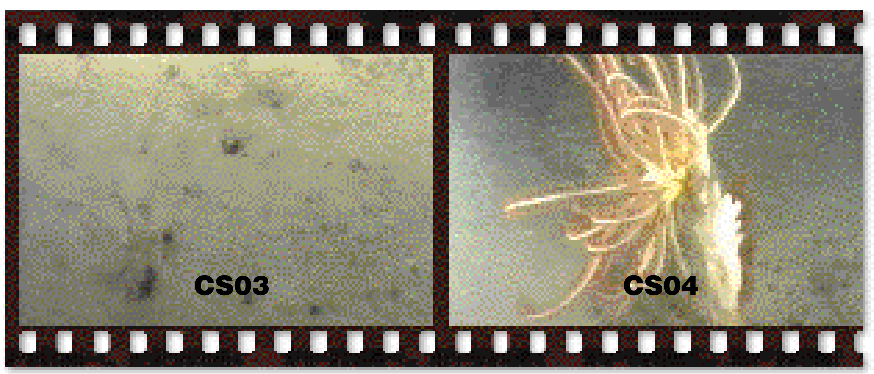
This phenomenon has also been noted on the Great Barrier Reef where Birtles and Arnold (1988) noted that where the sediment was composed of larger calcareous rubble, solitary and colonial organisms settled. They called these areas 'natural isolates' and most species were largely restricted to these 'islands' surrounded by a 'sea' of unstable, soft sediment.

These soft, easily resuspended sediments also pose another problem for filter-feeding organisms. In muddy sediments, deposit-feeding organisms often have a destabilising effect on the seabed, thus causing the silty sediments to be resuspended in the water column and causing heavily turbated waters. This may preclude suspension feeders from these areas, as they often depend on rather delicate and vulnerable structures to collect food from the water column. With high levels of resuspended sediments in the water, these structures tend to become clogged, therefore hampering food uptake.

Individual sites

Itchy and Scratchy

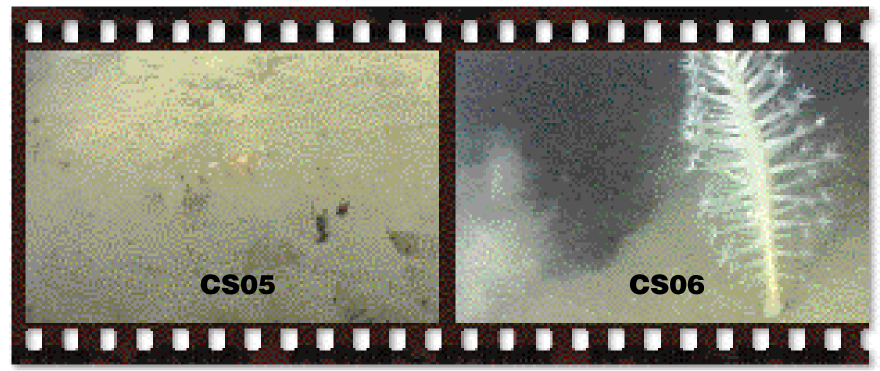
The Itchy and Scratchy site is located in relatively deep water area (80 metres). As a result, the benthic community is considerably different to the shallower banks (of the Big Bank Shoals). The sediment at Itchy and



Scratchy is composed of fine sand and silt with very little live benthic coverage. Fine sand covers the seabed, and comprises 97 percent of the quantitative benthic analysis. Minor occurrences of soft coral, turf algae, gorgonians and *Plexaurid* spp. are the major benthic groups in this area, with combined coverage of less than 5 percent (see film strips *CS03* and *CS04*).

Elang

The abundance of organisms visible on the Elang transect was extremely low. Very little macroscopic life was evident, less than 1 percent. Soft,

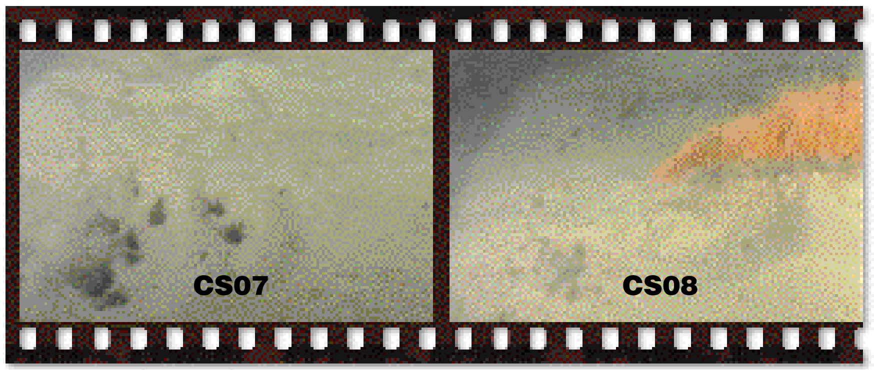


easily resuspended sediment makes up 99 percent of the bottom along the transect. The only visible organisms here were small sponges (0.5 percent) and the soft coral *Dendronephthea* sp. (0.5 percent). A high level of bioturbation was apparent, with numerous burrows of varying sizes (see film strips *CS05* and *CS06*), suggesting high levels of infauna (see *Infauna of the Continental Shelf*, page 78).

Bayu-Undan

This survey area was characterised by soft, easily resuspended sediment, making up on average 98 percent of the bottom. The abundance (percentage cover) of macroscopic, epibenthic organisms on the Bayu-Undan transects was extremely low, averaging less than 2 percent overall in the survey area. The only visible organisms were small sponges, soft corals and some turf algae.

Spatial variation was low at Bayu-Undan, indicating a highly uniform habitat. Maximum live epibenthos was 9.4 percent, occurring on a single transect. However, in general, live epibenthic cover was extremely low and very consistent within and between transects (see film strips *CS07* and *CS08*).



Considerable bioturbation was noted on all transects. The soft sediment had numerous holes and small mounds indicative of burrowing fauna, such as small fish or crustaceans. It would be expected from the video that considerable infauna would be found in these sediments. Grab samples revealed an extensive community living within the soft sediments of the Continental Shelf. Results of infauna surveys undertaken at Elang Field, Malle East-1, and Bayu-Undan are discussed in *Infauna of the Continental Shelf* (page 78).

Infauna of the Continental Shelf

Infauna is the name given to those animals that live within the sediments of the sea floor. The majority live within the first few centimetres of the surface where oxygen is more readily available. The most familiar animals are the easily visible macrofauna which include clams, worms, crabs, echinoderms and fish. These animals either ingest or displace the sediment particles around themselves as they move. At the other end of the size scale are those animals, often extremely numerous, which are less than 50 millimetres in size. These organisms, classed as microfauna, are normally studied with the aid of magnifying tools, such as the microscope. Intermediate in size between the macrofauna and microfauna is a very abundant group of animals, called the meiofauna. The meiofauna are also referred to as interstitial animals, as they occupy the spaces between sediment particles.

In many locations, particularly at depths where insufficient light penetrates to stimulate plant growth, the organisms of the sea floor depend ultimately on the steady rain of food particles that descend from the upper layers of the ocean. The sea floor collects and accumulates plankton, waste material, and other plant and animal debris that sink from the waters above. A variety of worms, molluscs, echinoderms, and crustaceans obtain their nourishment by ingesting the accumulated detritus and digesting its organic material. Other organisms filter particles out of the surrounding water and some roam across the surface in search of prey or to scavenge dead, organic matter. These animals play an important role in the cycling of nutrients in the world's oceans.

Research into the benthic ecosystems of the world's continental shelves has been most comprehensive in temperate rather than tropic latitudes (see Alongi, 1990), notwithstanding some substantial work on the east and west coasts of India and along the west coast of Africa. Our knowledge of the Continental Shelf soft-bottom ecosystems of tropical Australia is quite restricted, derived from relatively shallow water research in the Great Barrier Reef province (e.g. Alongi, 1989a, b; Alongi and Hansen, 1985; Birtles and Arnold, 1983) and a handful of studies across the top end of Australia and the North-West Shelf (see Long and Poiner, 1994; Hanley, 1993, 1994). This *Atlas* adds to this still largely incomplete picture by documenting the benthic infauna at three sites on the Australian Continental Shelf in the Timor Sea, in water depths of greater than 50 metres.

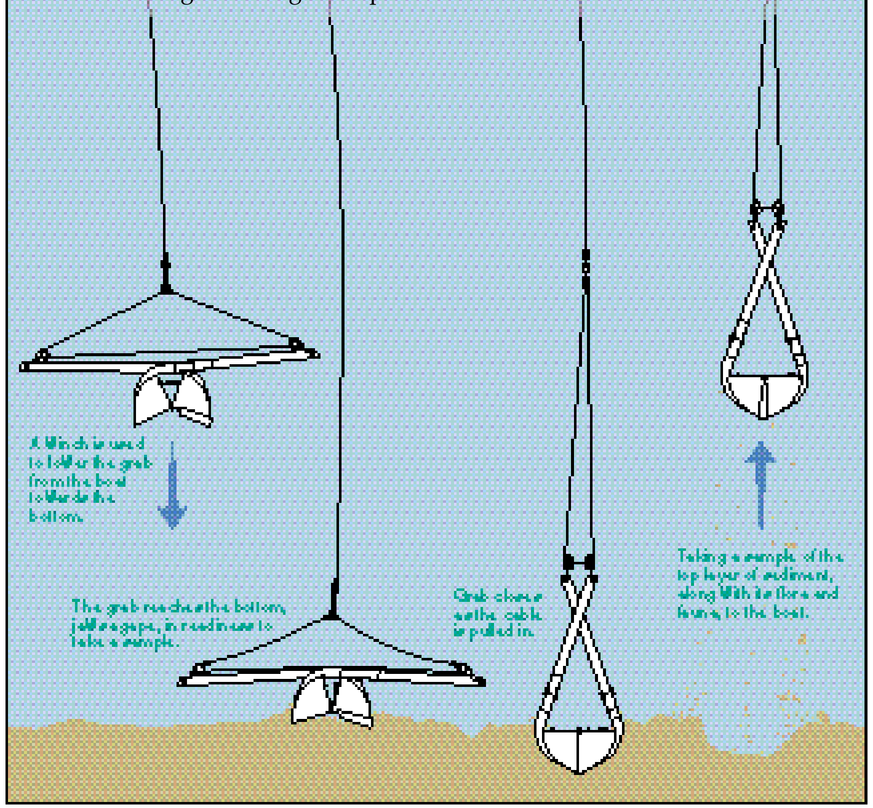
A number of sites on the Continental Shelf, adjacent to the Big Bank Shoals, were sampled to determine the infauna of the region. Polychaetes and crustaceans were the dominant organisms found here, with the rest of the samples made up of various echinoderms, molluscs, nemerteans, sponges and fish. These communities, sampled from greater depths than other similar studies in the region, are consistent with what would be expected from Continental Shelf regions. In the following section we will discuss some of the general biology of infauna and the ways in which this may affect the communities of the Continental Shelf.

Methods

At Elang Field, Mallee East-1 and Bayu-Undan Field (Figure 43), sediment samples were obtained for analysis of the composition of the infauna. At both Mallee East-1 and Elang Field, one location each was sampled. At Bayu-Undan three locations were investigated. At each of these locations a series of samples were collected using a 0.15m^2 van Veen benthic grab (see *van Veen grab*, page 79), raised and lowered by hydraulic winch from the ship. A series of point samples, radiating out in an X-shaped pattern from the central site location, were collected. Upon retrieval the grab returns were inspected by a marine biologist to ascertain sample adequacy. If adequate, all of the surface 20 cm of the sample was collected and preserved for subsequent infauna determinations, undertaken with the aid of microscopes in the laboratory.

