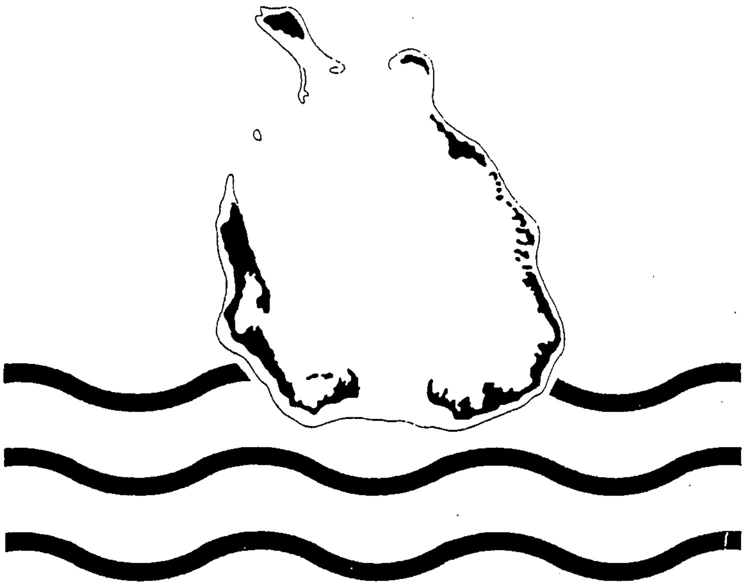
COCOS (KEELING) ISLANDS

VULNERABILITY TO SEA-LEVEL RISE



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Report to the Climate Change and
Environmental Liaison Branch,
Department of the Arts, Sport, the
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ACT Australia

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by

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Frontispiece: Erosion and undermining of coconut palms on the sandy lagoon shore of West Island. Photograph taken in July 1989 from the West Island jetty looking northwest toward the northern tip of West Island. Both jetty and adjacent shore are exposed to relatively high energy waves which pass across the lagoon and to a strong current that sweeps alongshore from south to north.

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EXECUTIVE SUMMARY

Below we summarise the major findings at each of the seven steps of the IPCC Common Methodology for the assessment of vulnerability to accelerated sea-level rise (ASLR) as they were applied to the Cocos (Keeling) Islands. We provide a critique of the shortcomings that we interpret for this approach in this case, and we outline our recommendations.

Step 1: Delineation of study area and specification of ASLR scenarios

1) The Cocos (Keeling) Islands comprise an atoll and an atollon in the eastern Indian Ocean. They are a Territory of Australia. They consist of a series of particularly low-lying islands, and represent one of the most susceptible parts of the Australian coastline to sea-level rise.

2) The IPCC Business-as-Usual high and low scenarios were adopted as ASLR scenarios for this study (30cm rise and 100cm rise by 2100, Table 1).

3) Cocos (Keeling) Island water-level trends reconstructed from large intertidal corals (microatolls), supplemented by the discontinuous tide gauge records, do not indicate the trend of rising sea level which is considered the global average. There is no evidence that the sea has risen relative to Cocos over the last 100 years.

4) The islands of the Cocos group are probably subsiding at an imperceptibly slow rate (<0.2 mm/yr).

Step 2: Inventory of study area characteristics

1) The physical characteristics and the marine and terrestrial fauna and flora of the Cocos (Keeling) Islands are relatively well-known, and are described in detail in a proposed special issue of the Atoll Research Bulletin.

2) Aerial photographs and SPOT satellite imagery form a part of the database on Cocos, together with a Geographical Information System held at DASET, and extensive survey data (particularly for Home and West Islands).

3) The reef islands of the Cocos (Keeling) Islands are geologically very young, and appear to have developed in the last 3000-4000 years during a period when relative sea level has fallen from a level around 1 metre above present.

4) The sediments of the islands are calcareous, formed almost entirely from the skeletal remains of organisms, and are continuing to be produced on the reefs and in the lagoons.

5) There are a range of coastal types, representing various grain sizes and stages of lithification, each of which exhibits a different degree of vulnerability both to present erosional and accretional forces, and to accelerated sea-level rise.

6) Coastal vegetation communities, particularly *Pemphis* and *Scaevola*, offer some protection to the beach crest, and may decrease shoreline erodibility.

7) In 1991 the population of Cocos was 647 persons; over the last decade numbers have ranged from 546 to 686. Settlement is concentrated on Home Island and West Island. Almost all Home Island workers are employed through the Co-operative Society; West Island workers are employees of the Commonwealth or West Australian government.

8) The Cocos economy relies heavily on imports from the mainland and public finance. The subsistence sector is minor.

9) A land use survey has been carried out recently. Land classified as open space occupies 100% of the land area of North Keeling and 83% of South Keeling. Land uses associated with administrative, transport and communication occupy 11% of South Keeling. Capital investment and infrastructure are concentrated on Home Island and West Island.

10) Title to all land on Cocos (with the exception of land used for Commonwealth purposes and Lot 14 on Home Island) is held by the Islands Council, in trust for the Cocos community.

11) Because of the unusual way in which land is owned, and because it no longer supports economic production, impact of sea-level rise cannot be rationally analysed using the benefit-cost procedures advocated in the IPCC Common Methodology.

Step 3: Identification of development factors

1) The Cocos (Keeling) Islands are presently in a state of transition, legislatively, administratively and economically. The islands have a very narrow economic base and have been reliant, directly or indirectly on Commonwealth funding in the past and this is likely to continue for some-time.

2) Several reports have indicated that tourism offers the most likely prospect for economic growth. A significant increase in the resident population of Cocos is not envisaged.

3) A preferred land use plan and planning scheme has recently been adopted and this provides a relatively firm basis on which to forecast future land use. Large areas of Reserved Land are included for nature conservation, marine protection, common useage, administrative purposes and for foreshore protection. A 20m wide foreshore protection zone is proposed around Home Island and West Island.

4) Whether or not there is a significant expansion of tourism over the next few years, there are a number of contemporary environmental problems which include deterioration of ground water supply on Home Island, waste disposal and siting of rubbish tips, degradation of reefal areas around sewage outfalls, and coastal erosion particularly on West Island. Of these only coastal erosion is likely to be exacerbated by future sea-level rise.

Step 4: Physical changes and natural system responses

1) Islands appear relatively stable where there are outcrops of lithified deposits (conglomerate and beachrock). Elsewhere, shorelines of reef islands in the Cocos (Keeling) Islands are naturally dynamic; sediment is continuing to be produced; beaches both accrete and erode; and there are seasonal and year to year shifts in the patterns of sediment movement.

2) In view of these uncertainties, there can be no consensus as to what effect sea-level rise will have on islands. At least three different types of impact have been forecast; erosion of sediment from the shore; redistribution of sediment on the shore; or accretion of new sediment onto the shore.

3) Reefs have a certain capacity to keep up with sea-level rise. Hard corals are particularly sparse on Cocos reefs, suggesting that the reef crest and reef flat may be delayed in their response to ASLR. The reef will need to be maintained in a healthy

condition if the full potential for reef growth is to be realised.

4) The effect of accelerated sea-level rise on freshwater lenses remains uncertain, but appears unlikely to have a large influence on groundwater resources, which are already under pressure on Home Island. Alternative groundwater resources exist on South Island.

Step 5: Identification and specification of response strategies

1) The full protection option is clearly uneconomical for all reef islands on Cocos which have a combined perimeter of 120km, but a surface area of only 14km^2. Except in isolated cases (perhaps parts of the airstrip) it may not be necessary.

2) Measures which accommodate sea-level rise seem the most appropriate, particularly those that incorporate 'soft' rather than 'hard' engineering responses, such as beach nourishment, ridge building, revegetation/ and planned retreat.

3) The planning strategies which have recently been adopted incorporate suitable measures to enable an integrated response strategy to sea-level rise on Cocos. In particular foreshore protection zones can be defined.

Step 6: Vulnerability analyses

1) We have demonstrated that it is presently not possible to forecast the physical impacts of sea-level rise on shorelines which already undergo complex patterns of erosion and accretion. We have also indicated that the unique social, cultural, political and strategic status of the Cocos (Keeling) Islands renders the benefit/cost approach inappropriate.

Step 7: Identification of tasks and needs

1) In the case of the Cocos (Keeling) Islands we consider that the threat of sea-level rise is not so immediate as to require precipitous action.

2) Sea-level rise, if it occurs, will be only one of a series of potential impacts eg. the atoll remains vulnerable to storm devastation. Any planning measures associated with ASLR need to be formulated in the broader context of coastal hazard awareness.

3) The recently adopted land use plan and planning scheme provides for foreshore protection and foreshadows the development of foreshore, reef and lagoon management plans.

4) Despite the considerable scientific information available on Cocos, there are still insufficient data to draw any firm conclusions on how reef islands will respond to sea-level changes, or how they are responding to the shore protection structures that are in place.

5) In the IPCC Common Methodology four response options are to be considered: no response, retreat, protect and accommodate. We have evaluated these options and suggest that a more flexible integrated response strategy be adopted for Cocos and for other atoll states and territories.

'It is difficult to realise the extreme lowness of the islands of the atoll, and it is always a cause of surprise to anyone who sees these for the first time'

F. Wood-Jones 1912 p139.

ACKNOWLEDGMENTS

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1. BOUNDARY CONDITION DELINEATION

The Intergovernmental Panel on Climate Change (IPCC) set up a series of working groups to consider the implications of anticipated climate change resulting from global warming. The Coastal Zone Management Subgroup (CZMS) of Working Group III, the Response Strategies Working Group (RSWG) has developed a Common Methodology for the assessment of vulnerability of the coast to accelerated sea-level rise (ASLR). The Common Methodology involves seven steps (RSWG 1991):

1. Delineation of case study area and specification of ASLR boundary conditions.
2. Inventory of study area characteristics.
3. Identification of relevant development factors.
4. Assessment of physical changes and natural system responses.
5. Formulation of response strategies and assessment of their costs and effects.
6. The assessment of the vulnerability profile and interpretation of results.
7. Identification of actions to develop long-term coastal zone management planning.

This study of the Cocos (Keeling) Islands represents a case study, endeavouring to employ the Common Methodology.

The Common Methodology was first developed in early 1991; the first revision was published in September 1991, and the second revision in March 1992, after a series of case studies were discussed at the IPCC Margarita Island Workshop (RSWG 1992). The purpose of this vulnerability profile is to 'provide the nation's decision makers with good insight into the vulnerability of the coastal zone, in order to anticipate the need for action' (RSWG).

The initial step in the Common Methodology is the delineation of case study area and specification of accelerated sea-level rise (ASLR) boundary conditions.

1.1 Study Area

The Cocos (Keeling) Islands are a particularly isolated group of islands in the eastern Indian Ocean (Figure 1). They comprise a southern group, the South Keeling Islands (12°12' S, 96° 54' E), which form a coral atoll with a shallow lagoon fringed by a series of reef islands. A single horseshoe-shaped island (atollon), North Keeling (11° 50' S, 96° 49' E) is located 27 km to the north of the main group (Figure 2).

The Cocos (Keeling) Islands are an example of a mid-ocean atoll, and they share many characteristics with other mid-ocean atolls. Such atolls represent some of the most vulnerable of places in the face of sea-level rise. There are several atoll nations, including Kiribati, Tuvalu and the Republic of Maldives, that some scientists have suggested may disappear totally if the more extreme predictions come to pass (Roy and Connell 1990, 1991).

The Cocos (Keeling) Islands are an Australian Territory. The population of the islands consists of a Home Island community of Cocos Malays (the descendants of plantation labourers drawn from Indonesia and Malaysia by Alexander Hare who settled on Cocos in 1826, and the Clunies-Ross family who ran the islands from the 1830s until 1978), and a transient population of Australian government officals and their families who live on West Island. These people all have the option of migrating or returning to the Australian mainland if their islands become uninhabitable, though the distinctiveness of the Cocos Malay culture needs to be recognised from the outset. Some of the observations of atoll response to sea-level changes contained within this report may also have application to other atolls, whose populations may not have the immediate alternative of emigration.

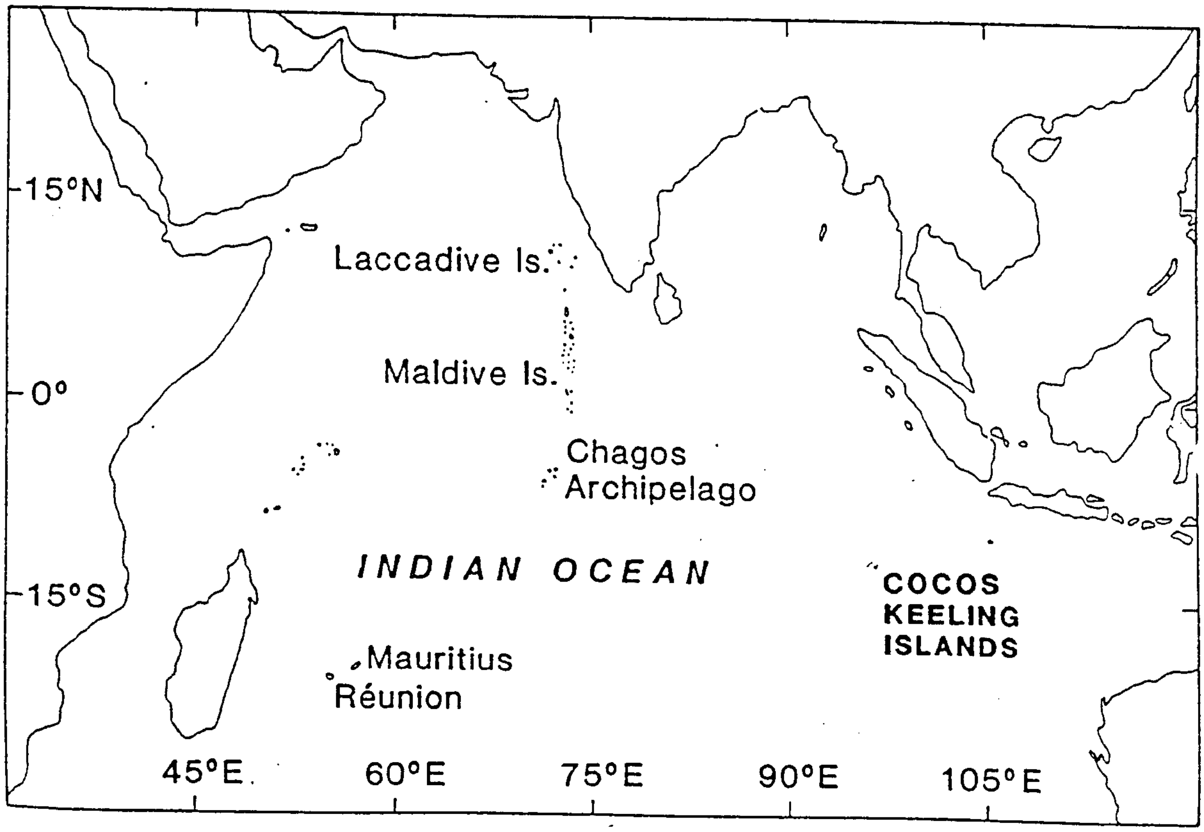


Figure 1. The Indian Ocean, showing the location of the Cocos (Keeling) Islands.

Table 1. Boundary conditions related to accelerated sea-level rise (ASLR) scenarios.

Boundary Conditions	ASLR 1	ASLR 2
Sea-level increase by 2100	300 mm	1000mm
Average rate of change 1990-2030	3.3 mm/yr	5.8 mm/yr
Average rate of change 2030-2070	3.3 mm/yr	10.5 mm/yr
Average rate of change 2070-2100	3.5 mm/yr	13.0 mm/yr
Maximum rate of change	3.5 mm/yr	15.0 mm/yr
Estimated rate of subsidence (Cocos)	0.02-0.1 mm/yr	0.02-0.1 mm/yr
Relative sea-level increase by 2100	302-311 mm	1002-1011 mm

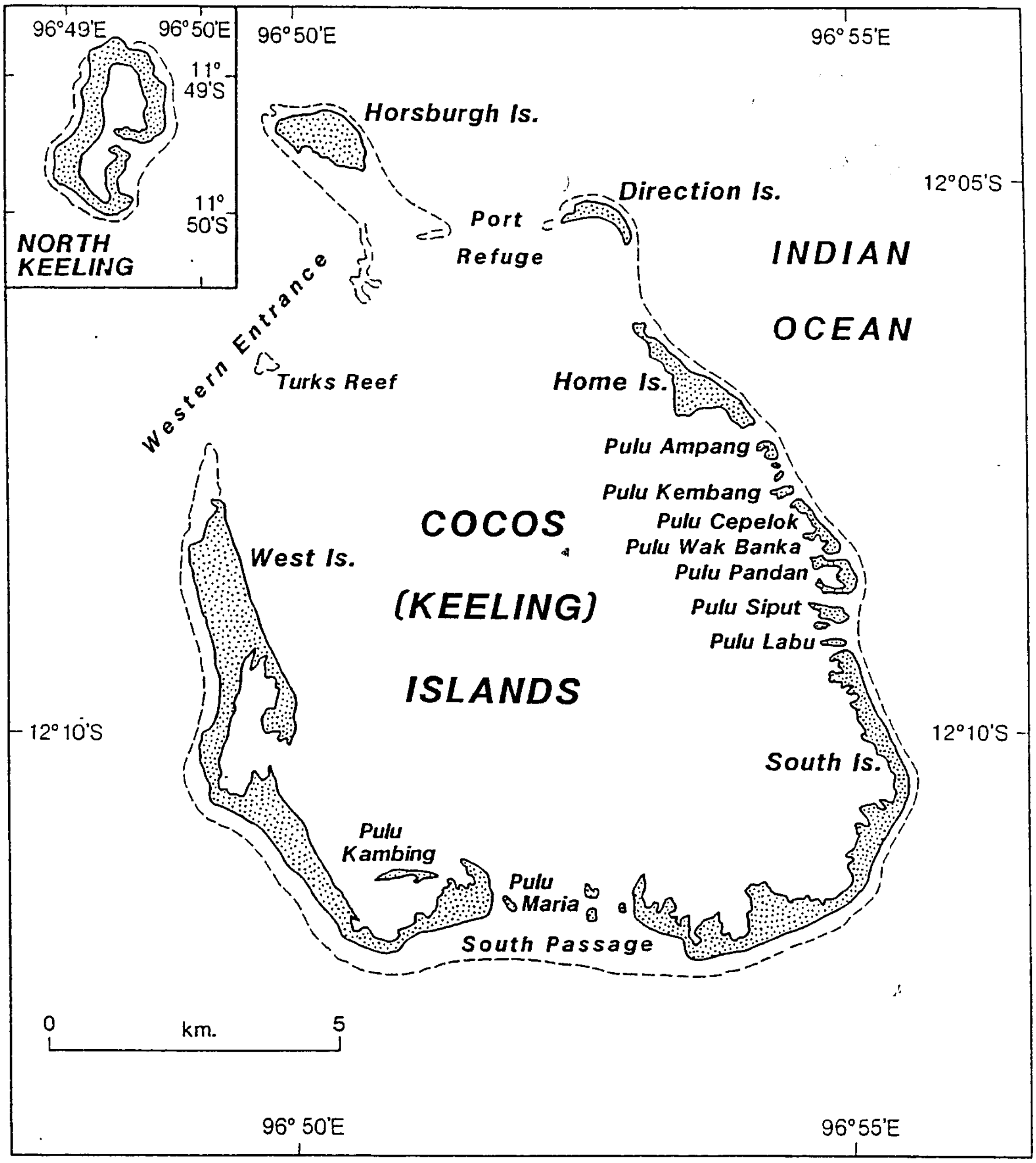


Figure 2. The Cocos (Keeling) Islands.

1.2 Sea-level rise

1.2.1 Global predictions

The sea-level rise scenarios adopted in this report are those recommended in the Common Methodology, corresponding to the low and high estimate for the Business-as-Usuaul scenario projected by the IPCC (Table 1); namely 30 cm higher by the year 2100 (ASLR1) and 100 cm higher by the year 2100 (ASLR2). The most probable pattern of future sea-level change is presumed to lie somewhere between these two scenarios. However, it is important to emphasise that there is still a great deal of uncertainty as to whether the sea will rise globally, and at what rate. Below we examine some of these uncertainties.

It is widely perceived that the level of the sea is rising, and will begin to rise ever more rapidly, as a result of global warming through the accumulation of greenhouse gases in the atmosphere (principally carbon dioxide, but also methane, nitrous oxide and chlorofluorocarbons). One of the first studies to look at this in detail was that of Hoffman (Barth and Titus 1984) who considered that the sea would rise by somewhere between 56.2 cm (conservative) and 345 cm (high) by the year 2100. The extreme scenario, entailing rapid sea-level rise, has understandably sparked considerable concern.

More recent assessment, such as the National Research Council (1990), the Commonwealth Secretariat (1989) and more general overviews (e.g. Stewart et al. 1990; Leggett 1990), as well as a series of reports from the Intergovernmental Panel on Climate Change (IPCC) have tended to revise these predictions downwards. The main IPCC report is the Scientific Assessment (Houghton et al. 1990). In that assessment Warrick and Oerlemans (1990), indicate three scenarios, high, low and best estimate based on business as usual. Sea-level rise for the years 2030, 2070 and 2100 respectively are predicted as 29, 71 and 110 cm for the high, 18, 44 and 66 cm for the best estimate and 8, 21 and 31 cm for the low scenarios(Warrick and Oerlemans 1990). IPCC emission scenarios were revised in 1992 (Houghton et al. 1992), with a series of 6 scenarios replacing the business as usual scenario in view of possible emission rates; these vary little in the predicted sea-level rise until 2050, but diverge slightly thereafter (Wigley and Raper 1992). Best case scenarios range between 22 and 115 cm rise by the year 2100, while best-guess scenarios (which incorporate feedback effects in the carbon cycle) vary from 15-90 cm by the year 2100 (Wigley and Raper 1992).

Initially it was considered that as the globe warmed sea level would rise as a result of thermal expansion of the ocean, the melt of polar ice, and further melt of mid-latitude glaciers. There is no longer the acute concern over imminent major ice-cap melt. The Antarctic ice cap seems likely to expand under warmer conditions, and hence to contribute to a slight fall of sea level (Oerlemans 1989; Zwally 1990; Alley and Whillans 1991). While the Arctic ice cap (Greenland) is generally expected to contribute to sea-level rise if the earth warms (Gloersen and Campbell 1991), the extent is still uncertain and some researchers have suggested that snow deposition might exceed melting in the Arctic also (Miller and de Vernal 1992; see Schneider 1992 for a response). Mid-latitude ice, held in mountain glaciers and small ice caps, is still expected to show net melt and contribute to sea-level rise, though modelling now suggests that for a 1°C rise in temperature such melt will only contribute 0.58 mm/yr to sea -level rise; a further downwards revision (Oerlemans and Fortuin 1992).

Predictions of future sea-level rise are now based primarily on thermal expansion of sea water as the ocean warms (Mikolajewicz et al. 1990), for which there is already some evidence (Bindoff and Church 1992; Roemmich 1992). Church et al. (1991) model sea-level rise based only on thermal expansion, and come up with a figure of 20-30 cm by 2050, similar to the best-estimate IPCC predictions.

1.2.2 Tide gauge records and predictions of future sea-level rise

Sea-level rise should already be occurring, given that greenhouse gases have been accumulating at increasing rates since the industrial revolution, and that a temperature increase of 0.3-0.6°C has been detected over the last century (Houghton et al. 1990). Global aggregations of tide gauge records have been analysed by several workers, and it is suggested that there is an average rate of rise in the order of 1.0-1.5 mm/yr (Gornitz et al. 1982; Barnett 1983, 1984). However, the aggregation of such data is not straightforward; gauges are clustered especially in areas which may be subsiding, and gauges were generally not installed to detect with sufficient precision a change of such magnitude (Pirazzoli 1986).

A detailed review of tide gauge data can be found in the volume on *Sea Levels, Land Levels and Tide Gauges* by Emery and Aubrey (1991). Instead of looking for a global sea-level (eustatic) signal, these authors emphasise the tectonic variability between stations. While some tectonic movement of the more active coasts is widely recognised and relative sea-level rise is known to be rapid on rapidly subsiding coasts (e.g. Louisiana, Turner 1991), most studies of sea-level changes ignore isostatic, particularly hydroisostatic, factors (Schnack and Pirazzoli 1990). When ice melts, sea-level rise will not be entirely uniform over the globe, because the ocean will need to maintain an equipotential surface (Lambeck 1990; Lambeck and Nakada 1990). Peltier and Tushingham (1989) have produced an estimate of global sea-level rise, based on tide gauges, corrected for isostatic effects from their modelling, of 2.4 ± 0.9 mm/yr. Douglas (1991) has produced a value of 1.8 ± 0.1 mm/yr based on 21 oceanic stations over 76 years, correcting for postglacial rebound using the ICE-3G model .

In an analysis of north Atlantic tidal records, Pirazzoli recognised a sea-level rise for the period 1920-1950, but suggests that it has been stable 1950-1980 (Pirazzoli 1989). He concludes that 'during the last 40 years there has probably been no global sea-level rise at all' (Pirazzoli 1990, p. 153). Woodworth (1990) similarly does not detect acceleration of sea-level rise in Europe over the period 1870 to present, but can show that that there has been an acceleration this century, compared to recent centuries. Woodworth et al. (1991) demonstrate that, for Britain and northwest Europe, trends in mean tidal range may exceed trends in mean sea level.

Most of the tidal records are for sites around the perimeters of the large oceans, with few mid-oceanic sites with sufficiently long records to determine trends. This is particularly true of the Indian Ocean. For the Cocos (Keeling) Islands there is a discontinuous record, described below, but of insufficient length to determine trends. In the absence of good tide gauge data other techniques have been used to determine low frequency sea-level fluctuations. A recent study, based on Geosat altimetry and simulations for 1987-88 suggests that a striking feature of the southern tropical Indian-Ocean is a strong annual sea-level cycle. The maximum amplitude is of the order of 12cm and is located about 90°E 12°S, that is just to the west of Cocos (Perigaud and Delecluse 1992).

Wyrtki (1990) has reviewed tidal data for the Pacific. Hilo on the island of Hawaii shows a record of rise of 3.8 mm/yr, but this is high because that island is subsiding rapidly. Those atolls from which there are records (i.e. in Kiribati and Tuvalu) generally show no discernible trend, though some mid-ocean sites do show a sea-level rise of up to 1.6mm/yr.

We have reported observations of intertidal corals, termed microatolls, which have grown up to the level beyond which coral growth is limited by subaerial exposure. Specimens are widespread on some coral atolls and can be used to detect long-term

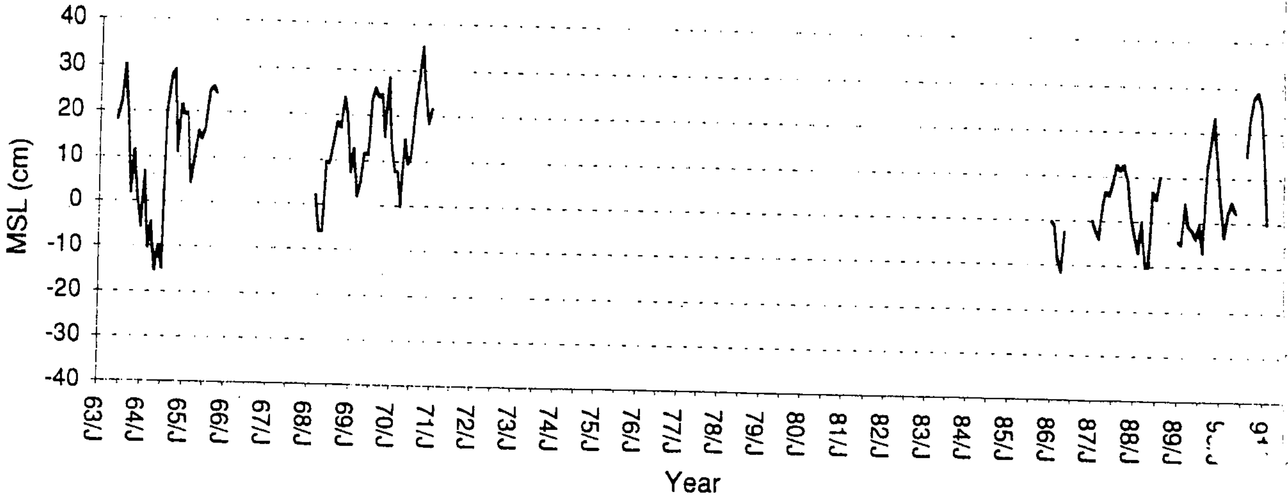


Figure 3. Mean monthly sea level at the Cocos (Keeling) Islands, 1971-1991, based upon the Home Island tide gauge.

Table 2. Tidal levels in relation to Chart Datum (metres) at Cocos.

	1990 Tide Tables	1993 Tide Tables
HAT (highest astronomical tide)	+1.3	+1.4
MHHW	+1.1	+1.2
MLHW	+0.9	+0.8
MSL (Mean Sea Level)	+0.7	+0.8
MHLW	+0.4	+0.7
MLLW	+0.4	+0.3
LAT (lowest astronomical tide)	+0.2	+0.3

(decadal) trends in water levels where they occur in suitable environmental settings (Woodroffe and McLean 1990, 1992b). Cross-sections of living specimens of massive Porites microatolls from the Cocos (Keeling) Islands, and from Kiribati in the Pacific, indicate little or no rise over the last few decades. These are discussed in more detail below.

1.2.3 Sea-level change in the Cocos (Keeling) Islands

1.2.3.1. Tidal records on Cocos

The Cocos (Keeling) Islands were first settled in 1826. A tide gauge was established there briefly in 1836 during the visit of H.M.S. Beagle, when Captain Fitzroy came up with a design which he had not used at previous sites (Fitzroy 1839). Tidal observations have been made on Cocos since 1963 by CSIRO Division of Oceanography; however, records have been discontinuous since then with large gaps in 1967 and 1971-1986 (see Figure 3). In 1992 a NOAA tide gauge was installed on Home Island as part of a global network of baseline sea-level monitoring stations. This gauge is linked by satellite to the National Tide Facility at Flinders Univeristy.

The record of monthly mean sea level shown in Figure 3 is evidently incomplete, but it does not suggest any long-term sea-level rise. We note that records within either the period 1968-1971 or 1986-1991 might, at first sight, appear to show a rising trend. Note also the large interannual variations in the record which reach a maximum range of about 40cm (1963-65).

Tidal prediction for Cocos have generally been reported with respect to Chart Datum. Predictions in 1993 are reported with respect to lowest astronomical tide (LAT). Furthermore, the tidal heights have been revised (Table 2), partly on the basis of records held at the National Tidal Facility, but also incorporating a factor for global sea-level rise (Paul Davill, NTF, pers comm.). The revision of the height of mean sea level with respect to Chart Datum is not an indication that the sea has risen.

1.2.3.2. Living microatolls and sea level on Cocos

Microatolls are large 'flat-topped' colonies, generally of the massive coral *Porites*, which are limited in their upward growth by water level, and consequently grow horizontally. Our fieldwork on Cocos in July 1989 was aimed at assessing the effectiveness of using individual coral microatolls to reconstruct water level changes over the last few decades. We sectioned microatolls using a motorised saw (some sections are shown in Figure 4), and cut thin slices 6-10mm thick, for X-ray analysis. The X-ray analysis, kindly undertaken for us at the Cocos Health Centre, revealed density banding, within which annual periods of growth of the coral can be identified.

We wished to test whether it is possible to recognise past water levels from the upper surface of the coral, determining timing of that water level from density banding within the coral skeleton. Fieldwork was aimed at assessing i) the reproducibility of coral record within any one location on the atoll, and ii) geographical variability between sites around the atoll.

We found that microatolls are widely distributed around the Cocos (Keeling) Islands. Figure 5 is a map of locations at which we have sampled specimens. Corals adopt a microatoll form in three settings: i) reef flat, ii) interisland channel, and iii) lagoon (the majority of which were dead and were not usable).

There is generally a high degree of reproducibility at any one site. Most microatolls show a similar sea-level story, and those that do not can be explained because they have not grown vertically to the point at which they adopted a truly microatoll form. There did appear to be some geographical differences in form. We believe that this is partly a

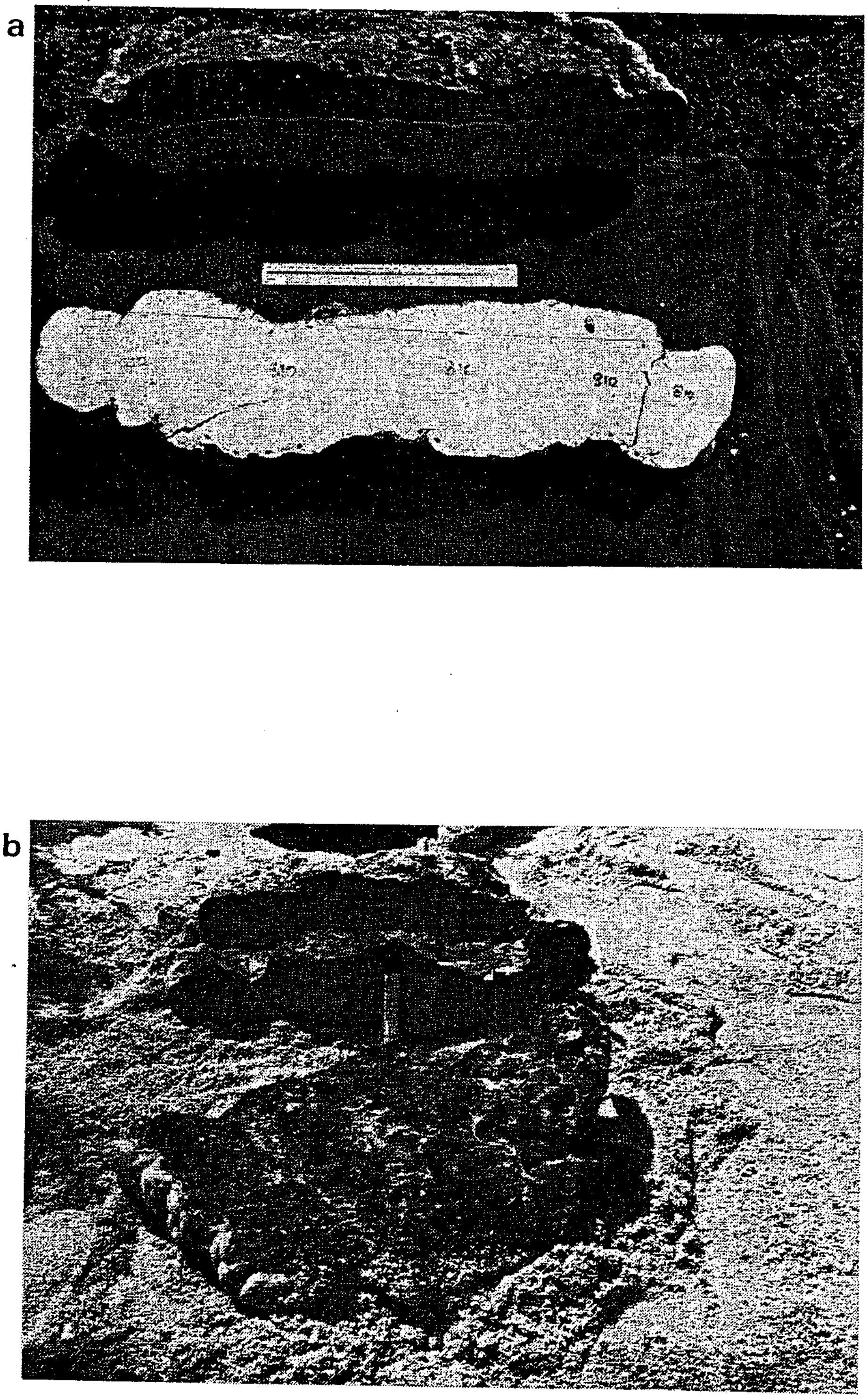


Figure 4 Cocos (Keeling) Islands microatolls. Slices cut across living microatolls. a) Cross-section of 1m diameter microatolls showing upper surface which reflects variations in water level. b) Banding can be seen in slices which reflect the coral's lateral growth, which is about 1cm per annum.

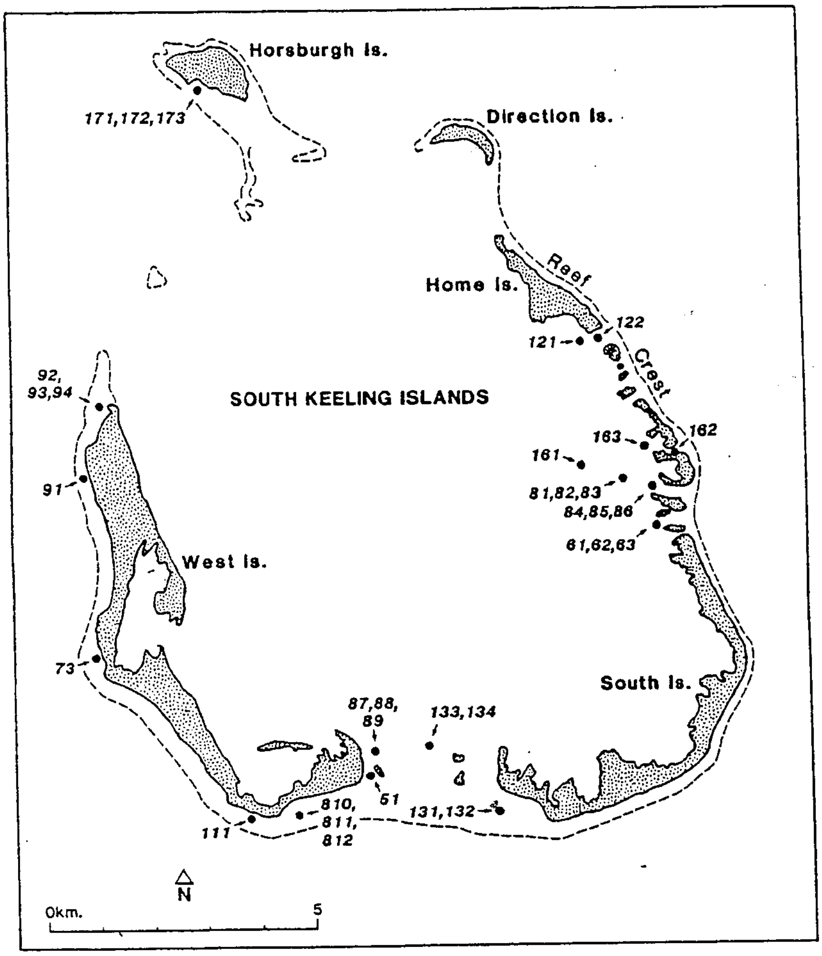


Figure 5 Location of living microatolls in the Cocos (Keeling) Islands, from which a record of past sea-level changes can be derived, including sample numbers.

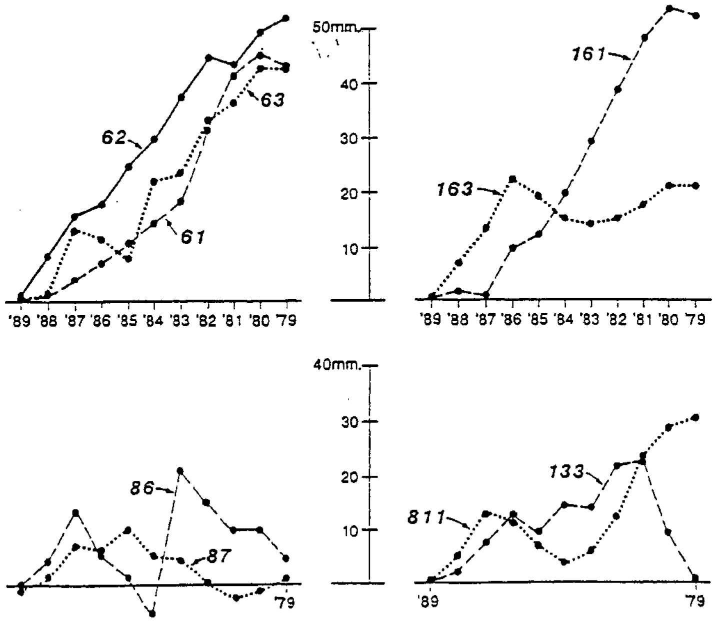


Figure 6 Water level changes over the period 1979-1989, derived from selected microatolls. Sample locations are shown in Figure 5

function of local differences in the degree to which microatoll form has been reached, and secondly a reflection of different patterns of water level change around the atoll (Woodroffe and McLean 1990). Figure 6 shows results of water level reconstructed from several microatolls.

The majority of microatolls that we examined showed a slight drop of water level over the last decade. This was most pronounced within the channels on the eastern margin of the atoll, where large falls in water level were indicated; the size of the apparent fall increasing into the lagoon. The upper surface of the middle of microatolls in these sites was found in some cases to be more than 6cm above the upper limit to living coral. A particular marker, dated by X-ray analysis of the coral, is a stress band identified in many coral specimens, resulting from conditions in March 1983. In that year the lagoon waters became anaerobic and fish and coral died (see Woodroffe and Berry, ARB). Many of the corals that we sampled showed evidence of stress at the time, many were killed, and in places we can identify that dead surface. There has been recovery over the dead surface on most corals that we sampled, though those in the lagoon do not presently have live surfaces and probably were also killed by this event.

Our results indicate that microatolls are very good water level indicators. We have since extended the approach to atolls in Kiribati and the Maldives (Woodroffe and McLean 1992b). The larger microatolls on Cocos (Keeling) Islands indicate that there have not been large changes in water level since they initially attained a microatoll form, in some cases probably 30-50 years ago. Around much of the atoll there appears to have been a slight fall in water level over the last decade. A detailed analysis of the form, growth pattern, and interpretaton of microatolls on Cocos is presently being undertaken by Scott Smithers for a doctoral thesis under the National Greenhouse Advisory Committee (DASET) climate change initiative. His work suggests that it will be possible to extend the microatoll record back to the last century.

These corals are living. They appear to sensitively record water level changes over the long term, and the corals will be a valuable monitor of future changes.

1.2.3.3. Land-sea relationships on Cocos: an historical perspective

While there is not sufficient tidal data to detect any trend of sea-level rise, and microatolls suggest that little if any has occurred, the issue of the sea overtopping islands on the atoll is not new. The Cocos (Keeling) Islands were visited by a series of naturalists in the nineteenth and early twentieth centuries, and were scientifically one of the best known atolls after publication of Gibson-Hill's pre-World War II collections from the atoll (Gibson-Hill 1950a). One of the most significant visits was that by Charles Darwin in H.M.S. Beagle for 10 days in 1836 (Darwin 1845).

Darwin had conceived his view of coral atolls as formed by the gradual subsidence of a volcanic core, combined with vertical reef growth, in South America, and further developed these views during his voyage across the Pacific. Cocos, however, was the only atoll on which he landed, and he particularly sought confirmation of his theory (see Armstrong 1991). Officers of the Beagle pointed out erosion of the shoreline on West Island, and Darwin considered this tolerably conclusive proof of his hypothesis (Darwin 1842).

Darwin's argument was that if the atoll were subsiding, then the implication was that the reef islands were disappearing below the sea. The problem is essentially the same as that resulting from sea-level rise. Darwin's conclusion that erosion of the shoreline indicated subsidence is similar to much circumstantial evidence of shoreline erosion presently quoted as confirmation of modern sea-level rise.

Other naturalists who have spent time on the Cocos (Keeling) Islands have been rather critical of this element of Darwin's reasoning. Vehement in his criticism was John

Clunies Ross, who in a review of Darwin's book, published posthumously, was at pains to stress that the islands were being undermined and not overtopped (Ross 1855). Subsequent naturalists either saw no evidence for subsidence (Guppy 1889), or believed that the sea had been above its present level, and that part of the atoll had emerged (Forbes 1885; Wood-Jones 1912).

Detailed geological investigations of the surface morphology of the atoll, summarised in chapters in the special issue of the Atoll Research Bulletin, confirm this latter view. The most recent trend, over the last 3000 years, has been a relative sea-level fall with respect to the atoll (Woodroffe et al. 1990a, 1990b). Though this counters Darwin's perceptions, nevertheless, his view of the importance of subsidence to the development of atoll structure has been found to be essentially correct (see Woodroffe et al., ARB).

In this review of the effect of a rise of sea level, we must be cautious not to fall into this same trap. There will continue to be erosion of the shoreline, without necessarily indicating that the sea is rising. Wood-Jones aptly summarised the situation when he wrote that 'the undermining of trees and the denudation of shore-lines do not necessarily indicate subsidence, for they are inconstant effects, and an area of land denudation is compensated for by an area of land construction at another part of the island ring' (Wood-Jones 1909 p674). There is ample demonstration of this happening on Cocos at the present time.

1.3 Subsidence

Whether or not the Cocos (Keeling) Islands are subsiding, was, as outlined above, a particularly contentious issue as a result of Darwin's subsidence theory of coral reef development. The arguments are summarised in the special issue of the Atoll Research Bulletin, and it is concluded that Cocos is subsiding. Woodroffe et al. (1991) initially proposed a rate of subsidence of 0.1 mm/yr, but Searle (ARB) has revised this in view of the basin-shaped form of the atoll, and the evident efficacy of solutional processes to 0.02 mm/yr. This rate is imperceptibly slow, even compared with the projected rates of sea-level rise

1.4 Other climatic change under greenhouse conditions

There is little information as to what other changes might be expected as a result of the greenhouse effect. It seems probable that air and sea-surface temperatures may increase. On the other hand, the temperatures are already close to 30°C for much of the time, and Wyrtki (1990) suggests that disproportionate increases in evaporation, cloudiness and precipitation at these temperatures are likely to partially offset any tendency for the temperature to increase.

Increased sea-surface temperatures could have two consequences. Firstly, water temperatures of around 3-4°C above ambient for prolonged periods can lead to coral 'bleaching' and mortality (Jokiel and Coles 1990; Williams and Bunkley-Williams 1990), a phenomenon which appears to have occurred on occasions at Cocos (see Woodroffe and Berry, ARB). Healthy coral reefs are vitally important for the ecological well-being of atoll communities, for the protection that reefs afford, and for the production of sediment.