VAN VEEN GRAB

For quantitative samples of organisms which inhabit the sediment, the benthic grab is generally used. It is particularly useful in sampling the slow-moving and sedentary animals which live on the bottom or in the sediment. The first grab was used early this century when the Peterson grab was employed in the study of the Norwegian fjords. Since then there have been many modifications and improvements on the Peterson design, one of which is the van Veen grab first used by van Veen in 1933. The van Veen grab improves on the Peterson grab in having long arms attached to the buckets, which provides better leverage for closing the jaws. Below is a diagrammatic representation of a van Veen grab taking a sample.



Regional infauna

In all, 1,620 animals representing 209 taxa were sorted from the grab samples at the three sites. The two major taxa encountered were polychaetes and crustaceans which made up over 84 percent of the total species found at each site. They were also the most abundant animals, accounting for more than 88 percent of the total number of individuals found, with echinoderms, molluscs, nemerteans, sponges and fish making up the remainder.

In a comparison of the three sites it was found that the sites at Bayu-Undan were characterised by low species richness (number of species present per sample), and abundance (number of animals per sample). In broad terms the infauna collected from the three regions was very similar (Figure 44). For example, the number of species of polychaetes and crustaceans at each of the sites was much the same, although the abundance of the particular taxa varied notably. The overall percentage of polychaetes at Bayu-Undan is nearly double the values for Elang Field and Mallee East-1. The mean number of species and mean abundances at Bayu-Undan sites were less than half those at the Mallee East-1 site and the Elang Field site (Figure 45). This may have been attributable to sediment size, which is known to directly affect community composition of benthic systems (Rhoads, 1974). Mallee East-1 and Elang Field seem to have greater similarity than Elang Field and

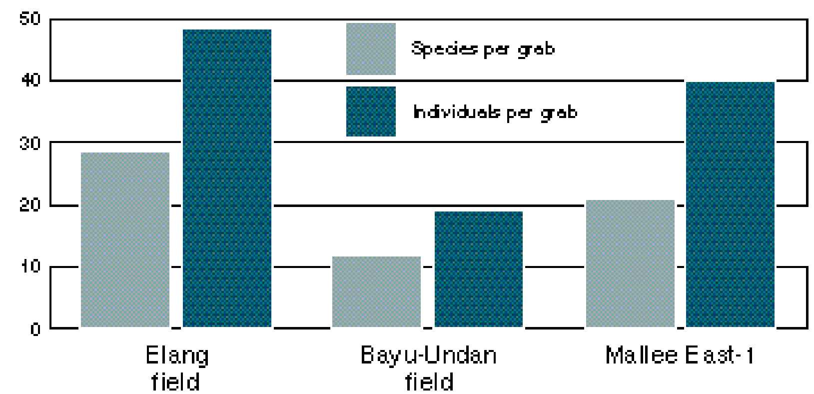


Figure 44. The number of species and individuals collected per grab at each site.

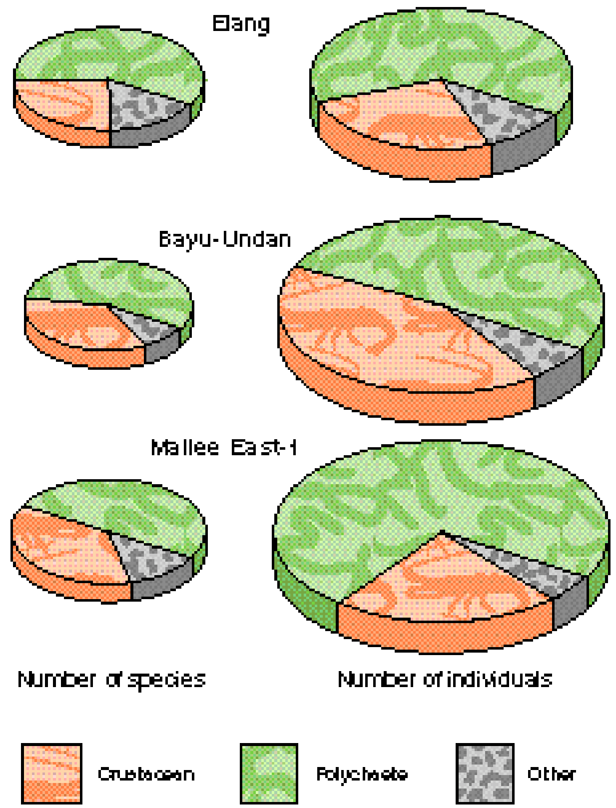


Figure 45. The proportion of the major infauna groups collected at each site in terms of total species and total number of individuals. Note that the size of the pie indicates total number.

Bayu-Undan, which are much closer together, providing some evidence that there may be significant spatial variability of benthic infaunal communities in this area of the Continental Shelf.

All sites had low species richness and abundance, in comparison with other studies conducted in the region (eg. Long and Poiner, 1994). This is not completely unexpected as these sites were at greater depths than the previous studies in the region. At depths of 20-80 metres, oxygen levels in the water begin to become stressful to benthic life (Alongi, 1990). It has been suggested by Alongi (1989c) that tropical, benthic habitats are subject to a wider range of environmental disturbances than temperate habitats, thus increasing variation in species diversity and abundance.

Most of the species found were usually present in very low numbers. A high proportion were found as either single records, or accounted for fewer than 5 percent of the samples. This seems to be a common trend in tropical benthic habitats (Saenger *et al.*, 1980).

Polychaetes

Polychaetes were the predominant organisms at all three sites, both in terms of number of individuals and number of species, (e.g. Elang Field), (see Figures 44 and 45). Similar patterns were found at both Bayu-Undan and Mallee East-1, where the polychaetes made up 51 percent and 73 percent of all individuals and 56 percent and 50 percent of the species, respectively.

Polychaetes belong to the Phylum Annelida, (segmented worms) which taxonomists have grouped into four classes. The Polychaeta, with over 10,000 described species, is the largest class. They are all aquatic, with most living in marine or estuarine environments. The other classes, Oligochaeta (terrestrial and aquatic earthworms), Hirudinea (leeches) and Myzostomida are much less common in marine waters.

A typical polycheate.

Many polychaetes live in burrows, either with or without tubes, underneath boulders, in crevices, on weed, in sand or on rock. Some are carnivores, others herbivores or scavengers and some are opportunistic omnivores, eating whatever comes their way. Many are filter-feeders that strain the water column for food particles, while some are deposit-feeders which ingest sediments to obtain nutrients from the algal and bacterial films that cover them. All of these different modes of life are represented in the polychaete collections from the three sites. Some of the more common polychaetes are described below.

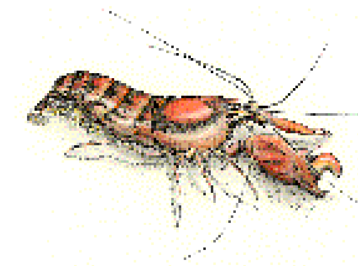
The samples collected contained a large number of tube-dwelling, deposit-feeding polychaetes. These included representatives from the Ampharetidae, Terebellidae, Magelonidae, and Spionidae families. The tubes can take a number of forms. They may be permanent calcareous tubes, or semi-permanent tubes created of soft mucous to which is adhered particles of sand, shell and other detritus. In general, these worms have long tentacles which spread like spaghetti over the substrate. The tentacles collect algal and bacterial films from the sediments and tiny hairs (cilia) create currents that draw the food into a groove, along the tentacles to the mouth.

A number of polychaetes burrow through the sediments and ingest them, much like earthworms. The Capitellidae and Cirratulidae are both groups of polychaetes which feed in this manner. Capitellids are small, opportunistic, surface deposit-feeders. They live in semi-permanent mucous tubes and burrow rapidly through the sediments, feeding on algal and bacterial film, which they ingest through their proboscis. Their presence is often considered to be an indication that an area has been recently disturbed. This is because their life history traits of small body size, large eggs, continuous reproduction and short life span enable them to rapidly colonise new areas (Hsieh and Simon, 1991).

Syllidae, Guniadidae, and the Eulepethidae are all families which have species that are free living predators. These polychaetes are carnivores that roam across the sediment surface in search of food. There are even syllids which feed exclusively on hydroids, using their muscular pharynx to suck out the polyps. Free living, herbivorous polychaetes were represented by *Nematonereis unicornis* and a member of the Lumbrineridae.

Crustaceans

The other major representative of the infauna were crustaceans, which made up 22-42 percent of all individuals and 25-37 percent of all species sampled at the three locations (see Figure 45). They are principally aquatic animals and in marine environments are found from the shore down to habitats upto 10,000 metres deep. The crustacea include about 30,500 species ranging in size from microscopic plankton to the giant spider crab of Japan, which has a leg span of 3.6 metres. Even though the species are very numerous, they are largely unknown, as detailed observations have been made of only a few groups.



The crustacean, *Alpheus* sp.

Large and diverse assemblages of amphipods were found at the three study sites. Amphipods occur as free-living algal grazers, scavengers, and also as symbionts of ascidians, sponges, and hydroids. About one-third of all Indo-Pacific amphipods belong to families that form tubes.

Alpheus sp., an Alpheid shrimp, lives in a variety of habitats. Many are free-living animals which live in burrows, and feed on both plant and animal matter. Others are commensal on crinoids or in sponges. Several species of *Alpheus* have a remarkable association with gobies, excavating and sharing the burrow with fish.

The Anthuridae are a suborder of isopods. Isopods, also called fish lice, slaters or pillbugs, are a morphologically diverse group. There are over 4,000 species and more than 700 genera. They are second in size only to the Amphipods. As most of them are free-living, they are found everywhere, even in the nasal passages of fish, although a few are planktonic. Large numbers of isopods are carnivorous and include some voracious predators.

They are even known to bite bathers or attack divers. A significant number of species are parasitic, living on fishes and other crustaceans.

Upogebia sp., which was particularly abundant at Bayu-Undan, belongs to the group Thalassinidea, which are commonly known as ghost shrimps, mud shrimps, yabbies or sponge shrimps. The *Upogebia* sp. constructs extensive burrows and are filter-feeders.

Other infauna organisms

The rest of the organisms sampled belong to a number of different phyla, which make up less than 16 percent of the species or individuals sampled. These include sea cucumbers (Holothuridae), sea urchins (Echinoidea), hydroids (Hydrozoa), tusk shells and bivalves (Mollusca), sponges (Porifera), acorn worms (Sipunculidae), ribbon worms (Nemertea), round worms (Nematoda) and fish (Vertebrata). In general, these organisms were encountered as single records.

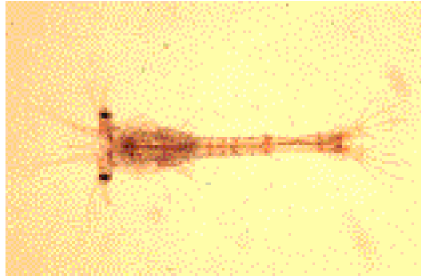
A brittle star.