Secondly, increased sea-surface temperatures have been generally supposed to lead to increased frequency and intensity of tropical cyclones (hurricanes). Cyclones are presently felt in Cocos (see Falkland for a list of recent recorded cyclones). Such storms are only rarely significant geomorphological events on Cocos. We had first-hand experience of Cyclone Frederick which passed over Cocos in 1988, but it was of insufficient magnitude to have a discernible geomorphological impact. On the other hand the cyclone experienced in 1876 seems to have been considerably stronger and was reported to have ripped up sections of conglomerate platform and transported them. We outline in section 4 that different atolls experience different intensities and frequencies of storms, and Cocos might alter with respect to its position on a storm gradient if the intesity and frequency of such storms increases.

Given the large degree of uncertainty, it seems inappropriate at this stage to incorporate any further factors related to climate change into this vulnerability assessment for the Cocos (Keeling) Islands.

2 INVENTORY OF STUDY AREA CHARACTERISTICS

The second step in the Common Methodology involves the collection of relevant data about the study area. Two broad groups of data are collected; those pertaining to physical and biological characteristics and those that characterise the human use system.

2.1 Physical and biological characteristics

The physical and biological characteristics of the Cocos (Keeling) Islands, are examined in detail in the special issue of the Atoll Research Bulletin on the Ecology and Geomorphology of the Cocos (Keeling) Islands. In this section a summary of the major features is given.

The initial description of the physical characteristics of the Cocos (Keeling) Islands, given by Darwin, remains unsurpassed:

> It is (the) reef which esentially forms the atoll. In Keeling atoll the ring encloses the lagoon on all sides except at the northern end, where there are two open spaces, through one of which ships can enter. The reef varies in width from 250 to 500 yards; its surface is level, or very slightly inclined inwards towards the lagoon, and at high tide the sea breaks entirely over it: the water at low tide thrown by breakers on the reef, is carried by the many narrow and shoal gullies on its surface into the lagoon: a return stream sets out of the lagoon through the main entrance. The most frequent coral in the hollows on the reef is *Pocillopora verrucosa*, which grows in short sinuous plates, or branches, and when alive is of a beautiful pale lake-red ... As soon as an islet is formed, and the waves are prevented from breaking entirely over the reef, the channels and hollows become filled up with fragments cemented together by calcareous matter; and the surface ... is converted to a smooth hard floor, like an artificial one of freestone. The flat surface veries in width from 100 to 200, or even 300 yards, and is strewed with a few fragments of coral torn up during gales ... Nothing can be more singular that the appearance at low tide of this 'flat' of naked stone ...
>
> The islets on the reef are first formed between 200 and 300 yards from its outer edge, through the accumulation of a pile of fragments, thrown together by some unusually strong gale. Their ordinary width is under a quarter of a mile, and their length varies from a few yards to several miles. Those on the S.E. and windward side of the atoll, increase solely by the addition of fragments on their outer side; hence the loose blocks of coral, of which their surface is composed, as well as the shells mingled with them, almost exclusively consist of those kinds which live on the outer coast. The highest part of the islets (excepting hillocks of blown sand, some of which are 30 feet high), is close to the outer beach and averages from six to ten feet above ordinary high-water mark. From the outer beach the surface slopes gently to the shores of the lagoon and this slope no doubt is due to the breakers, the further they have rolled over the reef, having less power to throw up fragments. The little waves of the lagoon heap up sand and fragments of thinly branched corals on the inner side of the atoll; and these islets are broader than those to the windward, some being 800 yards in width ...
>
> The lagoon alone remains to be described; it is much shallower than most atolls of considerable size. The southern part is almost filled up with banks of mud and fields of coral, both dead and alive; but there are considerable spaces, from three to four fathoms, and smaller basins from eight to ten fathoms deep. Probably about half its area consists of sediment, and half coral-reefs.

More detailed descriptions of the marine habitats of the Cocos (Keeling) Islands can be found in Williams (ARB), and of the reef islands by Woodroffe and McLean (ARB).

2.2 Maps, aerial photographs and survey data

The broad details of land area for the Cocos (Keeling) Islands are outlined in Table 3. There are good maps and aerial photographic coverage of the islands. Topographic maps are available at a scale of 1:50 000 (NATMAP), which covers the islands in one

Table 3: Island Area and Island Perimeters

Island	Area (hectares)	Perimeter length (km)
North Keeling	121.67	14.197
<u>South Keeling</u>		
Direction Island	29.21	3.396
Prison Island	0.12	0.130
Home Island	90.66	6.548
Pulu Ampang Kechil	0.04	0.080
Pulu Ampang	6.19	2.206
Pulu Wa-Idas	1.12	0.551
Pulu Blekok	1.73	0.8[illegible]
Pulu Kembang	2.91	1.1[illegible]
Pulu Chepolok + Pulu Wak Banka	18.74	4.813
Pulu Pandau	19.39	4.590
Pulu Siput	10.40	2.112
Pulu Jambatan	1.34	0.759
Pulu Labu	4.21	1.176
South Island	363.59	29.308
Pulu Klapa Satu	0.58	0.347
Pulu Blau Madar	2.07	0.563
Pulu Blan	2.96	0.686
Pulu Maraya	1.80	0.625
Pulu Kambing	9.41	2.549
West Island	621.68	39.737
Horsburgh Island	100.24	4.267
Total South Keeling	1288.39	106.362
Cocos (Keeling) Islands	1410.06	120.559

Source: Calculated from Cocos Islands GIS Database, DASET office, Canberra sheet, and at 1:25,000, which covers the islands in two sheets. Aerial photographic coverage includes RAAF panchromatic at a scale of 1:44,400 taken in 1976, and colour vertical photography of the land areas at a scale of 1:10,000 taken in 1987. A second set of photography was also undertaken in 1987, but has not been seen by us. In addition SPOT multispectral satellite imagery was acquired over the islands in May 1987; a colour composite image has been produced at 1:25,000, and enhanced images of water depth, exposure and marine habitat classification are also available. The later were produced largely without any ground truthing, and are not always reliable. More detailed bathymetric survey data exist, with a series of maps of lagoonal depths dating back to that undertaken by H.M.S. Beagle; the most detailed bathymetry was produced by RAN in 1987. Marine habitats are mapped in detail by Williams (ARB).

An essential part of the assessment of vulnerability to sea-level rise is a consideration of the elevation of islands. Survey data are now available for each island, though for many this consists only of one benchmark. Initially surveys were restricted to the inhabited islands, West Island and Home Island. On Home Island survey data have been related to a survey datum termed Mean Sea Level (MSL), corresponding to 0.70m above Chart Datum (the datum to which early bathymetric data were related, and above which tidal predictions were quoted (until 1993 predictions)). West Island surveys were related to Airport Datum, which is recorded as 0.146m above MSL. All survey data reported here are reported with respect to MSL.

Recently survey data have been collated and expanded by the Western Australian Department of Land Administration (DOLA), and benchmarks have been extended to Horsburgh and Direction Islands using a global positioning system (GPS). North Keeling has also been surveyed in by GPS, but in view of the distance elevational data may be of poor reliability (and on our map and profiles of North Keeling we refer to North Keeling datum rather than MSL).

As a part of our own work, surveying has been undertaken from Home Island around the eastern and southern rims of the atoll to West Island. Temporary benchmarks (ADFA1-34), have been established on the intervening islands by Major J. Mobbs. These have enabled us to reduce our surveyed cross-sections across these islands to MSL.

Table 2 outlines the variablility of tidal still water. Maximum tidal range is about 1.2m, and highest astronomical tide corresponds to 0.6m above MSL. Tidal characteristics, together with hydrodynamic observations of the lagoon, are reported by Kench (ARB). The closest tidal amphidromic point to Cocos lies off the southwestern coast of Australia, and the tidal wave, rotating anti-clockwise around that point, would be expected to set from the east-northeast. Tides are mixed mainly semidiurnal, and Kench indicates attenuation and lag (15-55 min) of the tide at the southern end of the lagoon.

In addition it is important to realise that the value of 0.6m MSL for the highest tide level, is a still water level, and takes no account of the meteorological and wave conditions. Winds are generally strong, and predominantly from the east and southeast (the tradewinds); mean daily maximum wind speed is highest in August - 14.2 m/s (see Falkland, ARB). These winds drive a strong surf onto the reef crest around all sides of the atoll for the majority of the year. The open ocean swell is effectively attenuated by the reef crest; on a comparable fringing reef in the West Indies about 95% of wave energy was dissipated on the reef crest (Roberts et al. 1975). However, at the highest tides the reef crest is least effective in attenuating wave energy, as the water level is highest then, and that is when the largest waves can cross the reef crest, or reform after crossing the reef crest (Gourlay 1990).

We have no observational data on the highest elevation to which waves may reach at high tide on the oceanward beaches of islands, but we suggest that wave crests up to 1.0m MSL are likely to be experienced on average at least once a year, and that swash

1.0m MSL are likely to be experienced on average at least once a year, and that swash may reach still further up oceanward beaches.

During storm conditions, water levels and waves are likely to be much higher. No data are available. We have first hand experience of Cyclone Frederick in 1988, but this was not a particularly devastating storm. Forbes (1879) describes the impact of the cyclone in 1876, during which portions of the conglomerate platform were excavated and moved up the beach.

We have no record of the effects of tsunami waves on Cocos. These tend to have their greatest impact where they approach a shore over a broad continental shelf, and the long wavelength is amplified through shoaling. Thus tidal waves, such as that recently reported to have been more than 20m above usual in Flores, are rarely more than 1-2m above ususal in open ocean situations such as Cocos.

2.3 Individual reef islands

Reef islands in the Cocos (Keeling) Islands are low-lying, and are generally composed of unconsolidated, biogenic sand. In places coral shingle is an important constructional agent, and in a few localities, as for instance towards the southern end and on the oceanward shore of Pulu Wak Banka, coral rubble, composed of boulders of more than 50cm diameter, forms a beach rampart.

A conglomerate platform, formed of cemented coral sticks and boulders, underlies many of the islands, although is not found everywhere (Jacobson 1976); it appears to act as an anchor upon which island sediments accumulate, determining gross island morphology. A clinker-like conglomerate, undercut by solution and ringing metallic to the hammer, is found along the lagoonward shore of many islands, and is particularly conspicuous around the perimeter of the lagoonlets or teloks.

The beaches of islands are not always unconsolidated sand, but may also contain cemented deposits of beachrock. Beachrock can be distinguished from conglomerate because it is bedded and exhibits a seaward dip; beds are scarped at the landward face, and the deposits are undercut along bedding stratification (Russell and McIntire 1965, p35; Stoddart 1971a p9). In places beachrock overlies conglomerate platform, as on the western shore of Horsburgh Island.

In this section individual reef islands are described and mapped. Mapping was undertaken from 1:10,000 colour vertical aerial photographs taken in 1987 supplemented by ground truthing. Elevational information was gained from a series profiles surveyed across reef islands and related to mean sea level datum. Additional data come from previous surveys and benchmark records. A more detailed account appears in Woodroffe and McLean (ARB).

2.3.1 Direction Island

Direction Island (also known as Pulu Tikus, or Rat Island) is a crescent-shaped island (Figure 7). It is 1.6km long and 300m maximum width, with an area of about 30ha. This width is insufficient to maintain a freshwater lens (Falkland, ARB). The island is dominated by coconut woodland, but with a band of *Scaevola* scrub along its eastern margin. It was the site of the Cable Station, with undersea links to Australia, Singapore and South Africa, which came into operation in 1901 and ceased in 1966.

The eastern portion of the oceanward shore comprises a prominent ledge of conglomerate platform, extending up to 35m from the beach (Figure 8a). The oceanward beach ridge is composed of coral rubble and shingle along most of the island, but this coarse substrate overlies sand. The ridge crest which reaches a height of around 3.0m along much of the island, but 3.5m towards the northern end. The

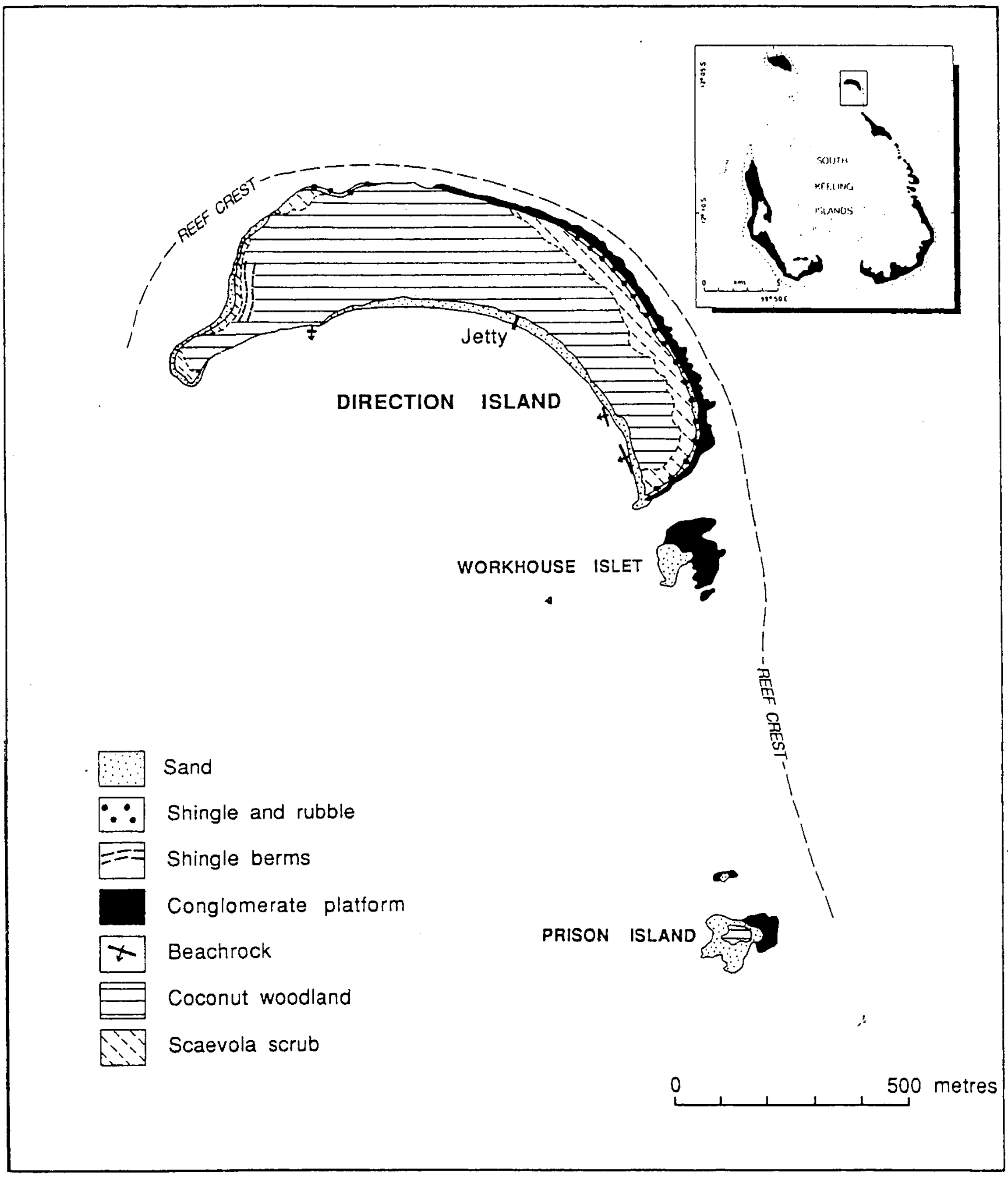


Figure 7 Direction Island, mapped from 1987 aerial photography.

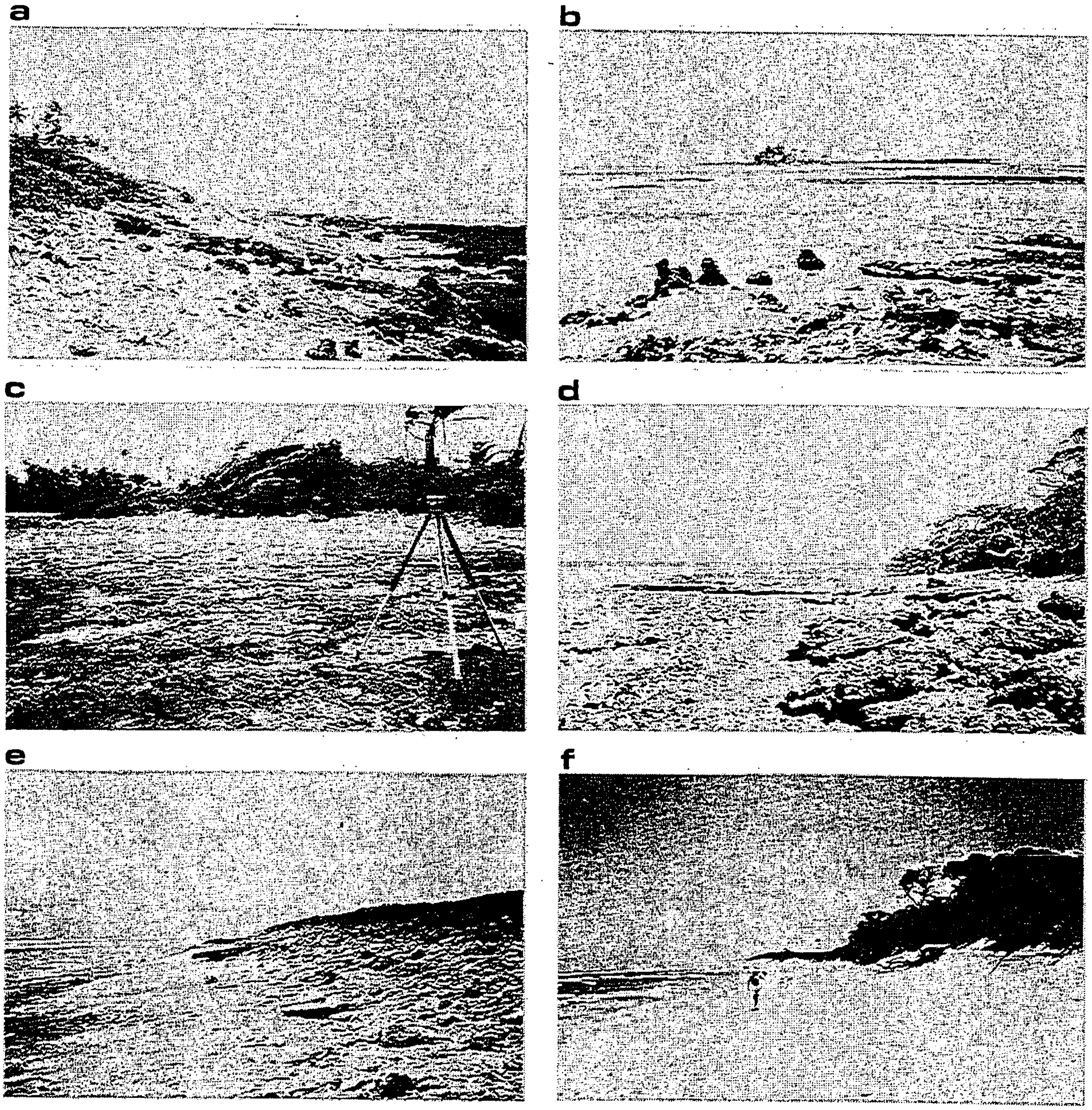


Figure 8 a: Oceanward shore of Direction Island; rubble is from ruins of Cable Station, b: View looking North from Home Island. Conglomerate platform in middle distance is where Button Islets were, Prison Island is in the middle of the photograph and Direction Island in the distance, c: Conglomerate platform on Ampang Island, d: conglomerate platform on Pulu Pandan; it appears to consist of a shingle conglomerate layer overlying typical conglomerate platform, e: Conglomerate ramp, oceanward shore of South Island, f: Sandy and beach dune on the southern side of South Island.

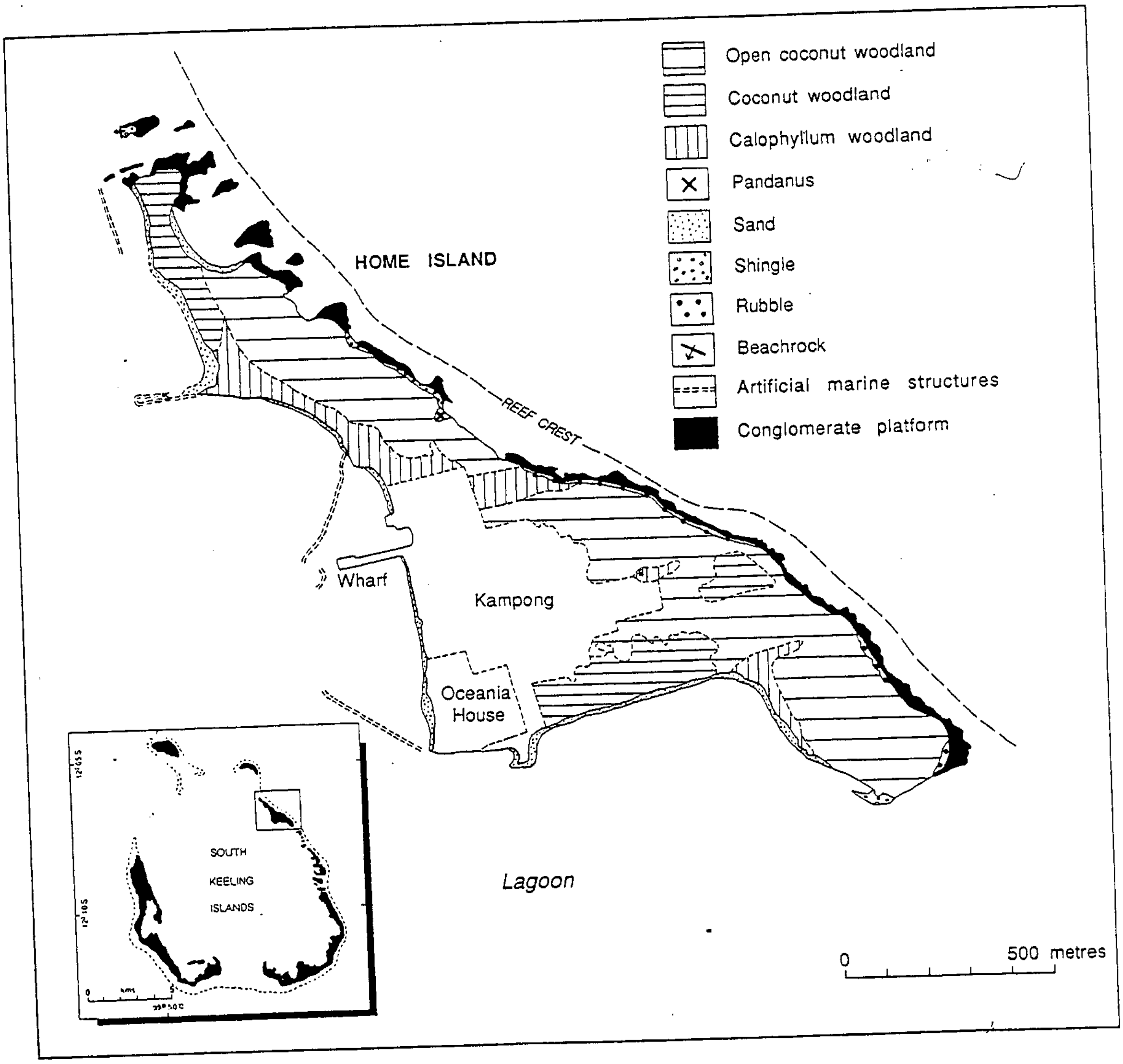


Figure 9 Home Island mapped from 1987 aerial photography.

lagoonward shore is dominated by a broad sandy beach. Minor outcrops of beachrock are found at the northern and southern ends of the lagoonward beach, indicating minor recession of this shoreline at some stage in the past. Direction Island is particularly scenic, is regularly visited by the inhabitants of West Island for recreational purposes, and has been the site proposed for a hotel development.

2.3.2 Prison Island

The island north of Home Island is known as Prison Island (Figure 8b). It is now considerably smaller than it must have been when Alexander Hare moved his household there in 1827. It presently reaches a height of 6.7m, though it is now eroding on all sides. It contains a mixture of coconut, *Scaevola* and *Tournefortia (=Argusia)*. Bunce (1988) implies that much of this erosion has taken place in the 30 years since Pulu Gangsa (where the graveyard is on Home Island) has been connected to Home Island.

2.3.3 Home Island

Home Island has been a centre of habitation since Alexander Hare chose it for his first permanent settlement in 1826. The island is also known as New Selima or Pulu Sel· It is covered by well-managed coconut woodland, with extensive groves *Calophyllum* (Figure 9). The burial island, Pulu Gangsa, was artificially joined to Home Island by placing coconut logs and concrete-filled drums across the channel in the late 1940s (Bunce 1988). The combined islands have a length of 2.6km, and reach a maximum width of 800m. Their area is 0.95km^2. Some part of this has been reclaimed from the sea; this is especially true of the landing area north and south of the present jetty, and the part of the village called kampong baru (new village), reclaimed by teams of women earlier this century (Bunce 1988). Oceania House was designed and built by George Clunies Ross in 1893.

There is considerable survey data available for Home Island. Most of the kampong lies between the 1m and 2m contours above MSL. The island generally rises to an oceanward beach crest that is around 3.30m though the ridge immediately northeast of the village rises only to 2.4m MSL and the dune further north rises to a height of 5.4m MSL. On the oceanward shore of Home Island there is a narrow outcrop of conglomerate platform, rising to 0.5m MSL, within which branching corals are especially prominent, and large boulder reach up to 1.0m MSL.

The sandy lagoonal shore has been extensively modified; sand has been bulldozed, a there is evidence of a series of seawalls along parts of the shore. The village extende along the southern shore, east of Oceania House earlier this century (Gibson-Hill 1950a). Nevertheless despite much interference the lagoonal shoreline appears relatively stable.

2.3.4 Islands of the eastern atoll rim

South of Home Island there are a series of small islands (Figure 10) on the lagoonward side of which Home Islanders have their pondoks (weekender shacks). Each island sits on an outcrop of conglomerate platform, which forms a prominent structure on the oceanward side (Figure 8c, d), in some cases, as in the Ampang Islands, linking several islands. Much of the conglomerate platform is inundated at high tide, particularly when there is a large swell. The oceanward beach is generally composed of shingle overlying sand, and individual boulders at the foot of the beach with diameters of up to 1m. On Pulu Wak Banka, the nature of the sediments on the oceanward beach changes markedly along the island. There are coarse coral rubble deposits, with boulders up to 1m in diameter, along much of the southern half of the island, but where the island is narrowest, the conglomerate platform is no longer present along the oceanward shore, and instead there is a broad sand beach. The ridge crest rises to 3.5m MSL at the

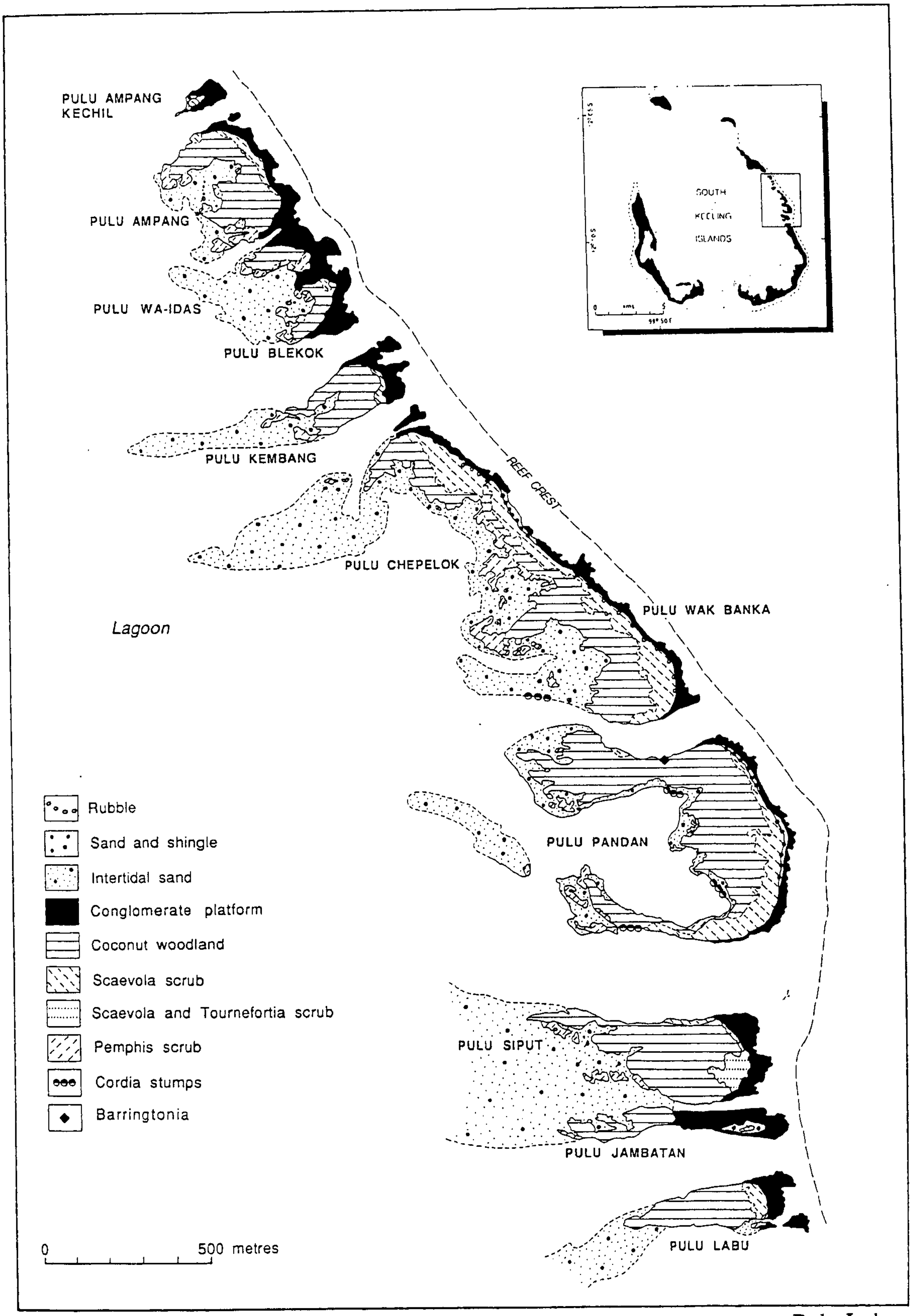


Figure 10 Islands of the eastern rim of the atoll from Pulu Ampang to Pulu Labu, mapped from 1987 aerial photography.

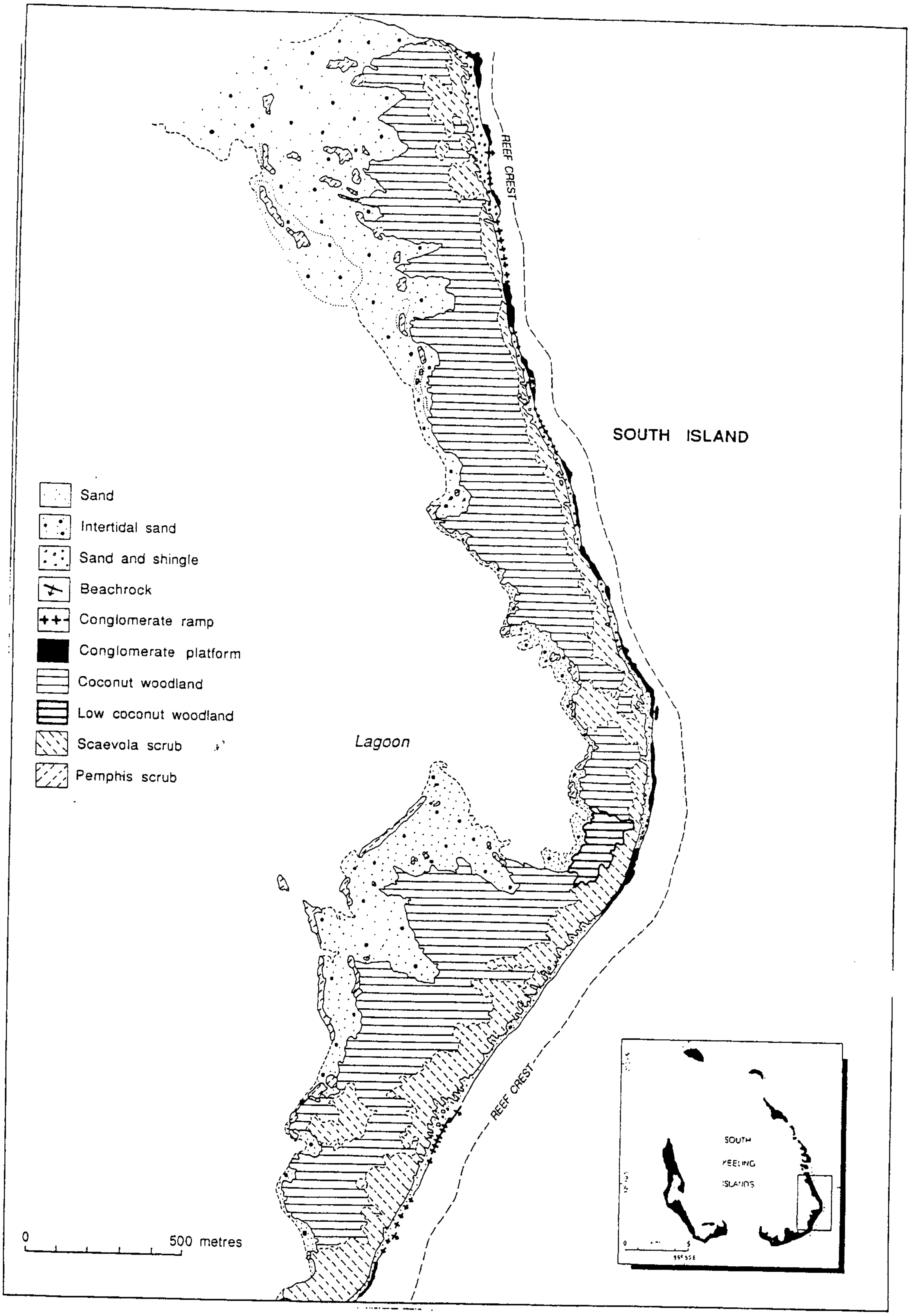


Figure 11 South Island, northern section, mapped from 1987 aerial photography.

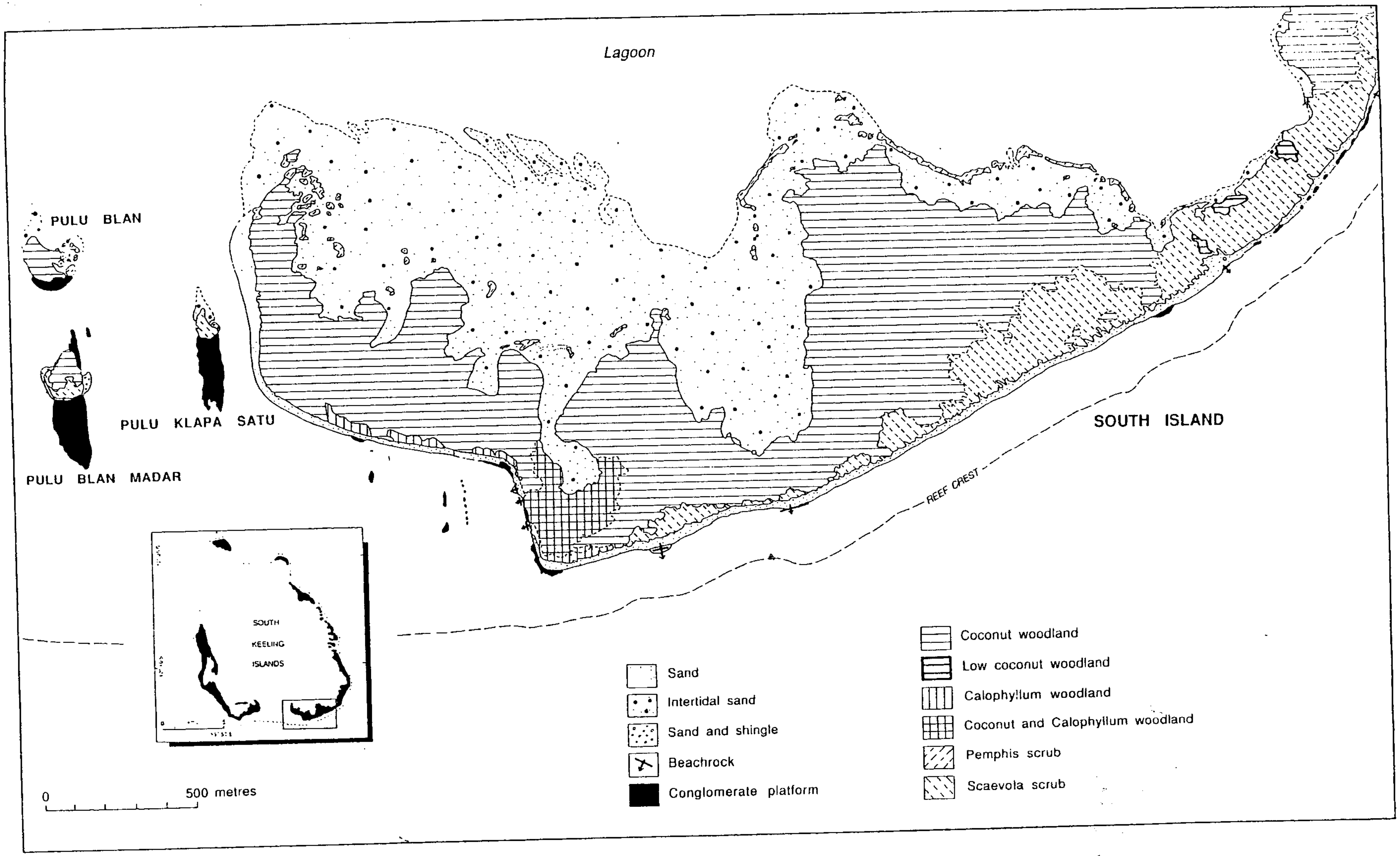


Figure 12 South Island, southern section, mapped from 1987 aerial photography.

southern end of the island, but is only 2.1m MSL where a profile has been surveyed across the island in the centre. The crest of this ridge, as on other islands, has a cover of *Scaevola* scrub, which is replaced 10-20m inland by coconut woodland. On the lagoonward side of the islands there are spits extending into the lagoon, colonised by *Pemphis*. These spits tend to cut off an interior lagoonlet; the clearest example of this is provided by Pulu Pandan. This island is composed primarily of sand, rising up to a ridge crest of 4.50m MSL, and does not have the shingle or rubble veneer characteristic of the oceanward shore of islands to the north. Shingle does form low elevation ridges along the lagoonward shore, and there are small outcrops of a clinker-like conglomerate around the margin of the lagoonlet.

2.3.5 South Island

South Island, also called Pulu Atas (meaning top island in reference to it being upwind), and Southeast Island, is the windward island of the atoll. It was chosen as the site for the first settlement by Captain John Clunies Ross in 1827, who dredged a boat channel to the island. The long lagoonal shore is presently the preferred site for a number of Home Islanders pondoks.

The island is 9.5km long, and reaches a maximum width of 1.1km (Figures 11 and 1 Much of the oceanward shore of South Island is formed of a dune (Figure 8f). Windblown sand reaches up to 6.3m and a coral rubble veneer reaches 4.7m above MSL on measured profiles. The vegetation of the dunes is primarily *Scaevola*, though with considerable *Tournefortia*, particularly as isolated shrubs within blowouts along the dune crest. Conglomerate takes two forms; conglomerate platform occurs in irregular outcrops along much of the eastern part of the island, often rising up to 1.20m MSL. There are also outcrops of conglomerate ramp, a highly worn form of conglomerate platform, which has been bevelled back to a steep ramp-like profile (Figure 8e). The latter superficially resembles beachrock, which can also be found at sites along the oceanward shore of South Island, but is not imbricated.

The interior of the island is now covered by thick, overgrown coconut woodland which has degenerated from the organised and harvested coconut plantations of the heyday of the Clunies Ross estate. On the oceanward shore and over the narrow necks of the island, there is dense, impenetrable *Scaevola* scrub. Little remains, except isolated stumps of the *Pisonia* and *Cordia* stands which were once widespread on the island. There is a large stand of *Calophyllum* at the southwestern corner of the island.

The lagoonward shore of South Island is highly irregular. The lagoonal flats ar composed of mud or sandy mud, and there are irregular linear shoals, covered by *Pemphis* and inundated at high tide, partially enclosing some of the larger lagoonlets, termed teloks.

Upon first impression this elongate island appears to have been made up from several islands which have been joined together. There are two areas, which resemble infilled passages between these former islands. These are covered mainly by *Scaevola* scrub, with few coconuts; those coconuts which do grow there are stunted, and stressed and are mapped as 'low coconut woodland' (Figure 11, 12). There is no freshwater lens developed beneath these narrow areas. Soil is absent or poorly developed, and the lagoonward portion of the island is composed of clinker coral shingle. These appear to have been former channels, though the evidence from early charts must be discounted and is seems highly unlikely that they have been sealed in historic times.

2.3.6 Islands of southern passage.

The islands of the southern passage are small, and low (Figure 12). The oceanward shore of Pulu Blan Madar rises up to a height of 1.20m MSL. They occur on linear outcrops of a conglomerate platform composed primarily of small clasts and sand-sized

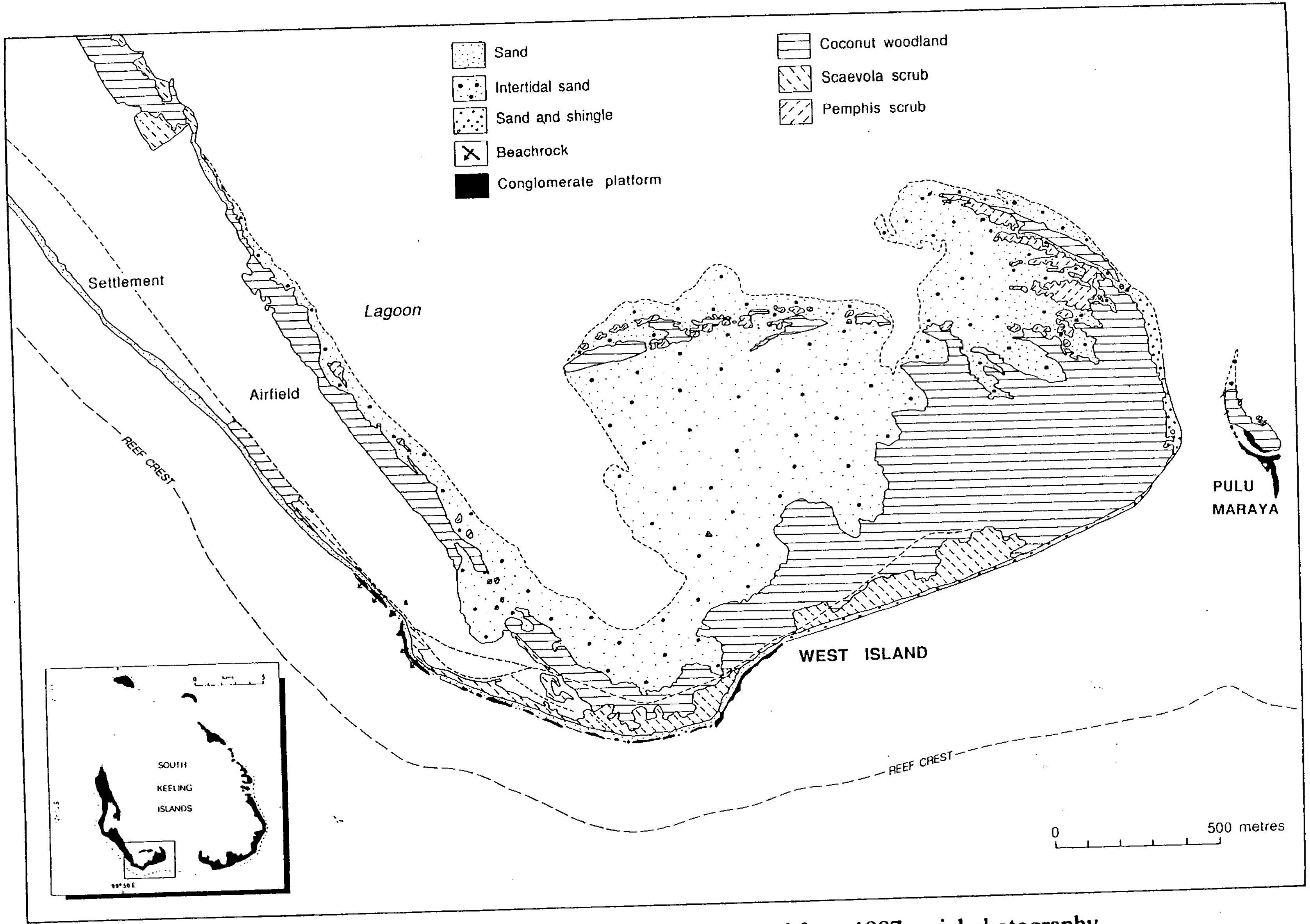


Figure 13 West Island, southern section, mapped from 1987 aerial photography.