These data, although limited in their scope and spatial origins, provide a novel contribution to our knowledge of the region. They are consistent with a shelf area, between the rising carbonate shoals, that supports moderate communities of polychaetes and crustaceans, interspersed with rarer representatives of other taxa. These sites were at greater depths than previous studies in the region and there is a suggestion that the deeper water infauna communities may be more uniform or predictable than sites shallower than 50 metres, where variations in sediment composition and inputs from photosynthesis may play a greater role.

Plankton

Plankton are those animals and plants that are free-floating or swimming weakly in the water column. Because they are unable to swim, or are very weak swimmers, they move freely with the current. Plankton range in size from large jellyfish to microscopic plants. Nearly all marine animals have representatives in plankton, whether it be as an adult or at a larval stage. Plankton is divided into two major categories: zooplankton, the free-floating animals; and phytoplankton, the free-floating plants. Plankton play an extremely important role in marine processes because they are the first stage in the food chain of the oceans. This chain begins with phytoplankton which are able, through photosynthesis, to convert the energy of the sun into chemical energy. In fact, it has been estimated that 90 percent of all photosynthesis and release of free oxygen takes place in the oceans. The zooplankton, which feeds on phytoplankton, is consumed in turn by larger animals, such as fish. Plankton are such a valuable food source that the largest animal on the planet, the Blue Whale (*Balaenoptera musculus*), feeds on it exclusively. In this way, energy is passed along the food chain. This vital role of initial fixation of energy makes plankton an important component in the economy of the oceans.

A copepod (AIMS).



A prawn larvae (AIMS).

The density of plankton varies, depending on the availability of nutrients and the stability of the water. A litre of seawater may contain more than 500 million planktonic organisms. They occasionally become so numerous that the organisms colour the water. These sudden population increases are called tides. Such tides can sometimes become dangerous because they can poison humans, shellfish and fish.

Plankton may be further divided into a number of categories dependent upon taxonomic grouping and size. Size classification does not distinguish between plant and animal. There are five subdivisions. Megaplankton are all those organisms larger than 2 mm. Macroplankton comprise the organisms from 0.2 to 2 mm in size. Microplankton are those plankton that fall between about 20 µm and 0.2 mm. The nanoplankton are very small organisms ranging in size from 2 to 20 µm. The smallest plankton are termed ultraplankton and are less than 2 µm in size. Finally, plankton are categorised according to their life history characteristics. Holoplankton are those organisms that spend their entire lives in plankton. Meroplankton, on the other hand, are those species that spend only part of their lives in plankton. This part of the plankton includes larval stages of animals, such as corals, sponges, fish and crustaceans.

Plankton of the Big Bank Shoals

Plankton samples were taken at three locations: Bayu-Undan, Big Bank and South Bank (Figure 47). Samples from the top 20 metres of water were taken at night, with a standard plankton net. The plankton samples were then preserved in formaldehyde-seawater solution for transport to the laboratory. Zooplankton samples were counted and identified using a stereo dissecting microscope to obtain abundances, while phytoplankton biomass was estimated separately by measuring chlorophyll concentrations. As chlorophyll is only found in plants and is vital for photosynthesis, this is an extremely useful method for measuring phytoplankton abundance.

The zooplankton assemblage in the top 20 metres of the water column was diverse and abundant at most sites. In each sample there were generally 7,000 individuals, representing 20 to 30 taxa. Three or four of these groups were common Calanoid and cyclopoid copepods (Figure 46). Planktonic crustaceans that feed on phytoplankton were the most prevalent taxa. Gravid (egg-carrying) copepods were found in a number of samples and this would explain the number of eggs and nauplii (larval stages) observed. Nauplii and eggs were present at all sites, indicating actively breeding populations. Unfortunately, the taxonomy of nauplii and eggs is very difficult and largely unknown, although their body forms and abundance indicate that they were probably copepods.

Appendicularids (Larvaceans) are long-tailed, planktonic animals which build an external 'house' of hardened mucous that is used as a filter-feeding apparatus (Figure 46). They are very common at South Bank where they contribute more than 20 percent of the total number of zooplankton.

A high degree of temporal and spatial variability is a common feature of zooplankton populations. This can cause problems with one-off sampling as it provides only an instantaneous 'snapshot' of the zooplankton assemblage occurring in the region. Spatial heterogeneity in the region was demonstrated through the variability in the composition and abundance

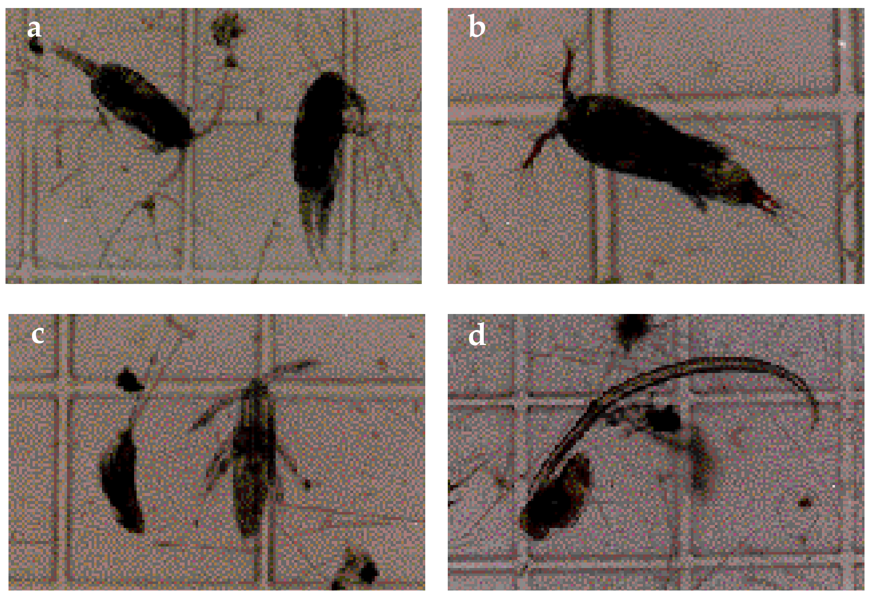


Figure 46. Plankton of the Big Bank Shoals. (a: Calaniod copepod, b: Cyclopoid copepod, c: Copepod nauplii, d: Appendicularid (Sandra Griffin).

of zooplankton assemblages sampled. Although, temporal variability could not be assessed from the present study, Trantor (1962) found that zooplankton abundance increased during July-August, and was related to coastal upwelling caused by offshore Southeast Monsoonal winds.

The seas surrounding Australia contain a relatively low zooplankton biomass, which reaches a maximum in an upwelling area between the northwest coast of Australia and Indonesia (Trantor, 1962). The Institute's study found zooplankton biomass to be in the range of 65-155 mgm^{-3}, which is similar to the 50-100 mgm^{-3} which was found by Trantor. Even though this is the highest level for the Australian Continental Shelf it is still relatively low in a world context. Trantor believes that zooplankton abundance in the waters of the Australian Continental Shelf could be as little as one-sixth that of high latitudes.

Apart from this work, very little has been done in this region. Kimmerer *et. al.* (1985) has carried out studies on plankton distribution in Shark Bay and McKinnon and Ayukai (1996) looked at copepod egg production and food resources in Exmouth Gulf. The Australian Institute of Marine Science has just recently conducted a survey of plankton in areas of the Timor Sea, which is yet to be published.

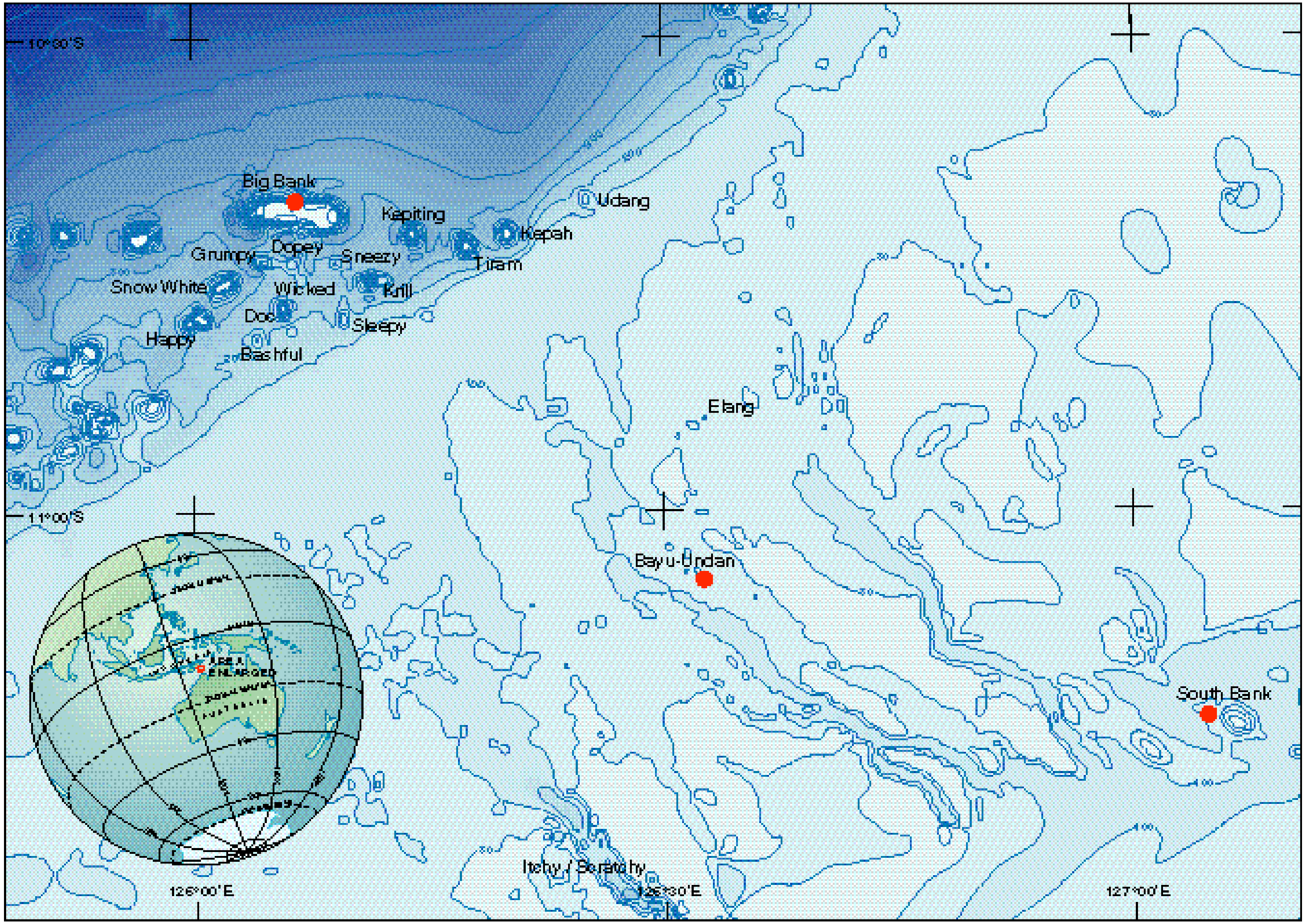


Figure 47. Map of the Big Bank Shoals showing the plankton sampling sites (shown as red dots).

Associated fauna

Corals and the calcareous algae, *Halimeda*, contribute structure to a reef, in the form of convoluted shapes and surfaces. They offer a myriad of refuges for organisms by providing areas to hide, settle and attach, and places to live. Consequently, a broad range of animals are found in conjunction with these reef-building species.

The offshore waters of the tropics are exceptionally clear. Clarity means that very few dissolved and suspended nutrients are present, so tropical seawater should not support many organisms. However, by forming an alliance with photosynthetic, pelagic algae, hermatypic corals have effectively concentrated the production of energy and used it to drive life styles that have colonised a nutrient-starved environment. Corals are not only able to produce energetically expensive carbonate structures, but have enough surplus energy to propagate themselves locally by highly successful asexual means.

Halimeda have their own mechanisms for efficient photosynthesis. Although compared to coral colonies their thalli are impermanent, they are hard structures of calcium carbonate and are replaced continuously by high rates of growth and asexual reproduction. Both corals and *Halimeda* provide an extensive habitat that is spatially variable, yet permanent through time. These are unique properties which have enabled the evolution of diverse communities of associated fauna.

Here we will discuss the associated fauna found on the Big Bank Shoals, as revealed by the ROV videos. This section is not all-inclusive but merely representative of the many animals that constitute the coral reef and *Halimeda* bank communities.

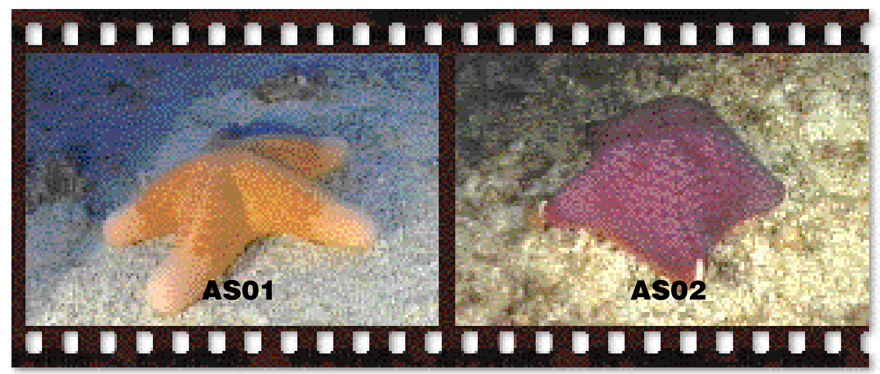
Phylum Echinodermata

Representatives of all five of the forms of the Phylum Echinodermata are present among the corals and *Halimeda* beds of the Big Bank Shoals, with at least one common to each of the communities identified (see film strips *AS01* to *AS06*).

Echinoderms are characterised by the possession of spines that project from a calcareous endoskeleton, a water vascular system that hydraulically powers tube feet and bodies that are based on a pentamerous (five-sided) symmetry. Many echinoderms have minute, pincer-like structures, called pedicellariae, studding the surface of their bodies. They are stalked and mobile, which enables them to grab, kill and remove small animals that attempt to settle on the echinoderm's body.

Starfish and cushion stars (Sub-class Asteroidea)

The best known of the echinoderm groups are the starfish, which are characterised by five (although there can be several more) thick arms radiating from a central body. Internally, the body consists of five equal portions, each with identical sets of the various organs. The conspicuous, blue starfish, *Linckia* spp., are common on the *Halimeda* banks. Cushion stars have plump, five-sided bodies but, unlike starfish, they show almost no arm



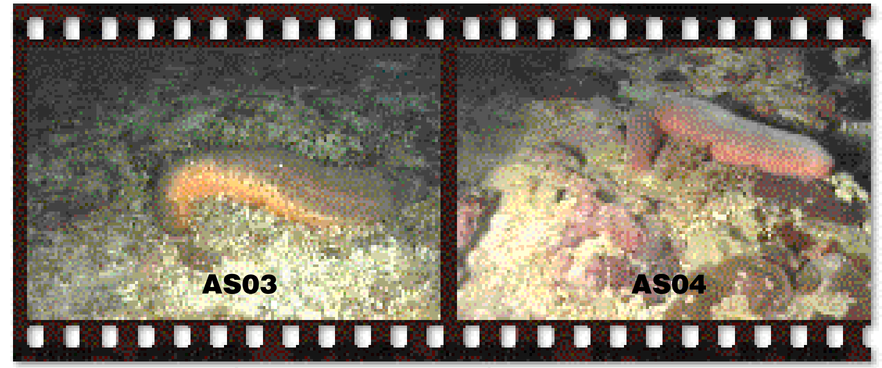
development (see film strips *AS01* and *AS06*). The arms of starfish have the ability to move and curl, but locomotion is achieved by the coordinated movement of numerous small feet, equipped with suckers, called tube feet. These form rows beneath each arm and are used for feeding and attachment as well as for mobility, albeit slowly.

Many asteroids feed on the film of detritus that covers rock, rubble and sandy surfaces. Other species prey on sponges, bryozoans, ascidians, crustaceans, molluscs and other echinoderms. Starfish that eat bivalve molluscs open them by gripping each shell with the tube feet of opposing arms and exerting continuous pressure until the mollusc's shell-closure muscle is defeated. Once the shells are even slightly apart the starfish can turn its stomach inside out while pushing it into the mollusc until the edible insides are actually surrounded by the stomach. Digestion begins in this everted state but later the stomach is withdrawn, bringing with it the partially digested mollusc.

Starfish are capable of incredible feats of regeneration. They are able to regrow their entire body from any fragment of themselves that includes a piece of the central body mass. In some species an arm will virtually pull itself away from the body and begin to grow itself into an entirely new body. This process is a form of asexual reproduction.

Sea cucumbers (Class Holothuroidea)

Sea cucumbers (or holothurians) are related to starfish and sea urchins but, unlike other echinoderms, their skeletons are reduced to microscopic ossicles and their fat, sausage-like bodies have a leathery texture (see film strips *AS03* and *AS04*). They are capable of moving in several ways; by pulling themselves along with their tentacles, by walking with small tube feet (that project from their underbellies) or by creeping along with rhythmic undulations of their body. Despite these varied abilities they are typically sluggish and generally only active at night, coming out from under rocks and from within crevices to feed in the open. Sea cucumbers



were seen on areas of bare substrate on several of the banks, in particular Dopey Bank and South Bank.

Holothurians have ten branched tentacles which form a circle around their mouths. Some feed by holding these up in the water currents so that they trap small plankton. However, the majority push their tentacles out onto the sediment. They are retracted, one at a time, and stuffed in their mouth where food is separated from inedible material.

When threatened by hungry predators, sea cucumbers are able to defend themselves in novel ways. Many are able to eject their guts, which is presumed to give their attacker something to eat while they escape. The lost viscera can regenerate in a very short time. Another group has special organs, called the 'Tubules of Cuvier'. These are like thin spaghetti and can be shot from the anus whereupon they elongate. As they are very sticky, an unsuspecting predator can become irretrievably entangled. Generally, tropical holothurians have compounds in their body walls that make them toxic, or at least unpalatable, to predators.

Feather stars (Class Crinoidea)

Feather stars or crinoids have a small, round body with a mouth on its dorsal surface and a multitude of colourful arms, in some species as many as 120.

Each arm has many fine side branches, giving them a feather-like appearance. This enables the feather star to present a large area of mucous-coated body to the water currents and from this trap planktonic food. This filter-feeding explains why they are commonly found above the reef floor, where currents are stronger.

Crinoids were frequently seen clinging to sponges and gorgonians on the deep water banks of Sneezy and Wicked. Although they appear permanently attached, they perch with a cluster of claw-like cirri, and if disturbed can swim briefly by rapidly flapping their arms.

Sea urchins (Class Echinoidea)

These echinoderms have no arms and their spherical bodies are composed of closely-fitting, bony plates. The entire surface of the body is covered in movable spines which provide protection but which also give the urchin mobility. In *Diadema* spp., a common coral reef genus, the spines are about 200 mm long. These distinctive sea urchins are frequently seen on the *Halimeda* banks of the Big Bank Shoals (see film strips *AS05* and *AS06*).

The body of sea urchins is orientated such that their mouth is directly beneath them. A complex, five-toothed apparatus, called 'Aristotle's Lantern', is used to scrape up and chew algae or small, encrusting animals from hard surfaces.

Brittle stars and basket stars (Sub-class Ophiuroidea)

Brittle stars are closely related to starfish but are distinguished by having a body that is a discrete disc, and arms that are long and slender and which rise sharply from the body. The arms are easily broken off, but readily regenerate. This accounts, no doubt, for their common name. A string of bony ossicles fill each arm. Musculature and the ossicles' articulation give the arms great mobility. Ophiuroids use their arms to move with surprising speed. Unlike their starfish cousins, their tube feet lack suckers and are not used for locomotion. Their slender arms are covered with a dense array of spines that improve traction when clambering around, but which also aid in feeding.

Many species use more than one mode of feeding. Some scavenge on the sea floor while others produce mucous that becomes strung between the spines covering the arms. When the arms are held upright in the water current small larvae and other animals in the plankton become trapped. The tube feet then roll the food-laden mucous down the length of the arms until it reaches the mouth.

Basket stars are a specialised form of brittle star. They commonly have more than five arms that are highly branched, giving the animal a lacy or feathery appearance. These complex structures are simultaneously held aloft in water currents (the effect is not unlike a basket). Basket stars are nocturnal filter-feeders. Like feather stars, they select places where currents are strong and may climb to high points on large sponges and gorgonians.

Phylum Cnidaria

This phylum encompasses the soft and hard corals, jellyfish and hydroids, as well as sea anemones and corallimorpharians. They have polyps and/or a medusa form (like jellyfish) that exhibits radial symmetry. They have a single body cavity, called the coelenteron, with a mouth being the single opening. The tentacles of cnidarians are equipped with stinging cells (nematocysts).

Sea anemones (Order Actinaria)

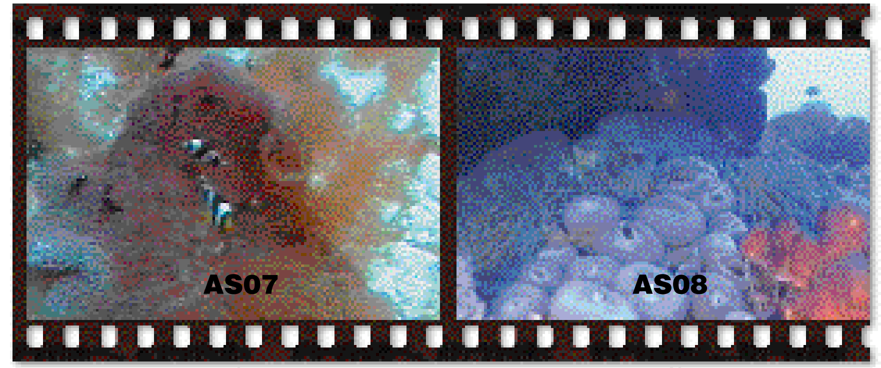
Sea anemones are solitary (although a few species are colonial) and live attached to hard and stable surfaces (see film strip *AS07*). Although they rarely move, they are capable of detaching and gliding along on the pedal disc they use for attachment. Many species are only a few centimetres across. However, one species on the Great Barrier Reef attains a size of 1 metre in diameter. Anemones are closely related to hard corals. They even look like massive coral polyps without skeletons. A ring of tentacles surrounds their mouth which sits on top of a hollow, tube-like body.