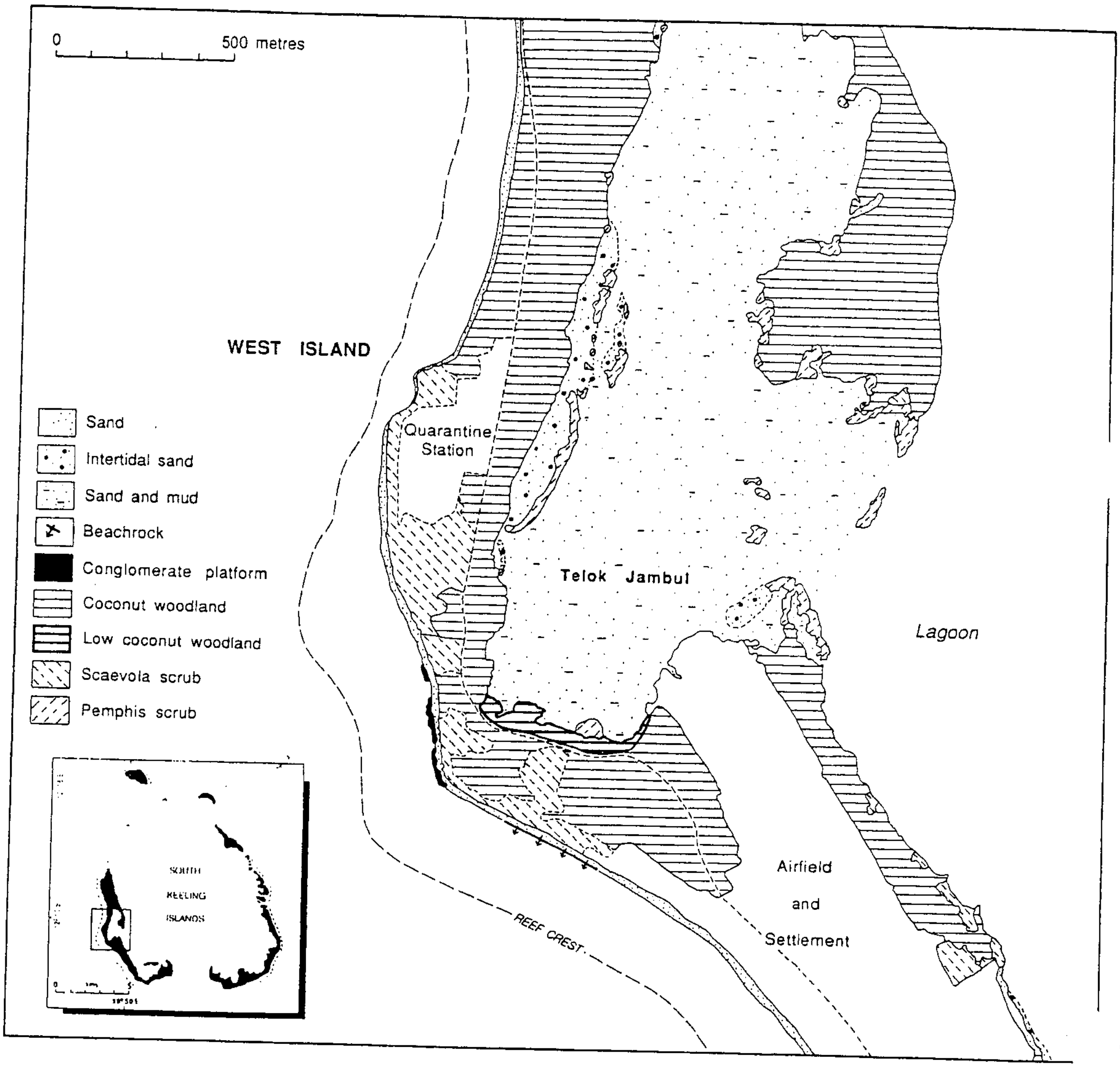


Figure 14 West Island, central section, mapped from 1987 aerial photography.

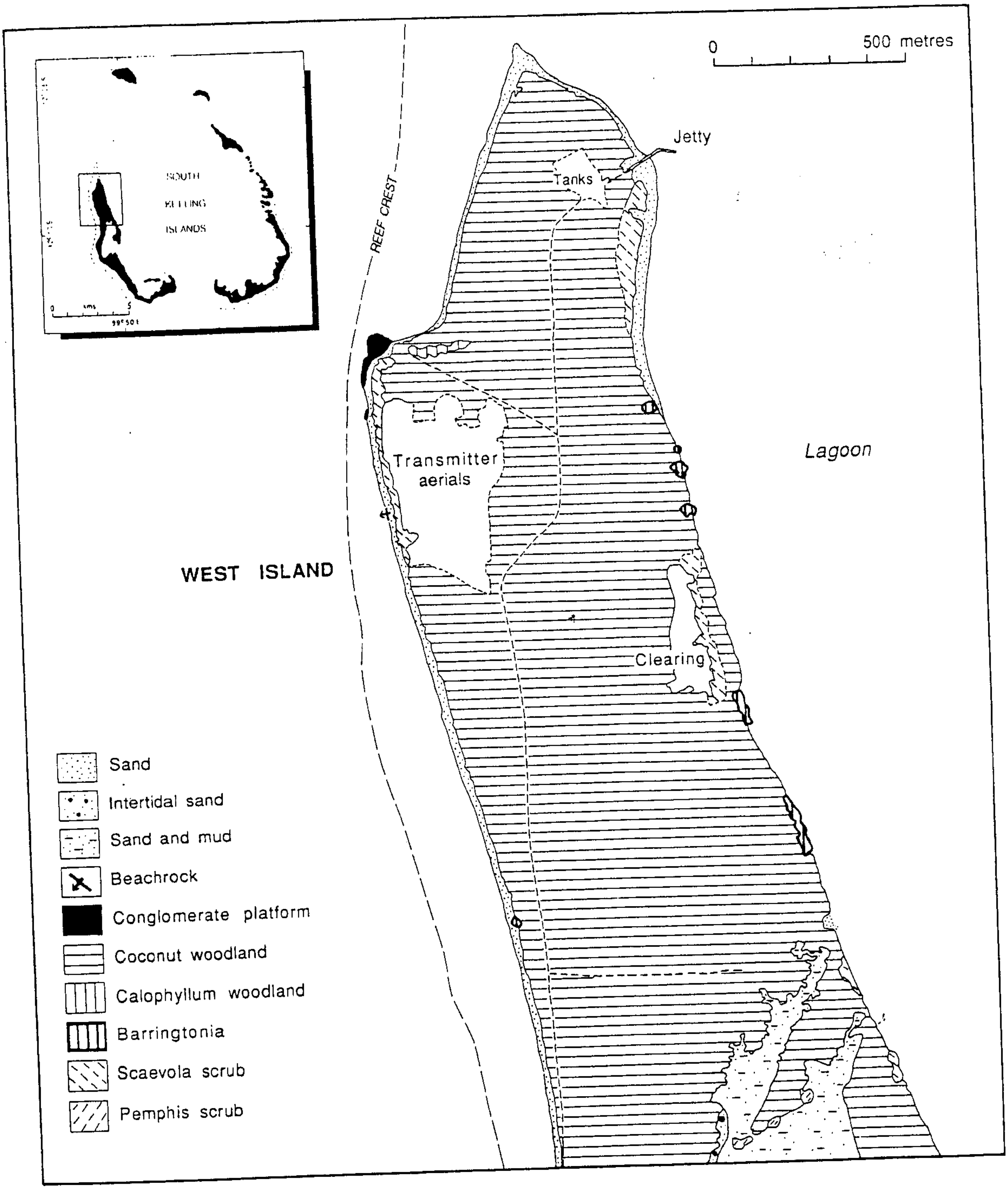


Figure 15 West Island, northern section, mapped from 1987 aerial photography.

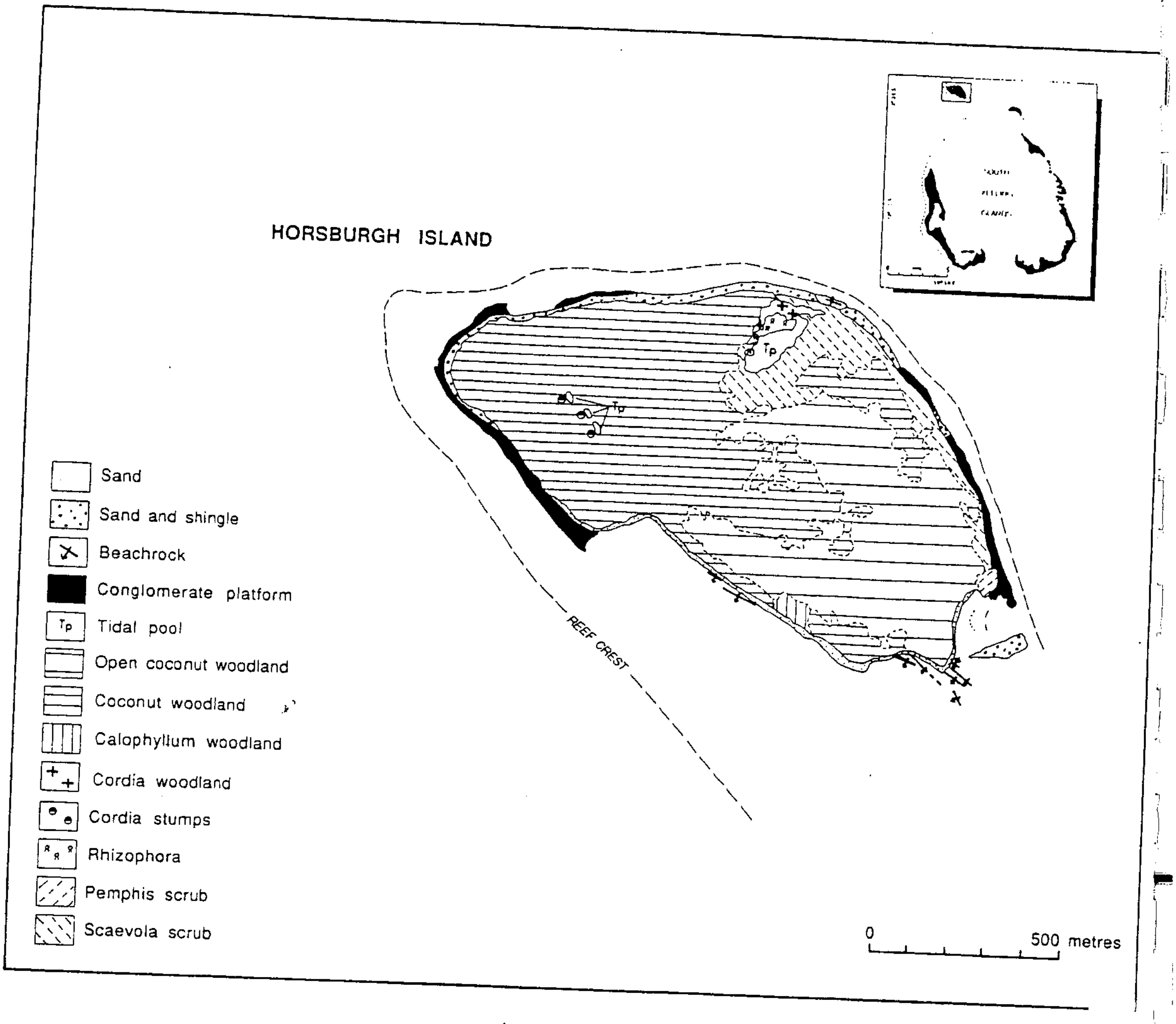


Figure 16. Horsburgh Island, mapped from 1987 aerial photography.

grains cemented together., The western island, Pulu Maraya is predominantly sandy though with a series of shingle berms on the oceanward shore. It is dominated by coconut woodland, with a fringe of *Scaevola*, replaced with *Pemphis* along the lagoonward flanks (Figure 13).

2.3.7 West Island

West Island, also known as Ross Island, or Pulu Panjang (Long Island), is the largest island, and has been associated with the airstrip and contains an Australian expatriate population at present. The airstrip was built, initially in 1944, but saw little action in the war, and was revamped for use by Qantas in 1951.

The island is 12.6km long and reaches just less than 1km wide at its maximum width. Most of the 6.2km^2 was covered by coconut plantation, but much is now covered by buildings, the airstrip, or radio transmitter and receiver aerials (Figures 13, 14 and 15). The coconut woodland has ceased to be cleared regularly, and has become largely overgrown, and penetrable only with difficulty.

The island comprises three broad sections, connected by narrow sections which may have been former interisland passages. These lead into the two large lagoonlet areas, Telok Jembu and Telok Kambing. Much of the western shore is a sandy beach, with a low dune. There is a large area of conglomerate platform at the southwestern end of the island, and isolated outcrops at the westernmost point and to the northwest. The outcrop to the southwest is one of the more elevated outcrops on the atoll rising up to 1.20m MSL, with a further cemented shingle conglomerate up to 1.80m MSL outcropping on the beach behind the conglomerate platform.

The easternmost end of the island is characterised by a number of sand spits and ridges, which are shown by Woodroffe et al. (ARB) to have built out over the last 1400 years.

2.3.8 Horsburgh Island

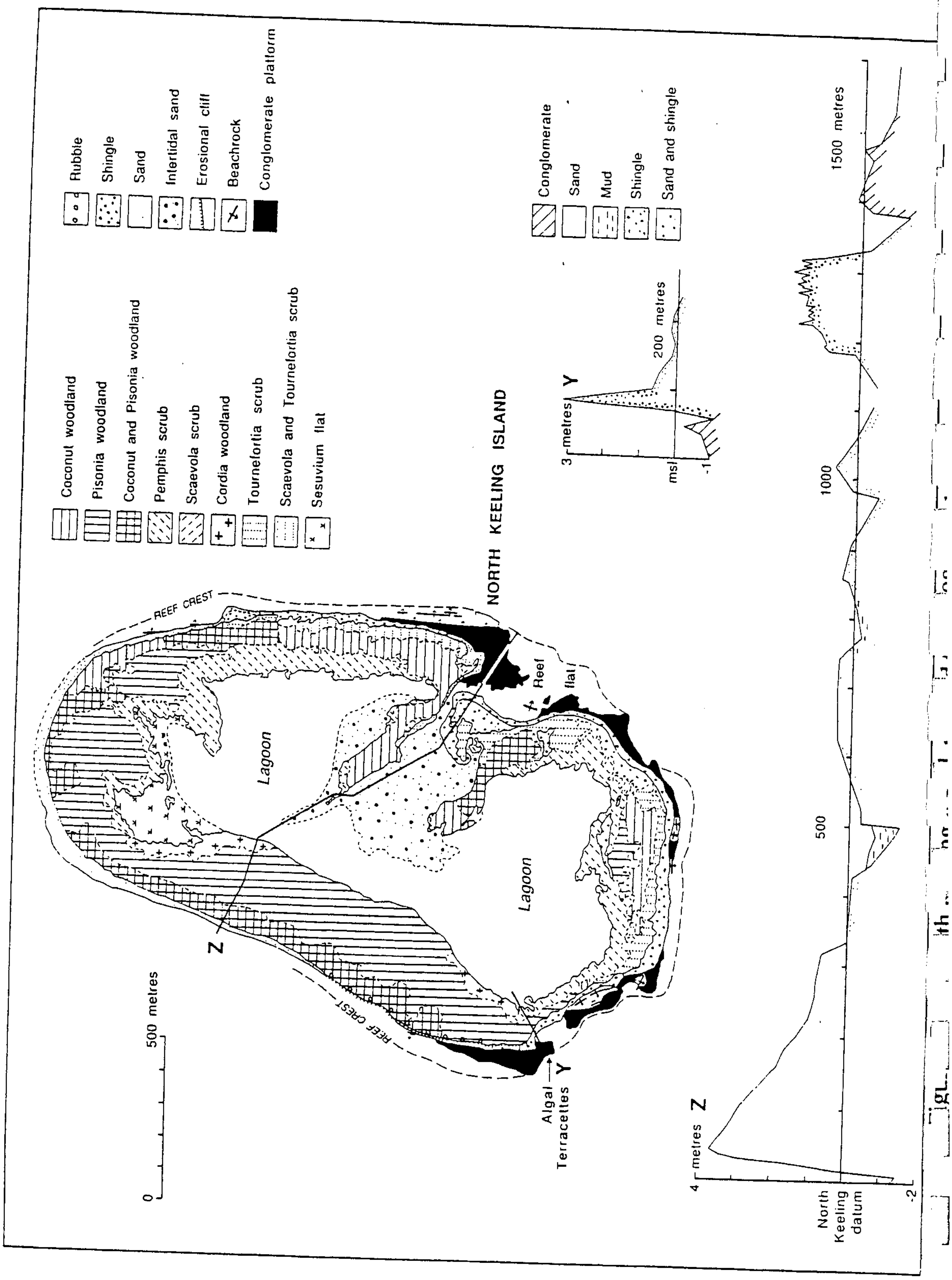
Horsburgh Island is also known as Pulu Luar (Outside island). It is 1.7km long and 0.9km wide, covering an area of over 1km^2. This island sits partly on an outcrop of conglomerate platform (Figure 16). The conglomerate differs from that on other islands; on the eastern shore of Horsburgh it is generally narrow, and often bevelled into a conglomerate ramp. On the western shore there is a broad platform with beachrock cemented to it.

Along the southern shore there is a broad sandy beach, in places with outcrops of beachrock which indicate that in the past the shoreline has had a slightly different orientation in this part of the island. The northern shore of the island is particularly exposed and consists of a bevelled conglomerate platform ledge, and boulder deposits over the top. A small lagoonlet with a stand of mangrove *Rhizophora apiculata, Cordia* stumps and *Sesuvium* occurs behind a boulder beach on the north of the island.

Much of the northern part of Horsburgh is composed of shingle or rubble, while the southern part is predominantly sand. Coconut scrub is especially open over the southern part of the island with a sward of grass and the sedge *Fimbristylis*, but forms denser coconut woodland to the north. *Scaevola* scrub is widespread over the island; to the south it is relatively open, but to the north it is dense, and made almost impenetrable by a tangle of *Turnera, Triumfetta, Wedelia, Premna* and the parasitic *Cassytha*.

2.3.9 North Keeling Island

Unlike the South Keeling Islands, North Keeling has been visited relatively infrequently, has not been inhabited for any continuous period, and remains relatively



Coconut woodland
Pisonia woodland
Coconut and Pisonia woodland
Pemphis scrub
Scaevola scrub
Cordia woodland
Tournefortia scrub
Scaevola and Tournefortia scrub
Sesuvium flat
Rubble
Shingle
Sand
Intertidal sand
Erosional cliff
Beachrock
Conglomerate platform
NORTH KEELING ISLAND
Lagoon
Lagoon
REEF CREST
REEF CREST
Reef flat
Algal Terracettes
Y
Z
0
500 metres
Conglomerate
Sand
Mud
Shingle
Sand and shingle
3 metres
msl
-1
200 metres
4 metres
North Keeling datum
-2
500
1000
1500 metres

unchanged. It contains large breeding populations of seabirds, and is regularly surveyed by the Australian National Parks and Wildlife Service.

The island is 2.0km long and 1.3km wide, with a reef crest around all of the island, except the northwestern corner (Figure 17). The reef island is almost continuous around the perimeter of a shallow lagoon, reaching a maximum width of 320m and a minimum width of 50m. There is one major opening into the lagoon on the southeastern corner of the atollon. This is the windward side, and the opening has no channel through the reef, but is a shallow entrance which drains almost totally at lowest tide. The lagoon is shallow, and it's surface sediments are muddy sands, except for two sandy spits which trail in through the entrance. Much of the lagoon is sea grass covered.

The island varies from sand to rubble. On the northern shore there is a broad sandy beach. This continues along the western shore but with varying amounts of shingle. On the profile (Figure 17) the sandy beach rises up about 4m above mean sea level (North Keeling datum). A pit shows some shingle fragments, but indicates that the majority of the substrate is sand. This becomes coarser to the south, where rubble outcrops on the beach, and there is an erosional cliff cut into this rubble. The southern shore of the island is composed of a spectacular steep shingle beach, with a series of berms identifiable. Much of the eastern shore is composed of a series of shingle berms, these are particularly well-developed just south of the channel into the lagoon, but continue to the north as well.

There are also outcrops of coral conglomerate. A broad platform of conglomerate extends out over the reef flat at the eastern part of the island, almost closing the channel into the lagoon off completely. Along much of the southern and eastern shore the conglomerate outcrops at the foot of the beach but contains a series of parallel rubble ridges, dipping and stratified like beachrock.

Much of the island is dominated by *Pisonia* forest (Williams, ARB) and over much of the island we have chosen to map this as *Pisonia* and coconut woodland. *Tournefortia* is a conspicuous element of the vegetation of the eastern shore, dominating the crest of the shingle or rubble ridges. In some cases *Tournefortia* is monospecific, north of the channel into the lagoon it occurs with *Scaevola* also. Around the margins of the lagoon, *Pemphis* forms a thicket. *Cordia* is also important in this location. There are also cleared areas; the grassy and *Sesuvium* covered area to the northwest of the lagoon is the most extensive area of this type.

2.4 Special ecological areas, habitats & species

The marine and terrestrial habitats of the Cocos (Keeling) Islands are described in detail in the special issue of the Atoll Research Bulletin, and species lists for the major groups of marine and terrestrial fauna and flora are given. In this section the case for special consideration is made.

For the groups that have been examined in detail, the present species lists amount to 99 species of hard, scleractinian coral, 198 species of decapod crustaceans, about 610 species of molluscs, 88 species of echinoderms, about 548 species of fishes, 38 species of birds and about 130 species of plants, of which about half are native.

The Cocos (Keeling) Islands are not only extremely isolated, but they also lie at the western extension of the Western Pacific marine biogeographic province, and for many species Cocos represents their western limit of distribution. The biota is derived primarily from western Java, Indonesian and eastern Indian Ocean region.

There is almost no endemism in the Cocos biota (Woodroffe and Berry, ARB). The Buff-banded Rail, *Rallus philippensis andrewsi*, is considered an endemic subspecies, restricted to North Keeling, and the rat on Direction Island, *Rattus rattus keelingensis*, has been accorded subspecies status, and can be traced back to the *Mauritius* which was wrecked in 1825. The angelfish *Centropyge joculator* is recorded only from Christmas and the Cocos (Keeling) Islands (Vadiz-Smith and Allen, ARB). The Pandanus *(Pandanus tectorius)*, or screw pine, which is only localised in occurrence, is also considered an endemic subspecies (Williams, 1990).

This lack of endemism may reflect the effect of rapidly oscillating sea levels during the late Quaternary, and the pattern of development of coral atolls, whereby the limestone surface which was exposed at the last glacial maximum was rapidly flooded during postglacial sea-level rise and all land was submerged in the early Holocene (10,000-8,000 years ago), with the present reef islands being no more than 4000 years old (Woodroffe et al. 1990a, 1990b, ARB; Woodroffe and McLean, ARB). This would have meant that all the terrestrial biota would have had to have recolonised the atoll in the last few thousand years. These sea-level fluctuations would also have had substantial implications for shallow-water marine biota, as the nature of the habitats would have altered drastically over that period also.

Some taxa which might be expected are conspicuously absent. There are no mangroves and *Nypa* palm, despite the arrival of propagules on the shore; the stand of mangr ·s on the northern end of Horsburgh Island can be attributed to planting by John Ge ; Clunies Ross. Some shallow marine taxa usually common on coral reefs are conspicuously absent in apparently suitable habitat (i.e. there are no benthic skates or rays in the lagoon), because taxa must either be pelagic as adults or have long-lived larvae or juveniles to reach Cocos.

Christmas Island is the nearest island, and there is less similarity than might at first be expected between the biota found at Cocos and that at Christmas. Undoubtedly this results from the contrasting physiography of the two islands. Christmas Island is an uplifted (and apparently still uplifting) limestone island, while Cocos is a subsiding atoll, where the only land is geologically very young.

In addition to the very different late Quaternary history, and the great contrast in the time available for establishment of terrestrial biota, the Cocos (Keeling) Islands are probably more subject to periodic catastrophic influences on the biota. The atoll has experienced several devastating tropical cyclones, which tend to have an impact all over the resticted land area of Cocos, as well as in shallow parts of the lagoon and reefs. There have been a series of coral and fish kills in the lagoon; the earliest recorded being in 1876 (though Darwin also recorded dead coral in the southeastern corner of e lagoon), when inky and foul smelling water spread through the lagoon from the isl; on the eastern rim. This fish and coral kill has recurred, most noticeably in 1983, but also in intervening years. Its cause is still unclear. Forbes considered that the 1876 event may have been caused as a result of an earth tremor. The 1983 event was correlated with El Niño in an incisive, but unpublished account of it by Blake and Blake; though other interpretations suggest that it may have coincided with coral mass spawning. A minor episode of fish kill was also observed in 1992 (Tranter, pers. comm.).

Present diversity and abundance of reef organisms closely associated with living corals may have been reduced by the reduction of coral abundance and diversity on the reef slopes and in the lagoon as a result of these events. In view of the isolation of Cocos and the distance to be covered by propagules, if species are lost from the atoll as a result of such events, they are likely to be slow to recolonise.

Human impact on the Cocos (Keeling) Islands has been most devastating on the South Keeling Islands (the southern atoll), where the vegetation has been almost totally altered to coconut plantation. The birds which once characterised the atoll have all but disappeared, and it is the absence of large numbers of seabirds, which strikes one as the most conspicuous difference between North Keeling and the southern atoll. The relatively unchanged nature of North Keeling Island gives that a particular value, and it is highly desirable to maintain this example of natural vegetation, and the breeding seabird populations. On the South Keeling Islands, there have also been impacts on marine organisms which are eaten, such as the giant clam, *Tridacna*, gong gong, *Lambis lambis*, and the palinurid lobsters. At the same time occupation of the atoll has resulted in an influx of new species to the Cocos (Keeling) Islands. These vary from ornamental and food plants, and deliberate animal introductions (such for instance as the chickens kept on the majority of islands and the green jungle fowl on West Island, or the sheep, cattle, alpacas and black rhinoceroses which have been temporarily contained within the Quarantine Station on West Island), to accidental releases (such as the rats or the lone King Parrot on West Island). In addition there are numerous insects which have been introduced, and a large number of insect pests (Gibson-Hill 1950b).

While a strong case can be made for the conservation of North Keeling Island, it needs to be recognised that the same case is not compelling for the South Keeling Islands. Their vegetation has been almost totally changed, and is now overgrown coconut plantation, which has not been maintained, and which has little present land-use beyond free-range chickens. In the case of the marine environments, there are no species which are known to be endangered, except those that have been collected for food. Nevertheless, the delicate nature of the reefal ecosystem, and the interconnected food webs, need to be recognised. Thus the teloks, which may appear unproductive, have a rich fauna and contribute to the overall healthiness of the marine ecosystem. Each of the marine components is to some extent important to the overall aesthetic value of the coral atoll ecosystem.

There are other values which need to be recognised on Cocos. Firstly, the Cocos Malay culture is endemic. The Home Islanders, particularly the Cocos-born, do not have an alternative home, although they do have relatives on Christmas Island, and in several towns in Western Australia.

Furthermore, there is a strategic importance to the Cocos (Keeling) Islands. This is particularly true of the airstrip. To a lesser extent the territorial waters around Cocos are a resource which would be lost if Cocos were ever completely inundated. By comparison, we draw attention to the efforts by the Japanese to keep one small island off their southern end above the sea, and the attempts by the Chinese and the Malaysian governments to extend their territorial waters in the South China Sea, through strategic protection of small islands.

2.5 Characteristics of the Human Use System

The second part of Step 2 in the Common Methodology is the collection of data relating to:

- socio-economic characteristics (population, economy)
- land use and land values
- cultural assets with high irreplaceable historic value
- large-scale (engineering) projects
- special ecological areas including those with conservation value

These 'development variables' influence the assessment of human use impacts of ASLR and are considered below. Many of the following comments are taken from a report titled the *Cocos (Keeling) Islands Land Use Plan and Planning Scheme* prepared for the Cocos (Keeling) Islands Council by the National Capital Planning Authority and the Commonwealth Department of the Arts, Sport, the Environment and Territories published in June 1992 and referenced here as NCPA-DASET (1992). Other data comes from the Annual Reports of the Cocos (Keeling) Islands Territory and other publications held in the Canberra office. Areal statistics are from the Cocos (Keeling) Islands Geographic Information System (GIS) Database which was accessed through DASETs ERIN computer network at the Territories office in Canberra.

2.5.1 Population and Settlement

The current total population of Cocos exceeds 600. Preliminary data from the 1991 Census enumerated a total of 647 persons, a decrease of 4.3% from the 1986 Census figure (Castles, 1992). Population estimates from 1982-91 are given in Table 4.

Settlement is concentrated on Home Island and West Island on the eastern and western sides of the atoll respectively. Some other dwellings are located on the lagoon side of the small eastern islands and South Island and these 'weekenders' are traditionally used by families from Home Island as rural plots (pondoks).

The population of Home Island on 30 June 1991 totalled 453 composed of 220 males and 233 females including 130 children NCPA-DASET (1992). Commonwealth records indicate that the population of the island increased by approximately one-third between 1981 and 1986, but by less than one-tenth since. There are 96 extended family households in the kampong on Home Island. All housing in the kampong, except for Oceania House (the mansion built by Clunes-Ross in 1893) is currently owned by the Island Council.

West Island presently has a population of approximately 160, though the number fluctuates according to the need for Commonwealth Government staff on the island. Houses on West Island are built on land owned by the Commonwealth and are occupied by contract staff and their families on a rental basis.

2.5.2 Economy and Employment

Since the late 1970s, when the Australian Government purchased most of the Clunies-Ross' interests in the Territory the major inter-related elements of the Cocos economy have comprised: the operations of the Commonwealth, the activities of the Islands Council and the commercial operations of the Co-operative Society. Ultimately however most of the income and employment has been generated directly or indirectly by the injection of some form of Commonwealth funding (Commonwealth Grants Commission, 1989).

Expenditure on administrative and capital works and services is met from monies appropriated from the Australian Government departments and agencies represented in the Territory. These include the Cocos Administration, Australian Construction Services, Quarantine Service and Bureau of Meteorology, and formerly the Civil Aviation Authority. Revenue is from postal services, aircraft handling charges and miscellaneous sources (Table 5).

Currently almost all Home Island workers are employed through the Cocos Islands Co-operative Society. The Co-operative carries out a range of economic activities including trading stores, freight handling, maintenance of marine vessels, tourist accommodation and catering and it supplies labour to the Commonwealth. The Co-operative maintains a barge, landing craft and other vessels.

Most of the residents of West Island are employees of the Commonwealth, or dependants of those employees. The majority are recruited from Western Australia and the ACT on (commonly) two year contracts.

Table 4: Population Estimates, 1982-1991

30 June	Home Is	West Is	Total
1982 [1]	320	226	546
1983 [2]	354	205	559
1984 [2]	376	208	584
1985 [2]	389	233	622
1986 [2]	414	202	616 [3]
1987 [2]	430	242	672
1988 [1]	465	221	686
1990 [1]	413	190	603
1991	(453) [4]	(160) [4]	647 [5]

Sources:
1. Year Book Australia
2. Annual Reports Cocos (Keeling) Islands Territory
3. 1986 Census of Population enumerated 676 persons
4. 1991 Census of Population and Housing, First Counts, ABS, March 1992
5. NCPA-DASET (1992)

Table 5: Public Finance - Revenue and Expenditure, 1981-1987

Year	Revenue ($ million)	Expenditure ($ million)			
		Salaries	General Expenses	Buildings Works etc	Total Expd
1981-82	0.811	0.732	1.497	3.638	5.867
1982-83	0.869	0.828	1.632	3.361	5.821
1983-84	0.718	0.924	2.511	3.203	6.638
1984-85	0.888	1.029	3.106	3.967	8.102
1985-86	0.817	1.116	3.087	4.672	8.875
1986-87	0.774	1.363	3.447	4.255	9.064

Source: Annual Report 1986-87.

Table 6: Cargo Imported and Exported by Ship, 1982-87

Year	Imports		Exports	
	Petroleum products (million litres)	General Cargo (tonnes)	General Cargo (tonnes)	Copra (tonnes)
1982-83	3.74	5,339	270	165
1983-84	3.84	2,751	218	160
1984-85	1.99	2,576	520	64
1985-86	4.16	2,713	138	118
1986-87	3.08	2,451	130	74

Source: Annual Report 1986-87.

The Cocos economy relies heavily on imports from the mainland and public finance. Imports include building materials, foodstuffs etc and petroleum products. Exports are limited to general cargo and copra until 1987 when production ceased (Table 6).

Tables 5 and 6 show large imbalances in the ratio of imports to exports and of expenditure to revenue. In this sense the Cocos economy has some parallels with the 'import and aid' economies of the Pacific atoll states and territories such as Kiribati, Tuvalu, Marshall Islands and Tokelau with their dependence on imports and outside aid.

2.5.3 Subsistence

The subsistence sector on Cocos is small since the Co-operative Society has virtually guaranteed wage employment to all eligible Home Islanders. South Island, Horsburgh and some of the smaller islands are currently used by the Home Islanders for small scale subsistence agricultural activities and family plots have been established for the raising and breeding of poultry. Although there is now no copra industry coconuts remain an important source of food and fibre. The lagoon supports a substantial domestic fishery.

2.5.4 Land Use and Local Productivity

Maps of existing land uses are included in the NCPA-DASET (1992) report. The distribution of land uses is summarized in Table 7. Areas have been extracted from the Cocos GIS Database.

Land classified as open space occupies 100% of the land area of North Keeling and approximately 83% of South Keeling. North Keeling is largely covered by *Pisonia grandis* and *Cocos nucifera* forest with areas of broadleaf trees and scrub (mainly *Pemphis*). The islands of South Keeling support a dense cover of coconut palms and in some areas remnant broadleaf forest. The coconut palms initially grew in plantations of various ages and heights and were used for the production of copra. Presently beneath the palms there is a dense scrub and sprouting palms, though in some areas, notably on Home, Horsburgh and West Island there is a low ground cover of grasses and herbs beneath the palms. Along the seaward shore the coconut palms are edged by thickly growing *Scaevola* and on the lagoon shore by *Pemphis* scrub.

Agricultural activities are limited since the copra industry closed down. A horticultural block, some 6.5 hectares in area, was established on West Island in 1987. It supplies a range of products to the local market on both West and Home Islands. There are t small horticulture blocks on Home Island. One of these is not currently in productic except from chicken runs and a plantation of fruit trees, but the other to the south of the kampong, supplies fresh produce locally.

Table 7 shows that land uses associated with administrative, transport and communications functions of the Territory occupy the second largest area (11.16%). These are concentrated on West Island. Residential, commercial and associated land uses are limited to Home and West Island; the total area of 'urban' land represents about 3% of the land area of South Keeling.

2.5.5 Land Value

In 1978 all land in the Territory, except for Lot 14 on Home Island (on which Oceania House, the mansion built by Clunies-Ross in 1893 is located) was purchased by the Australian Government from the Clunies-Ross family for over $6 million, which gives an indication of land value at that time. In September 1983 title to all land (with the exception of land used for Commonwealth purposes and Lot 14) was transferred to the Islands Council. This land is still held in trust for the community by the Council. At

Table 7: Existing Land Use (hectares)

Island	Open Space	Urban etc 1	Rec-reation	Admin & Utilities 2	Horti-culture	Roads etc 3	Total
North Keeling	121.67	-	-	-	-	-	121.67
<u>South Keeling</u>							
Direction	29.06	-	0.15	-	-	-	29.21
Home	61.09	16.44	1.90	2.80	0.29	8.01	90.53
Pulu Kechil to Pulu Labu	65.90	-	-	-	-	-	65.90
South	363.30	-	-	-	-	-	363.30
Pulu Klapa Satu, Blan, Madar	6.84	-	-	-	-	-	6.84
West	447.93	27.02	8.53	142.01	6.30	9.25	641.04
Horsburgh	100.20	-	-	-	-	-	100.20
Total South Keeling	1074.32	40.46	10.58	144.81	6.59	17.26	1297.02
Total Cocos	1195.99	40.46	10.58	144.81	6.59	17.26	1418.69

Source: Data extracted from Cocos GIS Database.

1. Includes residential, community facilities, commercial, industrial and extractive uses (incl gravel pit, sand pit).

2. Includes administrative and utilities, including cemetaries, rubbish tip, wind generator (on Home Island) and airport, meteorological station, transmitter, receiver sites (on West Island).

3. Roads, carparks and vacant urban land.

present Lot 14 is the only freehold land on Cocos; it recently changed hands for over $1 million.

2.5.6 Heritage and Cultural Assets & Values

There are presently two places affected by the *Australian Heritage Commission Act 1975*. This Act established the Register of the National Estate and provides that the Commonwealth may not take any action affecting a place on the Register unless there is no feasible or prudent alternative.

North Keeling Island was entered in the Register of the National Estate in 1990. Oceania House (and its surrounds) on Home Island is on the interim register.

Other sites of cultural historic interest but which have no formal heritage status include the cemetries on Home and West Islands, several memorials on West Island, gun emplacement on Horsburgh Island, the remains of the former cable station on Direction Island and the wrecks of the *Phaeton* and a catalina flying boat south of Horsburgh Island. NCPA-DASET (1992) notes that these places of historic interest provide the islanders with tangible evidence of the history of Cocos (Keeling) Islands.

2.5.7 Conservation Values

These were discussed in Section 2.4 where it was noted that while a strong case can be made for the conservation of North Keeling, the case is not so compelling for South Keeling. Three special ecological areas with conservation values were identified by NCPA-DASET (1992); North Keeling, Horsburgh and South Islands.

(1) North Keeling. The island of North Keeling retains most of its natural vegetation. It is largely covered by *Pisonia grandis* and *Cocos nucifera* forest with large specimens of *Cordia subcordata*. It is well known as a seabird rookery with 11 species breeding there out of a total of 19 bird species recorded on the island. The dominant bird species is the Red-footed Booby *(Sula Sula)* which maintains on North Keeling one of the largest breeding colonies in the world. Thirteen species of birds recorded on the island are listed in the Japan-Australia or China-Australia Migratory Bird Agreements. The island is the only locality where the endemic Cocos Buff-banded Rail *(Rallus phillipensis) is* found. Though North Keeling remains the only example in the Indian Ocean of a seabird colony unaffected by feral animals and only minimally visited by humans, it does not have any formal reserve status. However, wildlife is protected and visits are regulated by the Cocos Islands Administration. The Australian National Par[illegible] and Wildlife Service considers that the island is of significant conservation value a[illegible] two House of Representative Committees have recommended that it be declared [illegible] national park or nature reserve under the *National Parks and Wildlife Conservation Act 1975*.

The wreck of the SMS Emden, on the southern reef edge of North Keeling, is protected under the *Historic Shipwrecks Act 1976* with a 500m radius protected zone around the wreck site.

(2) Horsburgh Island has been modified through coconut plantings but significant areas of the original native vegetation, and the only mangrove community in the Territory, exist on the island. NCPA-DASET (1992) consider that Horsburgh Island should be reserved for conservation purposes, with traditional recreational uses retained and native vegetation and marine reef flats protected.

(3) South Island. Because South Island contains small areas of remnant vegetation and two breeding bird colonies of local significance, NCPA-DASET (1992) consider that the island should be reserved for conservation purposes and allow traditional recreational use while protecting the water lenses for future supply to settled areas.

2.5.8 Capital Investment and Infrastructure

In 1989 DASETT provided an indicative capital works program for the six years ending 1993-94 which showed total capital expenditure of between $650,000 to $3.15 million per annum (Commonwealth Grants Commission, 1989). Expenditure on earlier capital works and services programs, 1981-87 is given in Table 5. Capital investment and infrastructure is concentrated on Home Island and West Island.

(1) Home Island

In December 1983 the Commonwealth Government and Islands Council began a $10 million housing replacement program on Home Island to be spread over 10 years. The Home Island Development Plan involved replacement of over 80 houses and provision of utitlity services and is now virtually complete.

Electric power is supplied to the island by a diesel operated power station and a 17kw wind generator. Generating capacity is some 260kw with a 100% backup capability. There is a water reticulation system, supplied from a freshwater underground lens supplemented by tanks catching roof run-off. Consumption of reticulated water is understood to approximate 300 litres per head per day. The sewerage system is septic tanks linked to one large holding tank with a single outlet to the sea on the northern side of the island. The system has been installed only in recent years.

Home Island is the focus for marine activities in the Territory. It has a jetty, storage depot and vessel maintenance facility. A barge, landing craft, ferry and other vessels run by the Co-operative Society are based there. The island is also the headquarters of the Islands Council and Co-operative Society with recently completed administrative and community buildings.

(2) West Island

There is an international standard airfield on West Island. The air terminal is a small building which offers little in the way of services to passengers. A new terminal with international services has recently been completed. The airport area is on Commonwealth owned land which also includes the adjacent residential area, Quarantine Station, and communications facilities (receiver and transmitter sites). The recently installed RAAF receiver site is located towards the southeastern end of the island.

Electric power is supplied by a diesel operated power station with a 560 km capacity and full backup capability, and there is a backup diesel generator at the CAA transmitter site towards the north of the island. The power reticulation system is entirely underground.

Freshwater on West Island is reticulated from an underground lens, and supplies are regarded as plentiful and of good quality. Water bores are located on Council owned land licenced to the Commonwealth midway between the settlement and the northern tip of the island. Consumption is approximately 600 litres per head per day. The West Island sewerage system uses septic tanks, effluent from which is fed to holding tanks and from there out to sea. The holding tanks are small, each serving only a few houses. The outlets to the sea discharge onto the beach near the settlement. The system is generally old but the pipes are progressively being replaced with PVC.

There is a concrete jetty on the lagoonside of West Island towards its northern tip and the Sydney Highway, which stretches from the jetty to the settlement is fully sealed as are the roads within the settlement. Fuel storage tanks are located near the jetty.

Table 8: Indicative Value of Some Capital Assets

Capital Asset	West Island Asset Value ($000's)	West Island Replacement Value ($000's)	Home Island Asset Value ($000's)	Home Island Replacement Value ($000's)
Administration Offices [1]	1,050	1,680	-	-
Education & Health Services [2]	1,200	2,500	1,150	1,850
Works Depot [3]	1,415	3,005	-	-
Airport Services [4]	2,694	21,830	-	-
Electricity Supply [5]	1,020	800[6]	1,047	1,200[6]
Water & Sewerage [7]	NA	60	725	NA
Marine Services [8]	280	4,100	800	600
Residential Buildings [9]	5,040	9,450	10,700	13,650
Recreation Facilities [10]	730	2,200	-	-

1. Includes main office area, PO, CAA building, meteorological station.
2. Includes schools, hospital, medical centre etc.
3. Includes service store, mechanical workshop, storage sheds and yards, incinerator.
4. Includes terminal, runway, navigation aids, fire station.
5. Includes powerhouses, generators and wind generator (Home Island).
6. Excludes generators.
7. Includes water bores and storage tank (Home Island)
   NA = not available.
8. Includes jetty and lighthouse (West Island) jetty and marine centre (Home Island). Does not include navigation aids, channel markers, jetty and beacon on Direction Island totalling ($920,000).
9. West Island includes Government House and an estimated 63 buildings; asset value calculated at $80,000/building and replacement value at $150,000/building. Home Island estimate based on 91 buildings.
10. Includes cyclone refuge.

Table 8 summarises the book value of some of the fixed assets on Cocos from a list provided by DASET. Note that the summary does not include buildings associated with Oceania House, the Quarantine Station facilities or the extensive assets owned by the Co-operative Society and Islands Council, though buildings in the Home Island Development Plan are included.

2.5.9 Legislation and Administration

Sovereignty over the islands was formally transferred from the UK to Australia with the passage of the Cocos (Keeling) Islands Act 1955, when Cocos became a territory of Australia. In 1979, through the Local Government Ordinance, the Cocos (Keeling) Islands Council, the Cocos-Malay Community's local government arm, and the Cocos (Keeling) Co-operative Society, the community's commercial and business areas were established. In 1984 the Cocos Malay community voted to integrate with Australia. The Government undertook to bring its standard of living and levels of services in the Islands to comparable mainland standards not later than 1994.

Achievement of comparable mainland standards requires major law reform, upgrading of a range of Government works and services; application of mainland employment conditions; upgrading of work force skills; extension of Government assistance programs and taxation, and reform of local government powers and finances.

In 1991 a report of the House of Representatives Standing Committee on Legal and Constitutional Affairs (1991) found that the current legal regime of Cocos was "seriously inadequate and inappropriate". The Committee identified several options for reform and indicated there was general agreement that West Australia law be applied. This proposal was favoured for several reasons including the close links between Cocos and Western Australia and recognition that under this arrangement the Commonwealth's plenary powers to make laws for the peace, order and good government of the Territory would be preserved.

In September 1991 the Commonwealth Government responded to the Standing Committee's report, agreeing that the existing legal regime on Cocos would be replaced by a contemporary body of living law based on the mainland regime by 1 July 1992. In essence the Government decided to extend remaining Commonwealth laws to the Territory to the maximum extents practicable. As well it decided to apply a body of State type law based on the laws of Western Australia.

On 1 July 1992, a significant number of Western Australia Acts and the majority of Commonwealth Acts were applied to Cocos. Some 130 WA Acts were suspended in their application to Cocos (and Christmas Island) to allow time for further consultation with the Island community on these laws with the intention that they will be progressively applied by 1 July 1993. Included in the new laws are those that deal with land use planning.

Draft Land Use Plans were drawn up by NCPA-DASET on behalf of the Islands Council and were released on Cocos in March 1992. After a consultation process that took into account local social and economic issues and environmental and resource limitations and opportunities, the *Cocos (Keeling) Islands Land Use Plan and Planning Scheme June* 1992 was prepared. This document was endorsed by the Islands Council and *Part 11 Planning Scheme* (the necessary statutory document) has been approved by the Minister for Arts and Territories. The Planning Scheme was prepared in a format appropriate for Planning Schemes prepared under appropriate Western Australia Acts and Regulations, which now apply to the Territory.

3. IDENTIFICATION OF RELEVANT DEVELOPMENT FACTORS

RSWG (1992) notes that within the concept of vulnerability the nature and extent of future human activities play a critical role. This poses the problem of development of human activities in time, as the judgement with respect to potential vulnerability to accelerated sea-level rise can be greatly influenced by demographic and economic change. However, RSWG (1992) argue that, because of the time horizons involved in the effects of climate change becoming clearly manifest, it would not be realistic to make actual projections for economic, demographic or natural developments. On the other hand they feel that "ample consideration should be given to the possible consequences of such developments."

Thus RSWG (1992) proposes that the most relevant development factors should be considered as *scenario variables,* which 'drive' the assessment of socio-economic and other impacts. Thus step 3 of the Common Methodology considers a number of autonomous developments including:

- population size and distribution
- land use and level of production activities
- level of capital investment
- natural values habitat types and areas

For the vulnerability assessment case studies the RSWG (1992) proposes the use of a time horizon of 30 years.