Anemones are opportunistic feeders, ingesting a broad size range of animals. Covering their tentacles are stinging cells called nematocysts. Any creature bumping into the tentacles will either be repelled by the stinging sensation or will be paralysed. Immobilised animals range in size from microscopic plankton to small fish and crustaceans (shrimp and crabs).

Many tropical sea anemones, similar to their coral cousins, are host to zooxanthellae (see the *Biology and ecology of hard corals*, page 43). Algae live in the tentacles of the anemone and the food substances they synthesise leak out to the body of the anemone and supplement its energy needs. Because of this relationship, many anemones reach their maximum size in shallow, clear waters that light can easily penetrate. Elements like sulphur and nitrogen are not supplied by the zooxanthellae, but anemones still need these to remain healthy. Some species are capable of absorbing nutrients directly from sea water, but a more common source may be the faeces of small fish. Anemones are well known for participating in symbiotic relationships with clown fishes (or anemone fishes), and waste eliminated by these fishes may be very useful to the anemone.

Corallimorpharians (Order Corallimorpharia)

Corallimorpharians are anemone-like animals that may be solitary or form colonies that can cover extensive areas of reef (see film strip *AS08*). They represent an intermediate stage in evolution between anemones and corals. The oral disc of these animals may form a bag or a flat disc shape with a ring of tentacles around the mouth. The tentacles cannot be retracted and in some species appear reduced in size or almost absent. Wicked Bank supports numerous corallimorpharians of the genus *Metarhodactis*. These look like large, flat water lilies. *Amplexidiscus fenestrafer* is the largest known species and the most likely identification of the corallimorpharians seen in a transect video of Tiram Bank. It looks like a pumpkin with its distended, bag-like oral disc.



Very little biological research has been directed towards the corallimorpharians. However, the feeding behaviour of *A. fenestrafer* has been documented. They are predators, feeding on small fish and quite possibly other small animals. Juvenile anemone-fishes have been observed mistakenly settling on the oral disc of *A. fenestrafer,* as they would when starting a relationship with a host anemone. The oral disc closes rapidly, like a drawstring purse with the fish trapped inside. The mouth of the corallimorpharian then opens and the fish enters the animals's body where it is digested.

Christmas tree worms (Phylum Annelida, Class Polychaeta)

The most conspicuous of the many annelids which inhabit coral reefs are the Christmas tree worm. They are polychaetes, of the family Sabellidae, and have a feeding apparatus called a branchial crown which is composed of ciliated tentacles. The tentacles are arranged in a conical spiral that resembles a Christmas tree. The cilia draw water across the structure, which sieves out planktonic food. Christmas tree worms may be brilliant blue, red, purple, green, yellow or orange. An interesting fact is that one individual can produce offspring of different colours.

Male and female Christmas tree worms release either sperm or eggs directly into the sea, where fertilisation takes place. The juvenile worm settles on a suitable coral colony and secretes a small, calcareous tube around itself. Rarely will they settle on dead coral. The coral grows around the worm's tube and slowly envelops it, save for the opening at the top, through which the worm can expand its colourful branchial crown. Eye spots are often present on the tentacles and when disturbed, such as when a diver or fish passes overhead, they are rapidly withdrawn into the safety of the tube. The top of the tube is commonly protected by a calcareous plug, which is sometimes ornamented.

Phylum Mollusca

This is a large and diverse phylum composed of soft-bodied animals that are usually unsegmented and enclosed by a hard shell. They have well-developed sense organs, a nervous system and a blood system with a heart. Although species of snail-like gastropod molluscs were present on the banks, this *Atlas* concentrates on a less familiar type of gastropod, the nudibranch, and a member of the group that least resemble snails, the Cephalopoda. The cephalopod molluscs have evolved sense organs and behavioural patterns that rival the vertebrates.

Nudibranchs (Sub-class Opisthobranchia)

Nudibranchia is the largest of the orders of the Opisthobranchia, containing about 2,500 species. Adult nudibranchs, commonly called sea slugs, have no trace of the shell that characterises gastropods. Consequently, their gills are unprotected, which accounts for the name nudibranch, or 'naked gill'. As well as crawling like slugs they are capable of swimming by rhythmically undulating their soft bodies. This motion, and the fact that many species are flamboyantly coloured, has led to the name 'spanish dancers'.

Nudibranchs feed on every kind of epifaunal material. They are specialists that have evolved ways of dealing with antiherbivory mechanisms that deter more opportunistic grazers. Tritonidae nudibranchs all prey on soft corals, disregarding their chemical defenses. Several species attack the horny colonies of bryozoans. Members of several nudibranch families have independently developed an exclusive preference for the eggs of other gastropods, cephalopod molluscs and fishes.

Many sea slugs have fleshy outgrowths on their backs, called papillae or cerrata. They have a defensive function which involves being armed with prickly bundles of spicules or with toxins. Chemical defenses may be produced by glands in the cerrata or be sequestered from toxic prey, such as soft corals (see *The Big Steal,* page 23). In at least two sub-orders, the dorsal papillae have the ability to nurture nematocysts, derived from cnidarian prey (such as anemones), so as to use them for the nudibranch's own defense.

Cuttlefish (Class Cephalopoda, Order Sepioidea)

These astounding molluscs are classified with the octopus, nautilus and squid. Cuttlefish look similar to squids as they have streamlined bodies and well-developed heads surmounted by two large eyes. These are remarkably similar to vertebrate eyes, consisting of a lens that focuses an image onto a retina. Their position on the head affords a 360° field of view in the horizontal plane. Cuttlefish have ten arms, two of which are retractile and are carried in pockets that lie either side of the mouth. They are predators of fish and crustaceans, making lightning strikes with their retractile tentacles that grasp with sucker-equipped terminal pads. Cuttlefish have been observed catching prawns with strikes that take only three one-hundredths of a second. Captured prey are immobilised with poison, which is injected when they are bitten by the cuttlefish's horny, parrot-like beak.

The soft bodies of cuttlefish are stiffened with a calcified structure called the cuttlebone. By adjusting the volume of gas held in the cuttlebone the cuttlefish can alter its buoyancy. They move slowly by undulating lateral fins on the body, but rapid movement is effected by jet propulsion. Water is expelled through a funnel when the mantle cavity is contracted. An ink sac in the mantle cavity can add ink to the outgoing water, thereby producing a dark cloud that hides the cuttlefish long enough for it to escape predation.

Cephalopods are known for their ability to rapidly change colour. Cuttlefish are no exception. They generally display a zebra-like pattern which is altered during courtship and when hiding from prey or predators. Cuttlefish burrow into sand and lie in wait for prey. They not only adopt the colour of the substrate but erect papillae on their skin to mimic the rough texture in which they are surrounded.

Phylum Chordata

The chordates are dominated by the diverse sub-phylum Vertebrata but also include the urochordates and an even smaller sub-phylum, the Cephalochordata. Chordates have a notochord and at some point in their life history also have gill slits, which are only seen at the embryonic stage of vertebrates. They also have a hollow nerve cord that is usually dilated at the front end to form a brain.

Reef fishes (Sub-phylum Vertebrata, Class Osteichthyes)

The members of this grouping participate in benthic reef communities in more varied ways than any of the preceding classifications. Bony fishes reach their highest diversity in the reefs of tropical waters. As many as 200 species of fish may inhabit less than a hectare of coral reef. The abundance and diversity of reef fishes is evidence of the remarkable number of ecological niches provided by reef-building species and their associated fauna (see film strips *AS09* and *AS10*).

Fishes have evolved ways of feeding on every edible part of the reef community. Herbivores, such as rabbitfishes (Siganidae) have relatively easy pickings by grazing benthic algae. However, some damselfishes (Pomacentridae) and surgeonfishes (Acanthuridae) ensure their food supply by nurturing and defending a 'garden' patch. The elongate mouths of many butterflyfishes (Chaetodontidae) are used to extract coral polyps from their protective skeletons. Alternatively, parrotfishes (Scaridae) haveevolved strong beaks that enable them to scrape algae encrusting dead, hard coral colonies. Many species have an opportunistic and hence more varied diet, like an angelfish (Pomacanthidae) which supplements a preference for sponges with a range of other benthic invertebrates. Members of other families, such as fusiliers (Caesionidae) form schools above or off the reef and capture zooplankton, .There is also a large suite of species that are predators of mobile and evasive animals, including other fishes.

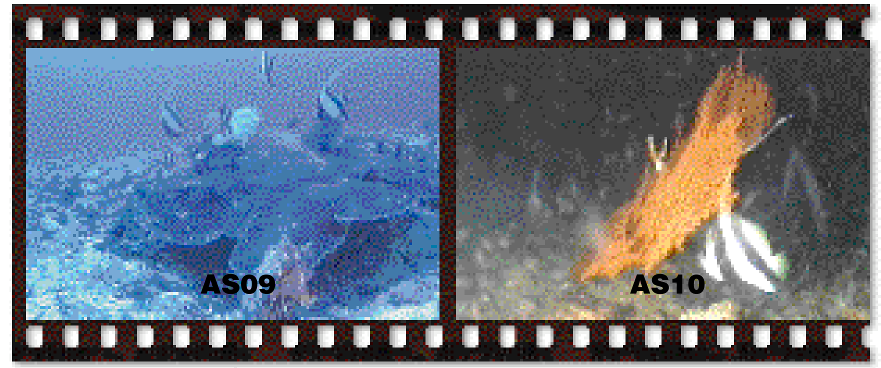
The distribution of fishes is often restricted by habitat type. Therefore, different parts of the same bank may have markedly dissimilar fish assemblages. This was obvious on the *Halimeda* banks that supported isolated outcrops of hard corals. A mixed and numerous group of fishes flitted around the coral bommies while the low-lying *Halimeda* beds appeared to be permanently inhabited by only a few small species, such as hawkfishes (Cirrhitidae). Many species defend territories, either continuously or briefly, to ensure a food supply during the breeding season.

The majority of reef fishes change sex during their lifetime, either beginning as a male and changing into a female or vice versa. The different sexual phases of a species are frequently characterised by particular colour patterns. Sex reversal is often socially controlled, such that individuals alter in response to a change in the sex ratio of the group. Males and females of a species may spawn demersally or pelagically. Demersal spawners usually pair off, with the male fertilising a mass of eggs which the female has laid on the substrate. Nesting areas are vigorously defended while the clutch develops. Pelagic spawning involves pairs or groups of fishes releasing sperm and eggs simultaneously in the water above the reef. This is usually timed to happen at dusk, when fewer planktivorous predators are active. Fertilised eggs hatch into larvae that may remain in the plankton for days or months.

Sharks (Sub-phylum Vertebrata, Class Selachii)

Sharks are cartilaginous fishes, which means their skeletons are composed of cartilage, an elastic, skeletal tissue that is hardened to form bone in other vertebrates, such as fishes. Sharks also differ from reef fishes in that they do not have a swim bladder to maintain buoyancy and so sink if they stop swimming. Sharks range in size from the gigantic whale shark *(Rhincodon typus)* measuring up to 18 metres in length, to the cookie-cutter shark *(Isistius brasilensis)*, which is less than 50 cm long. They inhabit all seas but are especially abundant in tropical and subtropical waters. Several species are strongly associated with reefs and maintain territories for their entire adult lives. Others have a more oceanic habitat and only occasionally visit reefs. Sharks, of the genus *Carcharhinus* were seen on Kepah Bank and Doc Bank, but most probably inhabit all banks (see film strips *AS12*).