3.1 Development Factors on Cocos

It is obvious from the previous section that Cocos is presently at a watershed in its development. However, the recently adopted NCPA-DASET (1992) Land Use Plan and Planning Scheme can be used as a basis for the development scenario over the 30 year time frame. This report distinguishes between a preferred Land Use Plan (and its statutory version, the Planning Scheme) which is concerned primarily with the short-term matters likely to arise in the next 5-10 years, and Land Use Options as a long-term planning strategy, which we see as most relevant in the present context.

The land use options for Cocos include:

- possible tourist developments
- additional housing
- expansion of commercial and industrial areas
- foreshore protection strip
- relocation of rubbish dumps

While NCPA-DASET (1992) suggest that these options should all be considered now "it is not intended that the options finally adopted should all be incorporated in the preferred Land Use Plan at the same time". Instead they suggest that the land use options should be considered in conjunction with the planning and development principles which are articulated in the report and which reflect both short-term and long-term considerations. These principles are concerned with such matters as tourist accommodation, housing, rural and non-urban areas, environment and conservation and social and economic considerations.

3.2 Population Size and Distribution

Projections of future population size and distribution are not included in the NCPA-DASET (1992) report. However, the report does identify a number of inter-related factors and trends that link employment and population change.

Since copra production ceased in the mid 1980s the Islanders have become almost totally dependant on government contracts for employment including a number of capital works projects undertaken to raise the living standards of the Islanders to mainland equivalent levels. These projects have now been mostly completed. As a result direct employment is diminishing. At the same time population growth on Home Island over the last 5 years has been slight. As wages increase, due to full integration with the mainland, significant unemployment can be expected if new employment opportunities do not occur. This could result in some outward migration. Similarly, the population of West Island has diminished overall during the last decade, a trend that may continue unless new employment opportunities are created on the island.

The NCPA-DASET (1992) report recognizes that some redistribution of population between Home Island and West Island is possible in the future. At present most Cocos Islanders live and work on Home Island and a number travel to West Island to work. Reduced employment on Home Island and increased employment on West Island could result in Home Islanders wishing, for reasons of convenience, to live on West Island if suitable housing is available.

While some additional housing could be accommodated on Home Island, without alternative water supplies or change in water use patterns, "Home Island must be seen as having a limited capacity for further residents" (NCPA-DASET, 1992). On the other hand, West Island should, due to its better water supply and range of existing facilities, be the preferred island should there be future pressure for significant amounts of housing.

In summary, NCPA-DASET (1992) do not forecast a significant increase in the resident population of Cocos. Rather they see outmigration from Home Island as a possibility while making provision for additional housing if required. Dependant on future employment opportunities on Cocos, this population movement may be either to the mainland or alternatively to West Island.

3.3 Socio-economic Considerations

Underlying the discussions of planning issues is the need for future economic developments to stimulate the local economy while at the same time recognizing the need for all development to conserve natural resources, to protect the quality of the environment and to respect cultural values.

The Commonwealth Grants Commission's 1989 report on Cocos suggests that tourism offers the most likely prospect for economic growth. A viable tourist industry is also perceived by many on Cocos as a necessary source of future employment and income.

It is expected that tourism will provide increased scope for the expansion of sustainable private sector activity and reduced dependence on government support. While tourism may offer the prospect of employment with resort development and could assist expansion of commercial activities, there are a number of potential problems associated with developing a viable tourist industry including the fact there can be no expectation of self-sufficiency in local food production, and that the local economy is highly vulnerable to fluctuations in prices for imports, transport costs, weather conditions etc. These, together with other financial and cultural constraints and infrastructure problems are discussed in the House of Representatives (1990) report on *Tourism in the Indian Ocean Territories*.

3.4 Land Use Patterns and Productivity

The preferred land use plan and planning options and principles enunciated by NCPADASET (1992) provide a relatively firm basis on which to forecast future land use and to assess potential vulnerability.

The plan creates two major land use types: Reserved Land and Land Use Zones. Reserves are identified for nature conservation, foreshore protection, marine protection, common useage and administrative purposes. Land Use Zones are for housing, community, recreation, commercial, tourist, industrial and rural purposes. Scheme maps are presented in NCPA-DASET (1992) and Table 9 summarizes proposed uses on each island and Table 10 the areas involved on Home and West Islands.

(1) Land Use Zones

The plan shows as firm proposals two tourist developments, the West Island scheme put forward by the Co-operative Society and the scheme to develop approximately half of Direction Island for tourism. The Council would also have discretion to approve tourist facilities elsewhere on Direction Island, on the small islands lying between Home and South Island and within the open space/rural area of West Island.

The plan allows for some additional housing on Home Island and West Island and a modest expansion of the commercial and industrial areas on these islands. The open space/rural areas of West Island, while suitable for a variety of recreational activities, are envisaged as being predominantly for rural production. Recreational land is identified on the Home, West, Direction Island as well as the smaller islands between Home and South Island and between South Island and West Island.

(2) Reserved Land

Land and waterways reserves identified in the plan have several purposes. Reserves for administrative purposes include the international airfield and adjacent facilities, quarantine station, communications facilities etc and are concentrated on West Island. Undeveloped land on Home Island is proposed to be "Common", which would be shared for community and recreation uses. North Keeling, Horsburgh and South Island are recommended to be reserved for nature conservation. Of these three islands North Keeling is regarded as a special case. Both the House of Representatives (1990) report on tourism and the House of Representatives (1991) report on legal regimes recommended that North Keeling be declared a national park or reserve under the *National Park and Wildlife Conservation Act, 1975*, the latter indicating that "the status of North Keeling requires urgent attention". The plan also envisages that the marine resources of the southern atoll lagoon and reef flats will be protected by careful management.

A need for foreshore protection, particularly aimed at minimizing erosion is identified for all of the islands, though in the plan Foreshore Protection Reserve is only mapped around the perimeter of Home and West Islands. The reserve would be a strip of land, generally 20m wide, and should be managed to minimise erosion and control activities which could disturb the natural form of the foreshore. Although Foreshore Protection Reserves are not shown elsewhere, it is intended that foreshore protection objectives will be set out in other relevant reserves and zones in the planning scheme and be observed by the Council and the Commonwealth in making management and development decisions

3.5 Capital Investment Levels

If, as the Commonwealth Grants Commission (1989) suggests "the Territory's economy will eventually be based on tourism" and resort developments along the lines of those proposed in the scheme plan eventuate, there will be a substantial increase in the capital assets on Cocos which will require some expansion of infrastructure. For instance, an earlier proposal for a tourist resort on Direction Island indicated a need for upgrading airport infrastructure at an estimated cost of $1.57 million.

Table 9: Land Use in Draft Planning Scheme

Island	Reserved Land				Zones			
	Nature conser-vation	Foreshore protection	Common	Admin-istration etc	Residen-tial, comm etc	Tourist	Recre-ation	Rural
North Keeling	X							
South Keeling								
Direction Is						X	X	
Home Is		X	X	X	X	X	X	
Pulu Kechil to Pulu Labu							X	
South Is	X							
Pulu Klapa to Pulu Maraya							X	
West Is		X		X	X	X	X	X
Horsburgh Is	X							

Table 10: Land Use Plan Areas - Home and West Islands

Land Use	Home Island	West Island
Reserved Land		
Nature Conservation	-	-
Foreshore Protection	12.04	74.71
Common	50.72	-
Administrative Purposes	0.66	124.12
Zones		
Housing	13.84	11.52
Community	1.41	2.87
Recreation	2.53	15.70
Commercial	0.56	1.35
Tourist	-	9.59
Industrial	2.56	6.38
Vacant Urban	6.25	1.60
Roads	-	7.07
Rural	-	366.77
Total	90.57	621.68

Source: Data extracted from Cocos GIS Databse

While other public and private capital investments will likely flow from the development of tourism, the intention is that, at least on Direction Island, the resort will be 'self-contained' in terms of services and utilities (eg power generation, water supply, sewage disposal) while on West Island the proposed tourist development could take up some of the 'spare capacity' on that island. The former development is unlikely to proceed until experience of the Co-operative Society's proposed West Island facility is evaluated. Moreover, because of the upgrading of municipal facilities and utilities as part of the capital works program during the last few years no substantial expansion should be necessary, at least in the near future Those developments that are noted in the land use plan relating to housing, commercial and community facilities, tourism, utilities and infrastructure are concentrated on Home Island, West Island and Direction Island.

At present the primary strategic significance of the Cocos (Keeling) Islands to Australia flows from the value of its airfield, though the islands could be potentially useful in terms of surveillance and intelligence collection (Babbage, 1987). Whether any defence-related facilities, beyond the recently installed RAAF receiver site on West Island, are contemplated is not known.

3.6 Development and Environmental Problems

In the foregoing analysis of development factors we have hesitated to forecast the pattern of population change and socio-economic development over the next 30 years because at the present time the Cocos (Keeling) Islands are in a state of flux (see section 2.5). Regardless of whether or not there is a significant expansion of tourism over the next few years, there are a number of contemporary and potential environmental problems that NCPA-DASET (1992) identify. These include deterioration of ground water supply and quality on Home Island, waste disposal and the siting of rubbish tips, degradation of reefal areas around sewage outfalls, exploitation of the lagoon fishery and coastal erosion particularly on West Island.

In addition the Commonwealth Grants Commission (1989) noted that "a further environmental function which must be performed relates to the control of coconut trees on the islands" (p 78) and argued that uncontrolled growth increases water use by vegetation and inhibits recharge of freshwater lenses.

Of these problems only one, coastal erosion, is likely to be exacerbated by future sea-level rise.

4. ASSESSMENT OF PHYSICAL CHANGES AND NATURAL SYSTEM RESPONSES

Step 4 of the Common Methodology begins the actual vulnerability analysis. It is initially concerned with an analysis of physical changes and natural system responses to sea-level rise, followed by an assessment of impacts on socio-economic and ecological systems resulting from those changes and responses (RSWG, 1992).

The effect of rising sea level on the reefal islands and groundwater systems of Cocos are addressed in the following sections. But in our view it is important to discuss these effects within the context of ongoing contemporary processes including the role of storms in island development, as well as past changes because both influence to some degree how the atoll will respond to sea-level rise.

At the outset however, it must be recognized that the islands on Cocos are composed of biogenic sediments produced on the reef and in the lagoon. These sediments are continuing to be produced, from the breakdown of dead coral and other organisms, and as sediment does not appear to be accumulating on the reef flat, it is presumably continuing to be supplied to the shoreline. For this reason, the reef islands are dynamic, and continually evolving.

On Pacific atolls, reef islands can be divided into a number of island types; a major division is into motu (the Polynesian term for island), which are often sand islands with shingle ridges on the more exposed atoll rim, and cays which are sandy islands in the more sheltered locations (Stoddart and Steers 1977). On Cocos the majority of islands are sandy, though shingle and rubble occurs on the oceanward shore of islands on the eastern rim and elsewhere.

4.1 Role of storms in island development

The sediment composition, morphology and stability of reef islands varies according to a series of factors, a major one of which is the frequency and intensity of tropical storms. Islands may be in a stable equilibrium with the processes which are acting upon them, but more typically, given the changeability of processes through time, they are in a dynamic equilibrium. The concept of dynamic equilbrium of reef islands has been examined by Bayliss-Smith for islands on the atoll of Ontong Java in the Solomon Islands (Bayliss-Smith 1988). His ideas have been modified to include a range of atolls, and the morphology and response to storms for each of islands in seas where storms are frequent, occasional and rare, are examined in Figure 18.

Some islands may be in a stable equilibrium with neither addition nor loss of sediment. However, on most islands, sediment is added and lost over time, and there is more likely to be a dynamic equilibrium between inputs and outputs. Islands adjust over a range of timescales. They may adjust to seasonal changes; thus in the Maldives the seasonal reversal of the prevailing monsoon can lead to sediment accumulation at one end of an island for a part of the year, and its redistribution to the other end for the rest of the year. Catastrophic storms play an important role in both construction and destruction in those areas which experience hurricanes over a longer timescale (Stoddart 1971b), though the effect of these episodic but high magnitude events is also likely to differ on different types of island. Sand and shingle motus, typical of high-energy settings of atolls which experience storms, are built up in part by rubble-sized material moved by storms onto the reef flat. The impact of Hurricane Bebe on the atoll of Funafuti, Tuvalu has been studied in particular detail (Maragos et al. 1973). A rubble rampart, composed of corals ripped from off the reef front, was thrown onto the reef flat or onto the elongate reef islands, adding about 10% to the total land area of the atoll. Regular, less severe storms have broken down and redistributed the storm rubble landwards (Baines et al. 1974; Baines and McLean 1976a, 1976b). Rubble is usually an important constituent of a well-developed conglomerate platform beneath islands, a

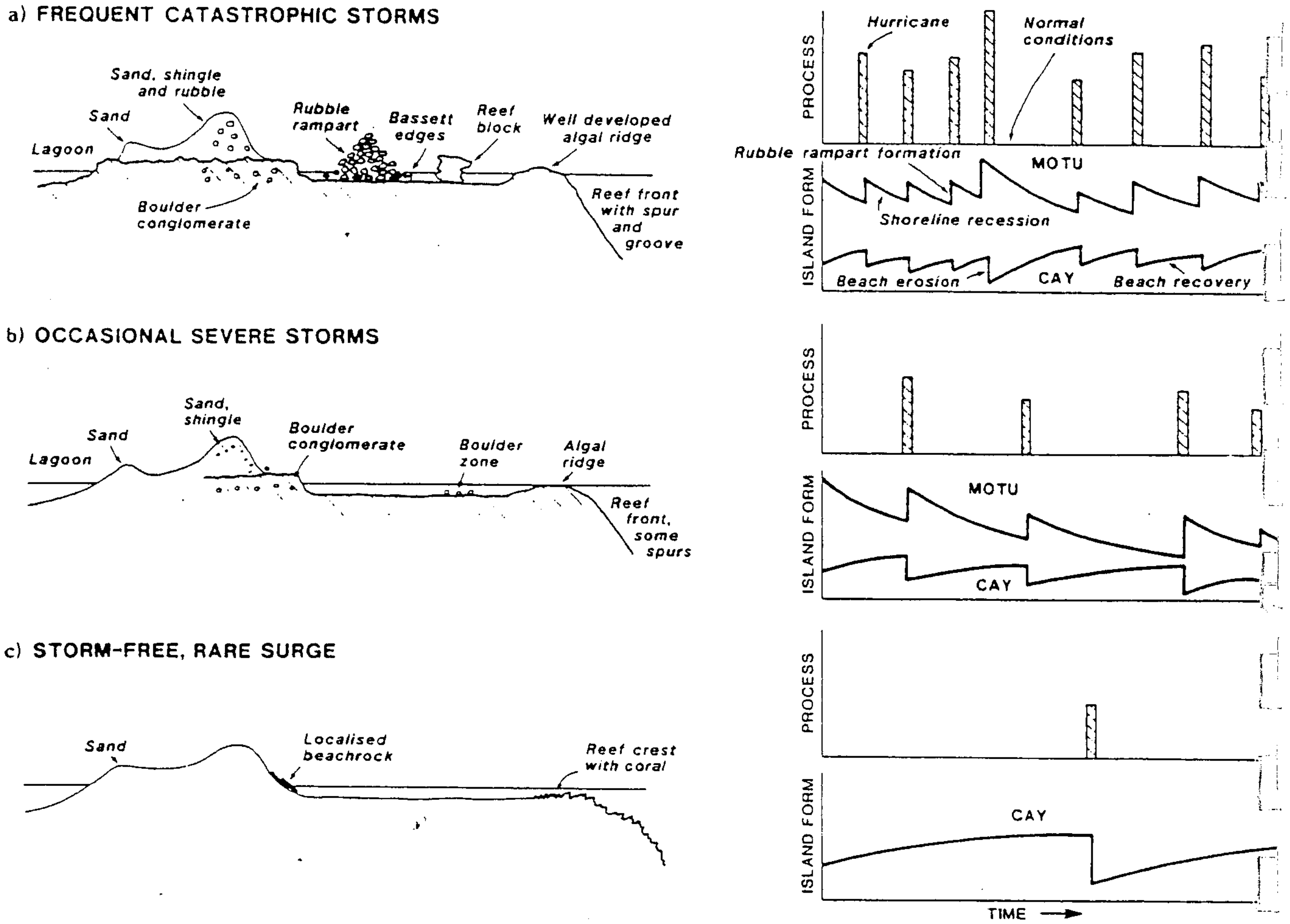


Figure 18 The morphology of reefs and reef islands in areas of different storm occurrence, and the response of form to process (from Woodroffe 1989).

legacy of past storms. Sand on the other hand tends to be stripped off islands by storms, but to be moved back onto islands by the more regular processes that operate between storms.

Not all islands are affected equally by storms and the morphology of islands differs accordingly (McLean 1980). Figure 18 illustrates schematically some of the features of the morphology of islands in areas of different storm frequency and intensity. Strong tradewinds outside hurricane belts can also serve to modify islands, as in Kiribati or the Maldives where storms of hurricane force are not frequent. Where storms are frequent, reef flats generally contain rubble ramparts or degraded rubble deposits on the motus on the more exposed side of the atoll. There is a well-developed algal ridge, and conglomerate platforms are prominent and may extend across much of the reef flat, underlying entire islands (i.e. northern Cook Islands); sand cays are found in the less exposed areas. Where storms are not as frequent or as severe, there are less extensive rubble deposits; the algal ridge is less prominent and the conglomerate platform is not as extensive across the reef flat (i.e. Cocos (Keeling) Islands; some islands in Kiribati). In storm-free, low energy areas, rubble is not a major component in island construction; instead sand cays are found even on the outer atoll rim (i.e. many islands in Kiribati, Maldives).

Figure 18 also depicts a series of schematic responses of island form to processes (modified from Bayliss-Smith 1988, after Woodroffe 1989b). Storms result in loss of sand from cays and motus, but an input of rubble to the motus in the form of ramparts. The motus which receive an input of rubble adjust with the medium-term breakdown and redistribution of that material as they return to equilibrium. Cays lose sand during storms, but are rebuilt towards equilibrium by beach recovery through normal processes. Relaxation time (time taken to readjust between high energy events) and recurrence interval (frequency of such events) are important in controlling reef island morphology. When storms are very frequent (or very severe) motus and cays may be in disequilibrium for most of the time. When storms are occasional, complete recovery is possible between storms and islands may be in dynamic equilibrium. Where there are no storms cays should reach a stable equilibrium; a rare disturbing event such as a storm surge, can cause devastation on these islands, and such catastrophes will require a long time for recovery.

Note that at the present time we believe the Cocos (Keeling) Islands most closely equate with category b) in Figure 18.

4.2 The effects of rising sea-level on atolls

If sea level rises then the effects most commonly predicted for atolls are shoreline erosion, flooding of low-lying areas, and saline intrusion into the freshwater lens. Below we consider the likely impacts on the reefs, the reef islands and on the groundwater lens of the Cocos (Keeling) Islands.

4.2.1 Effects on reefs

Massive corals can grow at rates of 5-25 mm/yr, and branching corals up to 100 mm/yr. Reefs, on the other hand, grow more slowly (Hopley 1982). When the sea rose at 10-12 mm/yr during the post-glacial marine transgression (in the early Holocene, around 10,000 years ago), only a few reefs (such as those on Huon Peninsula, New Guinea, where the land is being uplifted) kept up. Exceptionally a reef may accumulate at up to 16 mm/yr, where storm accumulation has occurred and branching corals comprise the matrix. At one location on Cocos, our stratigraphic dating has indicated reef growth rate (or at least vertical accumulation rate) of 25-30 mm/yr (Woodroffe et al., ARB); but this is exceptional, and nowhere does the Cocos reef appear to have been able to keep pace with postglacial sea-level rise. The most rapid reef growth rate consistently recorded on the Great Barrier Reef, determined both from stratigraphy and chronology of reefs, and measurements of calcification rates from water chemistry, is 7-8 mm/yr, and this rate seems to occur most commonly in water depths of around 5m (Buddemeier and Smith 1988; Hopley and Kinsey 1988). On atolls reef growth rates up to 5 mm/yr are characteristic, with rates of up to 8 mm/yr recorded locally (Marshall and Jacobson 1985; Woodroffe et al. ARB).

Little change would appear likely to occur on the reef front or reef crest in the initial stages of sea-level rise. Perhaps the most conspicuous response that has been suggested for reefs generally will be the recolonisation of extensive areas of presently bare reef flat by coral (Hopley and Kinsey 1988). Reef flats throughout the Indo-Pacific typically only support sparse coral cover, and more often support a veneer of coralline algae. This in many cases reflects the slight emergence that has occurred as a result of a lowering of relative sea level in the late Holocene, which is our interpretation of the case in Cocos (Woodroffe et al., ARB). These may revert to mature coral-covered reef flats in the first 50-150 years of sea-level rise; and in the longer term may become more similar to the less-frequently exposed, coral-dominated backreef areas characteristic of West Indian reefs where sea level has been rising for the last few thousand years (Hopley and Kinsey 1988).

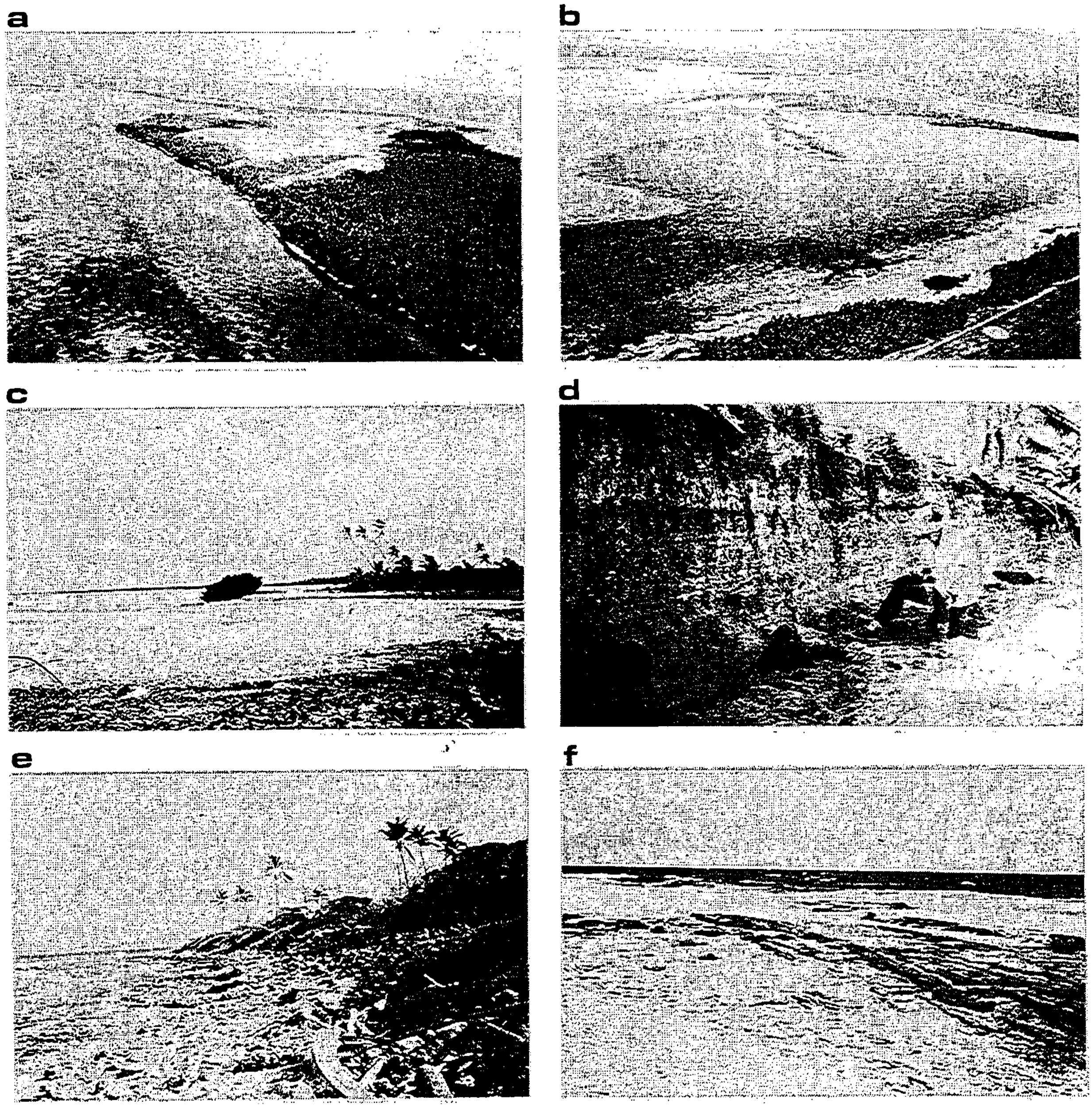


Figure 19 a: Telok Jambu, West Island viewed from the north, b: Telok Kambing, West Island viewed from the west, c: Sheltered telok on South Island with stand of *Pemphis* on ridge at the mouth of lagoonlet, d: Ocean-dipping bedding revealed in trench on Home Island, e: Rubble-strewn shoreline on Pulu Wak Banka, f: Arcuate ridges, southern North Keeling; these appear to have been termed former reef margins by Guppy, but are reinterpreted as beach conglomerate marking foot of former rubble-strewn beaches.