In general, sharks are flesh eaters that feed on fishes, crustaceans and molluscs. Fish eating species generally have several rows of sharp teeth that are designed for seizing and tearing prey. Those that specialise on molluscs have teeth modified into bony plates for crushing shells. Their reputation as ruthlessly efficient predators is quite justified. They have an astonishing range of sensory systems for the detection of prey. An acute sense of smell and eyes that increase their sensitivity at night are augmented by two systems for detecting vibrations in the water, an array of pores in the skin, like taste buds (which are poorly understood) and the ability to sense electrical fields. With this last sense sharks are able to 'see' potential prey buried under sand. Sharks play an important role in the dynamics of coral reefs. They are the top feeding level in many reef communities, frequently acting as predators of the predators. Predation serves to hold a prey population at optimum

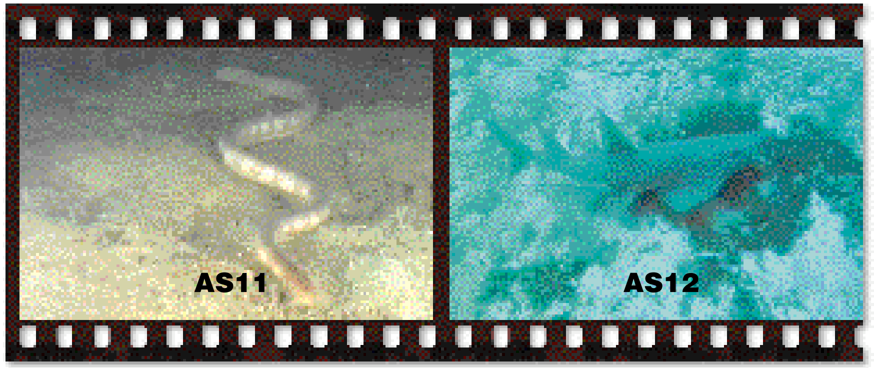


levels and keeps it healthy by removing sick or injured individuals.

Sea snakes (sub-phylum Vertebrata, Sub-order Ophidia)

There are approximately 50 species of sea snake, nearly all belonging to the family Hydrophidae. Most species live in warm, tropical to subtropical waters which stetch from the Indian to Pacific Oceans. Sea snakes are generally not very large, ranging from about half to one metre in length, although Stokes sea snake *(Astrotia stokesii)* can reach nearly two metres long. Generally there are considered to be two groups of sea snake. The true sea snakes spend all their lives in the water, giving birth to live young. They lack the enlarged ventral scales typical of most terrestrial snakes, which improve purchase when moving about on the ground. The other group, called seakraits, lay eggs on land and so have retained large, ventral scales.

The paddle-like tail of sea snakes is wide and compressed and makes an effective swimming organ. Unlike eels, sea snakes have no gills and must return to the surface for air. They can, however, remain underwater for several hours, obtaining dissolved oxygen from water that they swallow and later regurgitate. Sea snakes feed mainly on fishes, particularly small, benthic species. The toxicity of sea snakes is probably on a par with their terrestrial counterparts, and so bitten prey rapidly succumb and can be swallowed without a struggle.



Sea snakes pose very little threat to humans. They are generally not aggressive and will not bite unless handled roughly or forcibly restrained. Studies suggest that defensive bites rarely involve the release of venom. However, they are very inquisitive and will investigate divers that enter their environment. One specimen stayed with the ROV for several minutes during filming at Dopey Bank (see film strip *AS11*).

Social Environment

Richard Hortle, Craig Humphrey, Edward Pinceratto and Luke Smith

This section deals with social activities in the Timor Sea focusing particularly on the area surrounding the Big Bank Shoals. It includes geopolitical aspects of the sea boundary between Australia and Indonesia, fisheries and aquaculture.

The geopolitical setting

The area surrounding the Big Bank Shoals is situated in a complex international boundary setting, involving bi-national jurisdiction and a sharing of resources. Most of Big Bank, and the shoals immediately to the south, lie in an area designated as a 'zone of overlapping jurisdiction' by the Treaty between Australia and Indonesia signed in March 1997 (Figure 43). In this area, sovereign rights and jurisdictions, as provided in the 1982 United Nations Convention of the Law of the Sea (UNCLOS), are applied differently for each country. Indonesia may exercise Exclusive Economic Zone (EEZ) rights and jurisdiction for the water column, whereas Australia may exercise Continental Shelf sovereign rights and jurisdiction for the seabed.. This means that fisheries fall under Indonesian jurisdiction, and mineral resources, such as hydrocarbons, as well as sedentary species such as trepang and trochus, fall under Australian jurisdiction. Both parties are required to take effective measures as may be necessary to prevent, reduce and control pollution of the marine environment.

The shoals to the East of Big Bank, including the eastern portion of Big Bank, are situated in the Timor Gap Zone of Cooperation (Area A). This area is subject to the provisions of the 1989 Timor Gap Treaty between Australia and Indonesia which establish that mineral resources in this area will be exploited jointly by the two countries and shared equally. The water column in this area falls under the Indonesian EEZ and is entirely outside the Australian EEZ. A Joint Authority has been established under the Treaty to administrate contractual arrangements for the exploration and exploitation of hydrocarbons by private operators. Under the Treaty, employment in Area A must be distributed equally between Australian and Indonesian residents.

Fisheries of the Timor Sea

Commercial fisheries, having ranges that entirely or partly impinge on the Timor Sea, are located between the lines of longitude 122° South and 130° South. Their coverage in this *Atlas* is limited as only a few commercial fisheries that were considered to be significant in terms of area or value.

The group of banks on which this *Atlas* focuses on, are outside the Australian Fishing Zone (AFZ), therefore, any commercial fishing operations in the vicinity of these banks will be licensed under Indonesian law. Nonetheless, as fish do not observe international boundaries, several fish stocks of the region are fished by both Indonesian and Australian fishers. The most relevant Indonesian fisheries are considered first, followed by the Australian operations.

Fishing on the Big Bank Shoals

The Big Bank Shoals lie more than 45 nautical miles beyond the 200 nautical mile limit of the AFZ, consequently are inthe Indonesian EEZ. Fishing vessels that hold licenses for Australian fisheries do not fish on or around the Big Bank Shoals. However, Indonesian vessels are likely to move through the area and in some cases, may fish on or around the shoals. Indonesian vessels may take fish but not benthic animals, such as trepang and trochus, from the banks south of Big Bank (since the seabed in this area is under Australian jurisdication). Species that are likely to be targeted by Indonesian fishers are shark, tuna, mackerel and reef fish such as snapper (Lutjanidae) and emperor (Lethrinidae).

An Indonesian fishing prau. (AIMS)

LIFE ON AN INDONESIAN TRADITIONAL FISHING BOAT

The prau (or perahu) pictured below is typical of the type of sailing boat used to catch shark in the Timor Sea. Praus are generally about four tonnes in weight and carry a skipper and five crew (or 'sawi'). A round trip from Pepela (East Roti) to the Timor Sea and back is expected to last about three weeks. The vessels are loaded with 600-1000 litres of water (in plastic drums), 200 kilograms of rice, several large packs of instant noodles, sufficient salt for cooking (and for the preservation of dried fish, caught during the trip) and a small quantity of medical supplies. In addition to these provisions one and a half cubic metres of firewood is carried to fuel cooking fires.

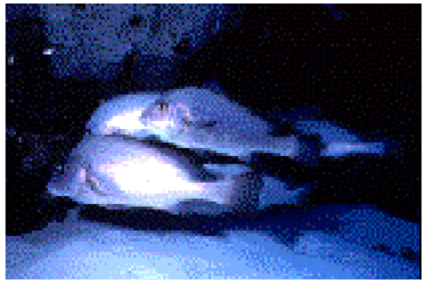
Praus carry two sails in reserve, a flashlight for checking the set of the sails at night and for communicating with other boats and a compass; however from the account given by Ataupah (1996) it seems unlikely that charts of the area are commonly carried. In addition to several 1000 fathom shark fishing lines the fishers use shorter (about 100 metres) lines for catching pelagic fish for shark bait, their own consumption and occasionally for drying and salting for sale. Floats, to use with the shark longlines, are collected when found floating as jetsam, or empty water containers are utilised if insufficient commercial floats are available. Home-made spears are used to kill hooked sharks before they are brought aboard and several goro-goro or shark rattles are an equally essential part of the equipment needed. These are three pairs of coconut shells attached to a bamboo stick that are used to chop the surface of the water. The rhythm produced attracts sharks to the boat and its lines.

Generally these men are to be respected. They are operating far from land, in essentially open and unmotorised boats, with primitive navigational aides and only the basic ingredients of life. Furthermore their prey is the top predator of the sea which they sail upon (Photograph by AIMS).

Indonesian fishing

Commercial fishing

Indonesian and Taiwanese vessels, with Indonesian endorsements, fish in the region for shark (fin) and reef fish. The gillnetters are relatively sophisticated, carrying modern navigational equipment and hydraulic net haulers. Nets are set on the sea floor in order to catch a wide variety of fish as well as shark (Anon., 1993a).



A snapper, *Lutjanus* sp. (GBRMPA).

Since 1992, timber boats more than 22 metres in length have targeted the reefs and shoals of the northern Timor Sea. They use demersal longlines to catch reef fish, such as snapper. Becuse the catch is packed in ice, hence these vessels being referred to as 'ice-boats'. These vessels have the capacity to carry more than 20 tonnes of fishes to markets in Singapore (Anon., 1993a).

Traditional fishing

The island of Roti, at the eastern end of Timor, is 550 km from the Australian coastline. Along the way are several coral reefs and islands, including Ashmore Reef and Cartier Islet (Figure 48). For centuries, the seafaring inhabitants of South East Asia have visited northern Australia and utilised its varied marine resources. The Macassans (from what is now called Ujung Pandang in Sulawesi) made yearly visits to northern Australia to collect turtle and trepang (sea cucumber). The fishery originated between 1650 and 1700, but started to decline in 1881 when the South Australian government (which initially controlled the Northern Territory) began taxing Macassan praus (sailing boats) fishing in Australian waters. By 1907 the South Australian government ceased issuing licenses to the Macassans (Cannon and Silver, 1986).

In 1974 the Australian government acknowledged the long history of traditional Indonesian fishing in Australian waters by signing a Memorandum of Understanding (MOU) with Indonesian. Under the terms of the MOU, Australian authorities agreed to allow traditional fishers from Indonesia to operate within the 200 nautical mile limit of the AFZ while employing traditional fishing methods in the MOU area, which includes Ashmore Reef, Cartier Islet, Browse Island, Seringapatam Reef and Scott Reef (Figure 48), (Caddy, 1995). This area is a source of trepang (sea cucumber), trochus (top shells or *Trochus niloticus*) and shark.

Trepang is traditionally collected by reef walking at low tide or by shallow, breath-hold diving. Certain species are preferred, notably *Actinopyga* spp., *Holothuria nobilis* and *Thelenota ananas*. However, as populations of these are reduced, other species are likely to be targeted (S. Uthicke, *pers. comm.*). The animals are cleaned, boiled and then sun-dried or smoked (Cannon and Silver, 1986). Trepang is a valuable catch for these fishers as it sells for up to $30 per kilogram in Asia (Caddy, 1995). However, although the meat is high in protein, however, its value may be more related to the belief that it is an aphrodisiac.


The highly valued *Trochus* sp. (GBRMPA).

Trochus is collected in similar ways to trepang, although the meat of this mollusc is of only secondary importance to its lustrous shell. The shells are used to produce jewellery, ceramics, ornaments, cosmetics and luminescent paints. Trochus shell is also used as mother-of-pearl for the manufacture of buttons (mainly in Europe and Japan). It is thought that stocks of trochus have been fully exploited (Caddy, 1995).

Shark fishing is practiced by as many as 200 Indonesian boats which operate from Pepela, Delaba, Tablolong and Mola in East Nusa Tenggara.


The white-tip reef shark (GBRMPA).

The sailing vessels each carry about six crew members (see '*Life on an Indonesian traditional fishing boat'* 'page 99), (Ataupah, 1996). As traditional Indonesian fishing boats have no refrigeration, any meat taken as catch during their fishing trips must be preserved by some other method. Drying is the preferred way. However, this method consumes considerable deck space, so usually only the fins are kept as they are the most valuable part of the shark. Shark fins are sold on Asian markets for soup. They command an average price of about $59 per kilogram, but high quality fin may attract as much as $100 per kilogram (Ataupah, 1996). The fishers catch demersal and pelagic fish to use as bait for shark fishing. Sometimes these fish are dried and salted and sold on Indonesian domestic markets, even though it appears to be a sideline of the crew and not a large source of income. Dried shark flesh returns a very low price as it apparently has an offensive taste and odour (Ataupah, 1996).

Longlines of approximately 1000 fathoms in length (one fathom is six feet or 1.83 metres) are set with baited hooks. The most important species for their fins are hammerheads (*Sphyrnidae* spp.) which have very large dorsal fins, makos (*Isurus oxyrinchus*) and blue sharks (*Prionace glauca*), with whaler sharks (*Carcharhinus* spp.) contributing a large proportion of the catch.

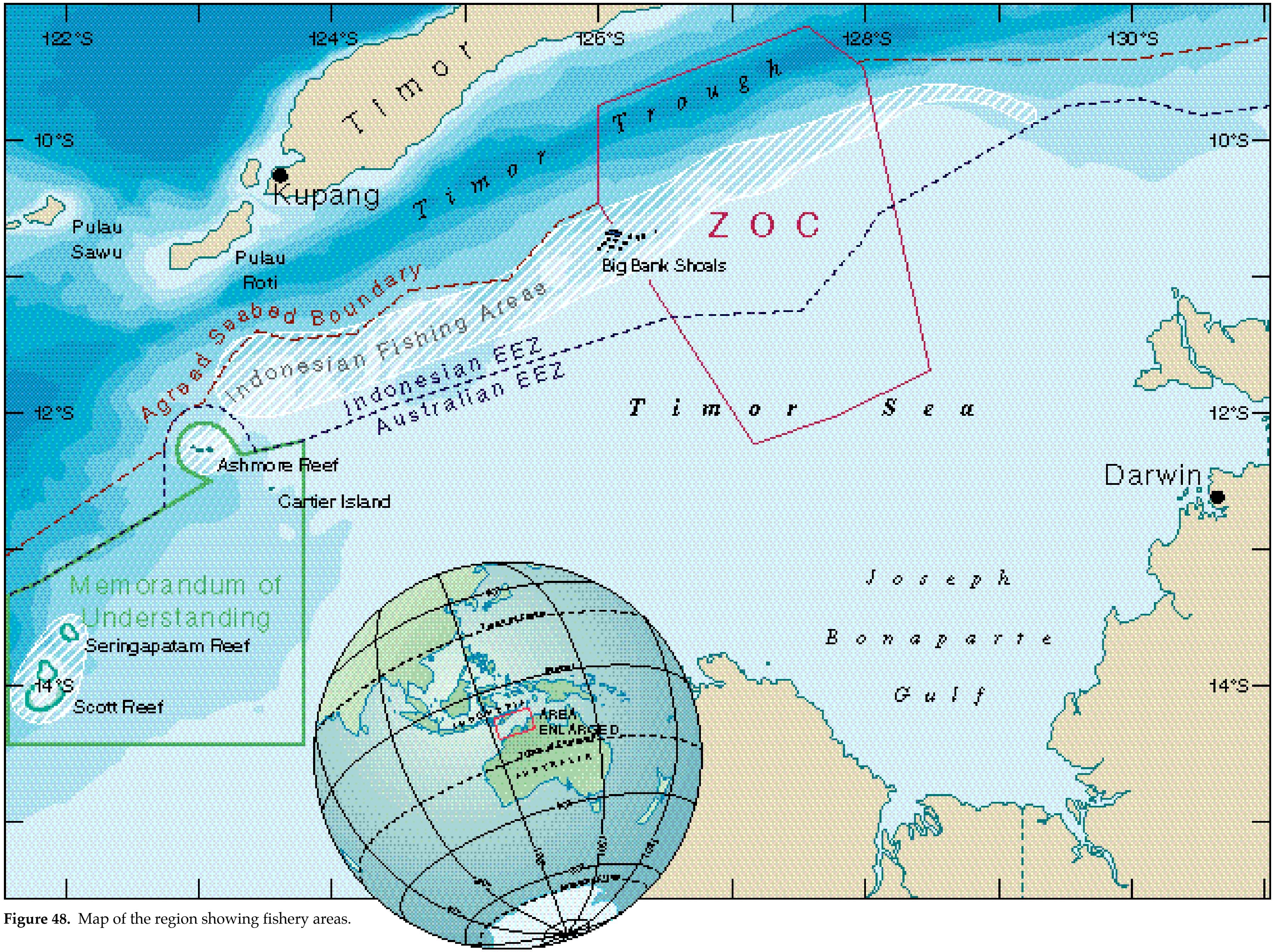


Figure 48. Map of the region showing fishery areas.

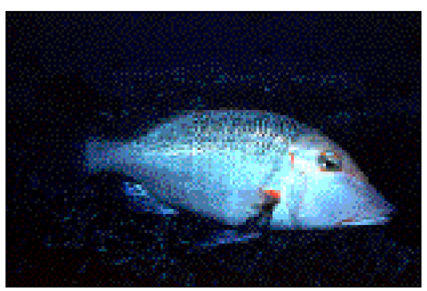
Australian fisheries

Demersal finfish trawling

Commercial fishing was first recorded in the Timor Sea region between 1959 and 1963, when Japanese stern trawlers targeted snapper stocks on the North-West Shelf (Sainsbury *et al.*, 1992). Taiwanese pair trawlers trawled the North-West Shelf during the 1970s and continued operating until 1990. Chinese pair trawlers worked in 1989, fishing the North-West Shelf and the Timor Sea (Ramm, 1994).

In November 1979, Australia declared the 200 nautical mile Australian Fishing Zone (AFZ). Foreign fishing continued, under license agreements, until 1991, when their licenses were not renewed due to increased domestic interest and management fears that fish stocks were being over-exploited (Anon., 1993b).

The long established notion that tropical ecosystems exhibit high species diversity is borne out by data collected from trawls of the North-West Shelf, Timor Sea and Arafura Sea. In these three areas, over 500 fish species have been recorded as common from trawls conducted at depths between 30 and 150 metres (Ramm, 1994). Close to 1,000 species have been recorded at the emergent reefs west of the Sahul Shelf; Rowley Shoals, Scott-Seringapatam Reefs and Ashmore Reef-Cartier Islet (Done *et al.*, 1994).


A sweetlip emperor (GBRMPA).

Benthic trawls are non-selective as they capture fish as well as associated fauna and flora. The targeted fish are part of a benthic community which typically provides them with both their refuge and food. Fish abundance and diversity is closely linked to the benthic community (sponges, corals etc.). If the benthos is removed it may take years or decades to re-establish the fish community. Sainsbury (1992) concluded that intensive trawling on the North-West Shelf had caused a shift in community structure that was likely to be related to the removal of benthic fauna. It was observed that important species of the families Lutjanidae (snapper) and Lethrinidae (emperor) had been replaced by species with which the Australian market were unfamiliar with and considered too small for consumption (threadfin bream, *Nemipterus* spp. and lizardfish, *Saurida* spp.).

Fisheries managers have pushed for a cessation of trawling and the introduction of less damaging methods of capture, such as traps and lines. Domestic interest in trawling began to wane as problems associated with license security, product prices and high investment costs began to increase. Most trawlers have left the fishery and only one has targeted snappers since 1992 (Ramm *et al.*, 1997).

The Timor Reef Fishery

This fishery (Figure 49) is managed by the Northern Territory Government and involves the taking of demersal fishes by dropline, vertical line and, initially, fish traps. Three species of the family Lutjanidae account for about 80 percent of the catch: gold-banded jobfish or snapper (*Pristipomoides multidens*), rosy snapper (*P. filamentosus*) and sharptooth jobfish (*P. typus*) are collectively marketed as gold-banded snapper. Other lutjanids and cods (family Serranidae) constitute the remainder of the landed catch. The value of this fishery increased markedly from 1989 to 1992 (from \$0.5 million to \$2.3 million), when it became the biggest Northern Territory fishery in terms of value and landed catch (Anon., 1993a).

The licensees of the Timor Reef Fishery have since rejected traps and are almost exclusively using hook and line methods. They had found that fish were becoming damaged in traps, which was affecting the market price. There is also a perception that the use of traps damages the benthic community more than line fishing (J. Lloyd pers. comm., NTDPIF).

The Kimberley Trap and Demersal Line Fisheries

The Northern Demersal Scalefish Fishery covers the taking of demersal scalefish by all methods. It uses several methods and operates in geographically defined divisions which are of relevance to this *Atlas.* The line and trap fisheries both share the same fishing grounds. The Kimberley region is defined as the area out to the 200 metre isobath, from 120° East to the seaward extension of the Northern Territory border.

The major fish species targeted by both these fisheries are the snappers or sea-perch (family Lutjanidae), emperors (family Lethrinidae) and cods or groupers (family Serranidae). At present, the red emperor (*Lutjanus sebae*) and jobfishes (*Pristipomoides* spp.) dominate the catches (Anon,1995).

The Kimberley Line Fishery involves the use of baited hooks deployed on either handlines, droplines, trotlines or demersal longlines. Line fishing causes minimal damage to the bottom and fish are caught in good condition. This fishery is minor in comparison to the Kimberley Trap Fishery as it accounted for only 166 tonnes of product in 1994 (Fowler, 1995).

The Kimberley Trap Fishery involves trapping target species rather than hooking them. Pressure from recreational fishing groups has led to the creation of a trap exclusion zone between Cape Bossut and Point Coulomb, from the coast out to the 30 metre isobath. Baited, wire enclosures are set on the seabed. The entrance is designed to only allow fish to enter, but in practice, however, many designs have been shown to have poor catch retention. Consequently, they are hauled in after a short soak time of only an hour or two (Gorman, 1992).

Heavy fishing of the grounds near Broome has made them relatively unproductive and fishers have been forced to move further north and east to the Timor Sea. The 1993 catch in the Kimberley Trap Fishery was 737 tonnes while the following year the total catch fell to 534 tonnes. It is believed that this resource has been seriously over-fished (Fowler, 1995).

The Northern Shark Fishery

The Northern Shark Fishery extends across northern Australia from northwest Western Australia, across Northern Territory waters to Cape York, Queensland. The principal species caught are the blacktip shark (*Carcharhinus tilstoni*) and the spot-tail shark (*C. sorrah*), although hammerhead sharks (*Sphyrnidae* spp.) also form a significant part of the catch. While sharks are the target species, other pelagic fish species are also taken, such as mackerels (*Scomberomorus* spp.).

In February 1995, management of the Northern Shark Fishery was altered by the implementation of the Offshore Constitutional Settlement. Previously, the fishery was administered by the Commonwealth and was divided into three state zones. Currently the Commonwealth liaises with the relevant state governments concerned to form three joint authorities that are responsible for strategic decisions in their area. Day-to-day running is managed by the appropriate state governments.

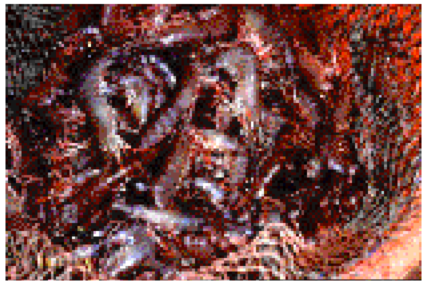
In this fishery, longlining and gillnetting are the two fishing methods which are allowed. Gillnetting predominates and no longlines were used in the Northern Territory portion of the fishery during 1995 (Johnson, 1995). Longlining involves deploying a long rope to which are clipped baited hooks. Gillnets are made of multi-filament nylon with a mesh size must be between 150 and 250 mm. Any sufficiently large fish that encounter the vertical wall presented by the net is caught up by their gill slits and becomes entangled. The pelagic gillnets used in the Northern Shark Fishery are legally required to float at, or near, the surface.

A white tip reef shark (D. Welch).

Although Australian fishers began gillnetting in 1980, fishing effort has remained low. Remoteness from the southern Australian domestic market has hindered expansion of the fishery. A growing awareness of other markets, for fins, livers and cartilage, may lead to an increase in fishing effort. Cartilage is being used as a food additive and in some medicines, such as for the treatment of cancer, while the squalene oil, present in shark livers, is of sufficiently high quality for lubrication purposes (Johnson, 1995).

The Northern Prawn Fishery

The Northern Prawn Fishery is one of Australia's largest fisheries in terms of both area and value. It covers about one million square kilometres of water from Cape Londonderry to Cape York. The value of the 1995-96 catch was $137 million which represents the most valuable Commonwealth fishery (Anon., 1996). Over 90 percent of the catch is exported, mainly to Japan.


Prawns caught in a trawl net (AIMS).

Fishing occurs mostly in the shallower (less than 65 metres), inshore waters of the Continental Shelf. Prawn boats tow a pair of demersal otter trawls, which can be trawled in different ways depending on the intended catch. When targeting benthic species, (tiger prawns -*Penaeus esculentus, P. semisulcatus* and *P. monodon*, endeavour prawn - *Metapenaeus endeavourui* and *M. ensis* and king prawn - *P. latisulcatus*), the nets are adjusted to just scrape along the bottom. Fisheries managers have restricted trawling operations for these species to the night-time.

Banana prawns (*Penaeus indicus* and *P. merguiensis*) may be caught during the day and the nets are set to 'fly' mid-water as these species form dense, pelagic aggregations. The catch of banana prawn fluctuates year to year; a phenomenon that has been strongly correlated to monsoonal rainfall in the region. Generally, the higher the rainfall the greater the number of prawns that enter the fishery. Once banana prawn catches begin to fall (usually around June), boats turn to targeting the benthic species (Anon, 1993b).

The North-West Slope Trawl Fishery

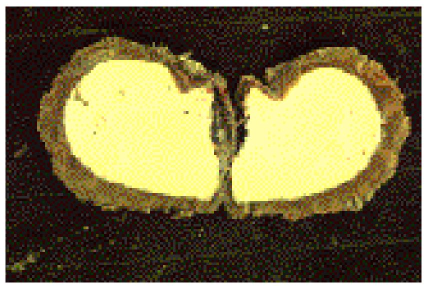
Even though trawling on the North-West Slope began in 1985, this resource is still largely unexplored. It is a deep water fishery, with grounds between the 300 metre isobath and the Australian Fishing Zone in depths of 300-600 metres. Scampi (*Metanephrops* spp.) still remain the target species, however, deep water carid and penaeid prawns have become a valuable component of the catch, principally the red prawn *Aristaeomorpha foliacea* and the royal red prawn *Haliporoides sibogae* (Kailola *et al.*, 1993). These deep water crustaceans are taken by stern-towing of demersal otter trawls. By-catch species include deep-sea bugs and lobsters, precious shells, fish and squid (Anon., 1994). The latter sometimes forms an economically significant component.

Interest in the fishery has fallen since 1991, when twelve boats realised $8 million (Anon., 1991) to 1993-94 when only two of the vessels participated and caught $0.8 million worth of product (Anon., 1994). In 1996 fishing effort was again low, with operators accessing the fishery on a limited basis in favour of more productive fisheries, such as the Northern Prawn Fishery (Anon., 1996).

Aquaculture

The Pearl Oyster Fishery

Collection of pearl oysters from the Kimberley coast of Western Australia and grounds near Darwin began in the 1890s and continued until the late 1930s. The shells were prized for their lustrous nacre which was used to produce mother-of-pearl for buttons and other decorations. World War II and the post-war development of plastics meant there was little activity in the fishery until the 1960s, when the cultured pearl industry began to develop (Lea, 1994).



Pearl shell (AIMS).

The production of cultured pearls has been historically dependent upon wild stocks of pearl oysters (principally *Pinctada maxima*, the golden lip pearl oyster) collected by divers. Pearl oysters live on the seabed from the low-water mark to a depth of 85 metres on the Continental Shelf. They exhibit a wide distribution across northern Australia with commercially viable oyster beds in the Timor Sea region including areas west of Melville Island (N.T.) and around King Sound (W.A.). Kupang, the capital city of East Nusa Tenggara in West Timor, also has a number of commercial oyster farms.

The Western Australian pearling industry is the most valuable component of the aquaculture sector in Australia. Pearl production had an estimated value of $120 million in 1993 (Anon., 1994). Since the 1990s, pearling companies have been developing hatchery techniques for the mass production of pearl oysters (Kailola *et al.*, 1993). Such initiatives may reduce future fishing pressure on stocks of wild oysters.

Pearl oyster farms in Timor are found in the channel between West Timor and the island of Senau. The sheltered waters in the channel have proven ideal for pearl oyster aquaculture, due to the low run off input from rivers, clean waters and adequate current regime necessary for providing the nutrient flow required for the growing of oysters. Two pearl companies operate in this area which has over 2 million shell in the water with potentially over a million mature, productive oysters. It is an advanced production system with its own hatchery and considerable infra-structure. The industry employs 400 people in the deployment and monitoring of oysters. The production period for pearl oysters in Kupang is 3.5 years. Hatchings are deployed on lines that hang in the water and are monitored for 1.5 years. At this point, the oysters are seeded with nucleii, made from the shells of freshwater mussels, which will develop into a pearl in approximately 2 years.

Conclusion

This *Atlas* has sought to provide insight into the shelf edge region of the Timor Sea and in particular to present hitherto unpublished information from our research into the ecosystems of these submerged shoals. The compilation of individual surveys, which had each provided limited assessments of specific areas, allowed a picture to emerge with multiple unifying themes in a broader regional context, thus forming a comprehensive review of the current state of knowledge of the area.

The available information on this area support, in our view, the notion that the shelf edge, carbonate based ecosystems o f the Timor Sea can justifiably be considered a national bioregion. These open ocean, biogenic structures, with a significant degree of shared biological features, include the emergent reefs of the Rowley Shoals, the Scott, Cartier and Ashmore Reef areas and the submerged shoals along the shelf edge of the Timor Trough. Together, they constitute a very large and complex set of ecosystems, which have many common coral reef related flora and fauna associated with abrupt bathymetric structures and experience little or no direct terrigenous influences due to their remoteness from any landmass. The region includes a major *Halimeda* province of national significance and limited drill core data indicate that the *Halimeda* derived sediment accumulations are possibly amongst the thickest in the world. Preliminary results also suggest that this region may be achieving some of the highest levels of carbon fixation in the world. Ecosystem diversity among the shoals is notable, with significant coral cover being discovered. There were marked differences in dominant fauna between shoals, but factors determining the habitats and community structure encountered require further research. When comparing one shoal to another, the one common factor was that phototrophic organisms such as *Halimeda* and hermatypic corals would be major components in habitats shallower than 45m below the sea surface. In this regard, the recent bathymetric mapping initiatives in the region by the Royal Australian navy using the LADS system, should prove especially useful in quantifying the area of the shoals region capable of supporting these types of communities. Our research shows that the banks in the Big Bank Shoals fall into three distinct categories of epibenthic ecosystems:

- The *Halimeda* dominated ecosystem, which was the dominant type for the area and included Big Bank itself as well as Bashful, Doc, Dopey, Grumpy, Happy, Snow White and Udang. *Halimeda* was noted to be viable in a wide range of habitats, which contributes to the considerable success of the group in the area.

- The Coral dominated ecosystems which, as with *Halimeda*, were restricted to the shallower banks and included Kepah, Kepiting, Tiram and Sleepy Banks. Coral was most important where hard substrate existed on the plateaus of the banks, most noticeably around the bank rims.

- The Filter-feeding ecosystem, which dominated the deeper banks due to light restrictions, included Sneezy, Wicked and South Banks. A mix of sponge types and soft corals such as gorgonians were common features of these banks.

Identifying appropriate environmental condition indicators (ECI's) in the region presents a great challenge, but is desirable to support environmental performance evaluation, outlined in ISO 14000, as industrial exploration and development of the Timor Sea region increases. Future research into ECI's may include more extensive mapping to determine the extent of major communities and species, together with the development of a biodiversity index for the region. The marine habitats between northern Australia and southern Indonesia may support particularly high biodiversity. This is likely to be especially so amongst the habitats of the submerged shoals, which are areas of both species and biomass accumulation. Biodiversity has been identified as a high conservation value attribute of complex tropical ecosystems such as coral reefs and identification and preservation of representative habitat types may be more effective for conservation of biodiversity than focusing on specific taxa. The differences in epibenthic community structure found between individual shoals thus far indicates that extensive assessment of shoal ecosystems will be required in order to ensure that the full range of representative habitats are documented.

The remoteness of the region places logistical constraints on levels of human activity which would otherwise be agents of change. However, natural disturbance by cyclonic activity such as loss of *Halimeda* at Big Bank, has already been documented during the course of our current research. The temporal dynamics of key species such as the *Halimeda* and reef building corals require clarification in order to put the short and long term natural variation of populations into perspective. Oceanographic and ecological studies have the potential to identify the biological linkages in the region as well as quantify the long term range of natural disturbance and change experienced in these ecosystems. Data sets spanning a decade or more may be required to detect slight but significant trends.

These studies have been initiated by AIMS on the emergent reef systems at Scott and the Rowley Shoals, but implementation in the submerged shoals habitats is a more difficult exercise and may benefit from new technologies to quantify underwater communities. To that effect, the resource industry is well placed to contribute to the acquisition of additional field data and regular monitoring in synergy with its own operations. This would enable the industry to enhance the present knowledge of the area as well as implement the required management strategies in line with a sustainable development approach in a multiple use resource scenario. Long-term monitoring programs and ongoing assessment of research protocols, and of their power to detect change, would also contribute to the effective environmental management of the Big Bank Shoals Region.

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