It will depend upon the rate that the sea rises in the future, and upon the healthiness of the reef, as to what extent the Cocos reefs are able to either catch up or keep up with sea-level rise. Recent projections of sea-level rise by the IPCC range from 4.4-5.5 mm/yr for best estimates and these rates seem unlikely to exceed the rates at which healthy, windward reefs could be expected to grow. Nevertheless, the Cocos reefs have a very sparse cover of living hard coral (perhaps as a result of the crown of thorns starfish as suggested by Colin (1977), though this is reviewed by Marsh, (ARB); more likely related to the periodic coral kills described above). Areas in which coral was described by Darwin now seem much barer (eg. reef crests in which he described *Millepora*, and lagoon reefs). Some areas may be bare of coral because of human impact (though for the majority we see this as caused naturally); one example is the reef flat off West Island, which receives a heavy nutrient load from the island, and has extensive sea grass and algal cover, suggesting eutrophication. The Cocos reefs do not seem well prepared to catch-up, yet alone to keep-up, with future sea -level rise and it will be necessary for hard corals to recolonise extensive areas before the reefs realise their full growth potential. Furthermore, tropical storms can have a devastating, almost instantaneous, impact on reefs, from which it may take a long time to recover, with inputs or losses of sediment that are equivalent to decades of reef accretion.

4.2.2 Effects on reef islands

The areas of reef islands which are lowest lying at present are often subject to extensive inundation at exceptional high spring tides or by storms or surges. These areas occur around the eastern end of West Island, and around teloks in particular (Figure 19a-c). Further flooding of the lowest-lying parts of islands is likely to occur under higher sea level. These areas are generally dominated by *Pemphis acidula*, which appears to be stabilising spits of muddy sand that are encapsulating the lagoonlets.

However, it is not clear to what extent reef islands will erode, or whether sediment from the reef front or reef flat will contribute to continued growth of islands. There are at least three responses of islands which can be envisaged in the face of sea-level rise. These are illustrated in Figure 20, and consist of i) the Bruun response, ii) the equilibrium response, and iii) continued growth.

a) Bruun response: The Bruun rule is an empirical observation that in order to maintain an equilibrium shore profile as the sea rises, sediment will be eroded from the beach and shoreface and deposited on the ramp beyond the toe of the beach (Bruun 1962, 1988). The width of the beach eroded depends upon the amount of sea-level rise and the beach slope, which is postulated to have reached an equilibrium reflecting the mutual adjustment between sediment and processes, minimising the expenditure of wave energy (see Figure 20b). It is most applicable to clastic beaches, which do not extend across immovable materials, and where the entire profile is thus free to adjust. This is not the case with reef islands, where the lower shoreface comprises a reef flat, constraining the adjustment of the profile, and generally bare of loose sediment. The reef flat would be the region which might be expected to accumulate sediment under the Bruun hypothesis, although reef flats are characteristically areas of sediment transport from reef crest to reef island. The Bruun rule does not take into account the upper boundary of the foreshore, and on this count has been found inadequate for transgressive barrier islands where the theory would postulate sediment accumulation in the offshore ramp, which would mean sediment loss from the barrier as it migrated landwards. Nor does the Bruun rule appear to hold over long-term sea-level rise, such as the Holocene marine transgression, where landward reworking of sand on barrier coasts, presumably by overwash, has been demonstrated (Thom and Roy 1988). It has yet to be demonstrated that this is the response of carbonate beaches where there is an ongoing supply of sediment, although the approach has been adopted in assessing the vulnerability of some atoll shorelines (Crawford et al. 1992).

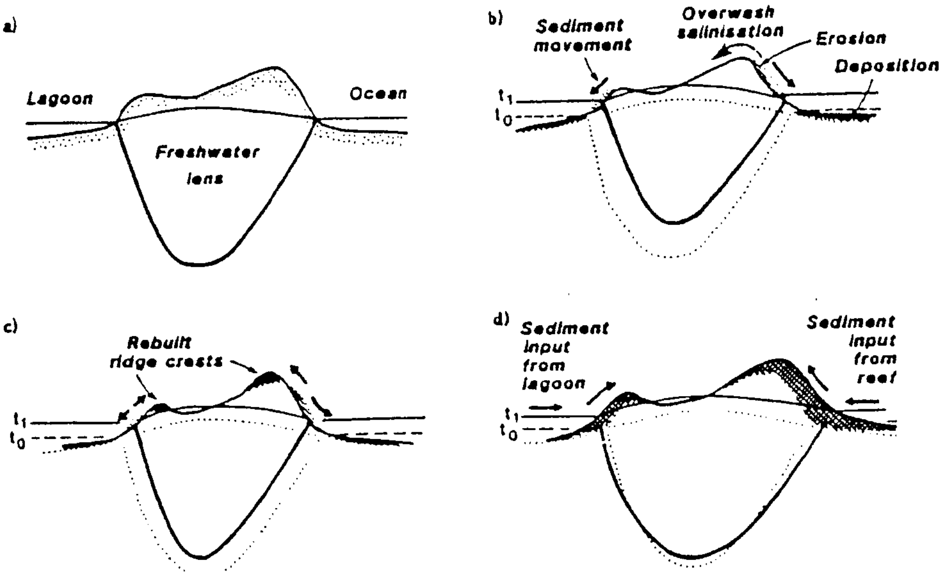


Figure 20 The possible responses of reef islands to sea-level rise. Details in text.

b) Equilibrium response: Oceanward beaches of reef islands are generally characterised by a ridge of sand or shingle, that can be seen as a feature of reef islands around Cocos (Figure 19e). Ridge morphology varies somewhat, presumably in response to the energy the shoreline experiences, a function of both location around the rim and distance from the reef crest. Ridge height is increased where it is topped by a dune. This form appears to represent an equilibrium and an equilibrium response is shown in Figure 20c. If sea level rises at a gradual rate, this equilibrium may be maintained at higher sea levels. The height of the ridge is determined by wave setup and runup height, and these are influenced by the form of the reef crest, reef flat and depth of water (Gourlay 1990). A sea-level rise would increase the wave setup and runup under high energy and high tidal conditions, and this would allow the beach ridge crest to build up to a higher elevation. A postulated response is shown in Figure 20c. As with the Bruun response sediment loss from the foreshore is proposed, but as with barrier islands, some of the eroded sand is redeposited on the ridge crest, building it up and maintaining a profile in balance with the processes dominating the shoreline. Erosion of material from the beachface might occur and some retreat of the shoreline may be likely, although as the angle of the beachface is generally steep, we do not envisage major retreat of the shoreline. Catastrophic retreat of shorelines is only going to occur where sea-level rise is so rapid that large storms which did not overtop the ridge under normal condtions frequently overtop it under the higher sea level. Overwash will be more frequent if storms do not re-establish the equilibrium.

c) Continued growth: The third view of island response to sea-level rise is one of continued growth through sediment accretion (Figure 20d). Greater efficiency of sediment movement may, in the short term, build up islands to match sea-level rise as more energy crosses the reef flat (Hopley and Kinsey 1988). If the sea rises at rates of only a few millimetres a year then reef islands are unlikely to be catastrophically affected; some shoreline erosion is likely, but the continued supply of sediment, both from that erosion, and as a result of enhanced sediment transport and perhaps production on the reef flat, is likely to build the shoreline up into a new equilibrium form.

Three possible responses have been suggested which can be summarised as shoreline erosion, redistribution of sediment on the shoreline, and shoreline accretion. Each of these processes can be observed on Cocos reef islands today. Further research on past phases of reef island development, and on processes of sediment transport on reefs, is needed in order to establish which will occur in the future. Perhaps the most likely response is some combination of all three; beach erosion will continue to be experienced on some reef islands, though it may be interspersed with phases of beach recovery and perhaps net growth, with sediment moving between shoreface, reef flat and beach ridge crest. Once again, the health of the reef, and the extent to which natural routes for sediment movement are disrupted (ie. through engineering structures) will influence the likelihood that reef islands can adjust to higher sea levels.

We now examine two lines of evidence in an effort to resolve which of the above alternatives is more likely. First, we summarise how reef islands appear to have responded to past sea-level changes. Second, we examine the chronology of reef island deposition.

4.2.2.1. Response to past sea-level change

On the basis of our stratigraphic and radiocarbon dating studies on Cocos, we have been able to summarise the late Quaternary development of the atoll. Of particular relevance is the geological development of the atoll rim during the Holocene (the last 10,000 years). The pattern of sea-level change during this period consists of a rapid period of sea-level rise up until 6000 years ago when the sea reached a level close to present. Since then the sea seems to have risen slightly above present, and fallen gradually to its present level. This pattern is characteristic for the Indo-Pacific region (Thom and Chappell 1975; McLean et al. 1978; Geyh et al. 1979; Thom and Roy 1985). We recognise three phases within this period in the development of the atoll. The first phase is one of catch-up reef growth. Reefs grew vigorously during the period 8000-5000 years B.P., but they appear to have lagged behind sea level (See Figure 21; see Woodroffe et al., ARB for discussion). This period of catch-up reef growth resembles what may happen in the future only partially, for the starting point is very different. If the sea rises at accelerated rates in the future, it will come immediately after a gradual fall and after 6000 years within which extensive carbonate deposits have built up close to present sea level. During the postglacial transgression the sea had been rising rapidly for several thousand years when it inundated the last interglacial limestone plateau, there was no pause for reefs to gain momentum. More significantly, we have no evidence that reef islands did exist or indeed could have existed at that time. The second phase was one of reef flat consolidation, and is represented by the conglomerate platform which we interpret to have formed as a reef flat under a higher sea level 4000-3000 years ago. The third phase was one of reef island formation. Reef islands post-date the conglomerate platform, and must therefore be about 3000 years or less old. These last 3000 years were a time during which the sea was gradually falling, as determined from the fossil microatoll record from around the atoll (Woodroffe et al., ARB).

We must ask to what extent it has been necessary for the sea to fall for reef islands on atolls to have accumulated. Though it is still not widely accepted, there is now evidence that the sea has seen a gradual fall over the last 4000-3000 years across most of the Pacific, and much of the Indian Ocean, that is over most of the area within which coral atolls are found (e.g. Gardiner 1903; David and Sweet 1904; Buddemeier et al. 1975; Pirazzoli et al. 1987, 1988; Woodroffe et al. 1990c). Several authors have suggested that it was the emergence of the reef flat as conglomerate platform which provided a suitable substrate for islands to form (eg. Schofield 1977). It is our opinion that the strongest evidence that a fall of sea level is not essential for reef island formation comes from the West Indies, where the history of sea level over the same period has been quite the reverse of that in the Indo-Pacific reef province. In the West

Indies the sea has been rising up to the present, but at a decelerating rate over the Holocene. Reef islands are found on a few atolls in the Caribbean, but are also common along the Belize barrier reef; these have evidently formed as the sea has risen.

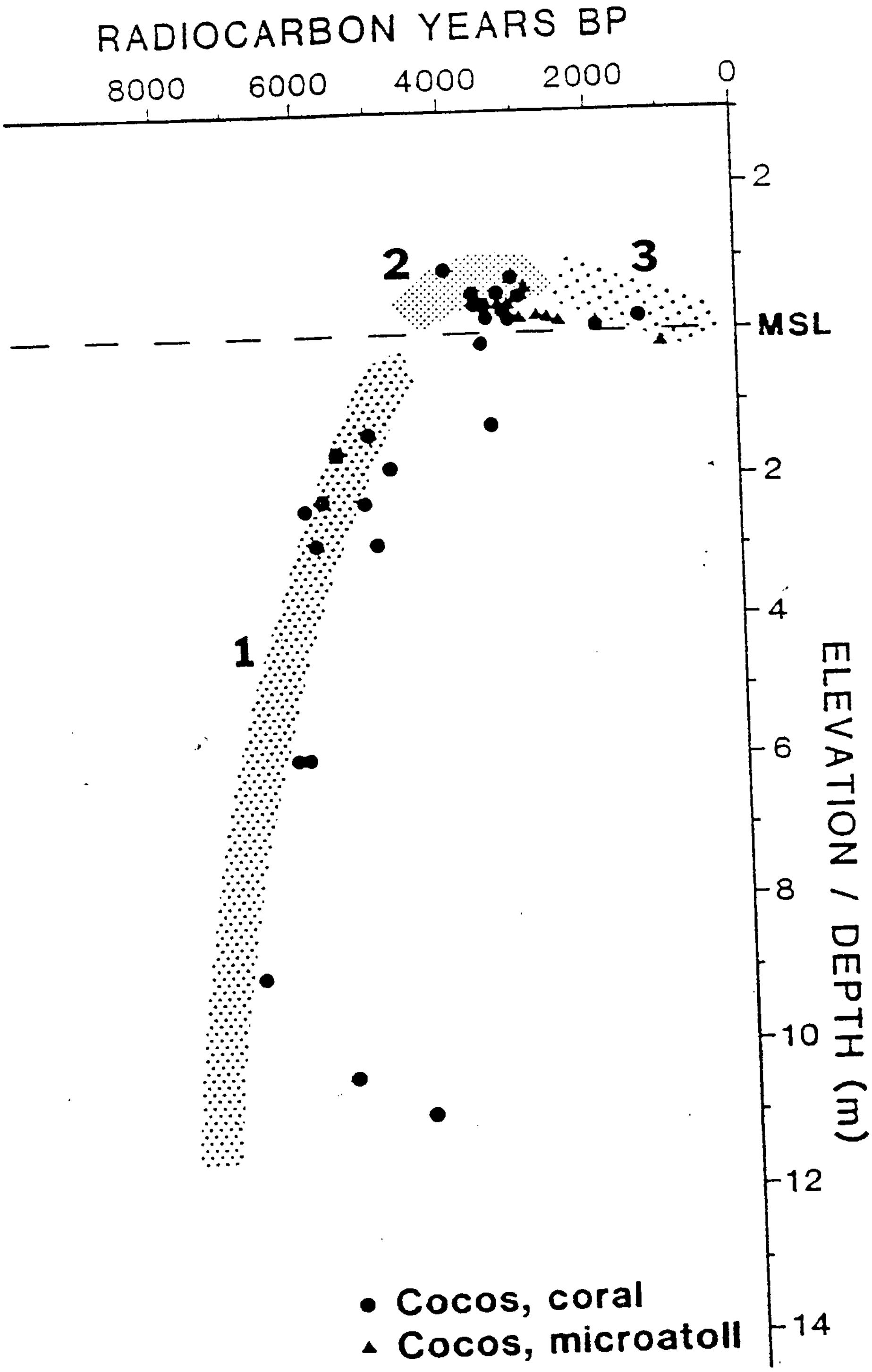


Figure 21 Age-depth plot of radiocarbon dates from Cocos, showing dates from drillholes, conglomerate platform and microatolls. Three phases can be recognized: 1) catch-up reef growth, 2) reef flat consolidation, and 3) reef island formation.

4.2.2.2. Chronology of reef island formation

It seems likely that the reef islands on the Cocos (Keeling) Islands, in common with those on other atolls for which data are available) have come into existence in the last 3-4000 years since the formation of the conglomerate platform which has been reliably dated to this period (see Woodroffe and McLean, ARB). In that case there still remain a whole series of different ways in which these reef islands might have developed. A number of these alternatives are illustrated in Figure 22, using isochrons to represent deposition.

Perhaps the simplest suggestion is that islands may have formed in one single episode of deposition. This might have occurred 3000 years ago with little or no subsequent change to island morphology, or there might have been a period of depositon at some other time between 3000 years ago and now.

As we know that sediments are continually produced in the reef and lagoonal environments and so are available to supply to islands, and there appears to be little if any storage on the reef flat, the single episode model seems unlikely. For similar reasons so too does the suggestion that islands are erosional remnants of formerly larger islands. Storms do cause erosion of islands, but as demonstrated in Figure 16 the shoreline recovers in periods between storms.

More likely is that islands have been subject to continual accretion over 3000 years, though again a number of scenarios can be envisaged. The pattern of accretion, shown by schematic isochrons in Figure 22, may show regular accretion, with little change in the rate of progradation over time; it may show accelerating accretion, decelerating accretion, or distinct episodic accretion, with phases of more rapid build-up.

The reef islands might accrete in at least seven different ways. First, the island might form as a central core, with subsequent accretion to oceanward and to lagoonward. Oceanward accretion might be prominent, supplied with sediment off the productive reef crest and reef flat. Alternatively, lagoonward accretion may be dominant with the bulk of the sediment being produced in the lagoon, or brought into the lagoon and redistributed onto islands.

The three alternatives described above suggest that buildout is largely horizontal; however, it may be that islands have accumulated as vertical accreting, with gradual buildup of ridges at both lagoon and oceanward shores by successive storms. Overwash may be an important process in island construction. Such overwash sedimentation would resemble that of the lagoonward accretion, except that sediments successively building into the lagoon would be reef flat sediments rather than lagoonal sediments. A variation on the overwash model is one in which sediment rollover and the island moves progressively lagoonward. Finally, such cross-island analysis may be inappropriate because longshore sediment movement may dominate, and particular parts of islands may vary in age substantially along the length of their shoreline.

In practice some scenarios of island development are much more likely than others. Thus on the majority of well-vegetated islands washover and rollover no longer seem to occur, though they may have operated in the past. Isochrons of island deposition, together with sediment provenance, should provide a test of which of the scenarios has occurred.

We are able to present some preliminary dating results from Cocos which indicate some trends in island formation, particularly from a trench on Home Island (Figure 19d) and a series of pits on West Island (Figure 23). These dates (see discussion on reef islands in Atoll Research Bulletin,) indicate firstly that sediments get progressively older with depth. The relatively narrow age range down pit 3, transect 1, on West Island is consistent with rapid vertical buildup, and suggests that vertical accretion

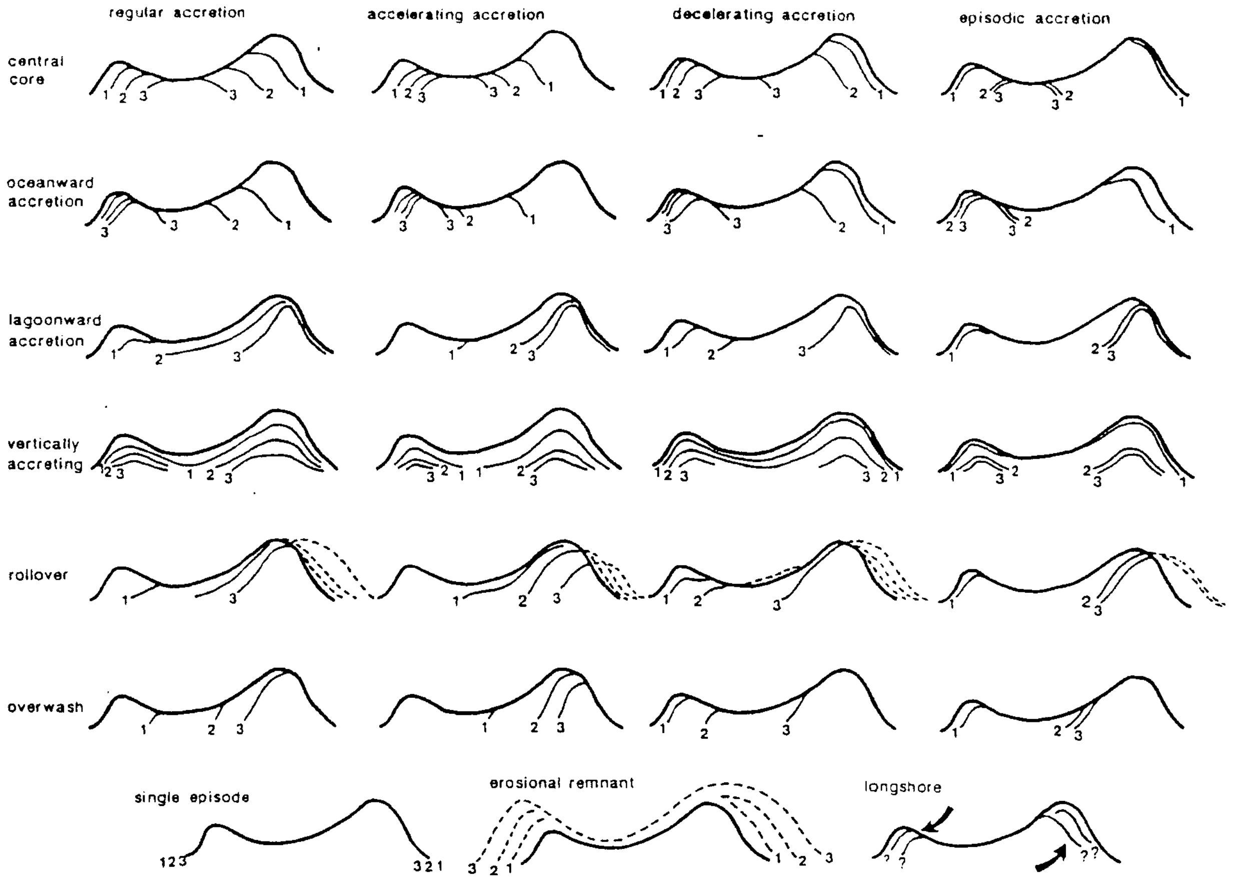


Figure 22 Possible models of reef island formation. Schematic representation of isochrons. Details in text.

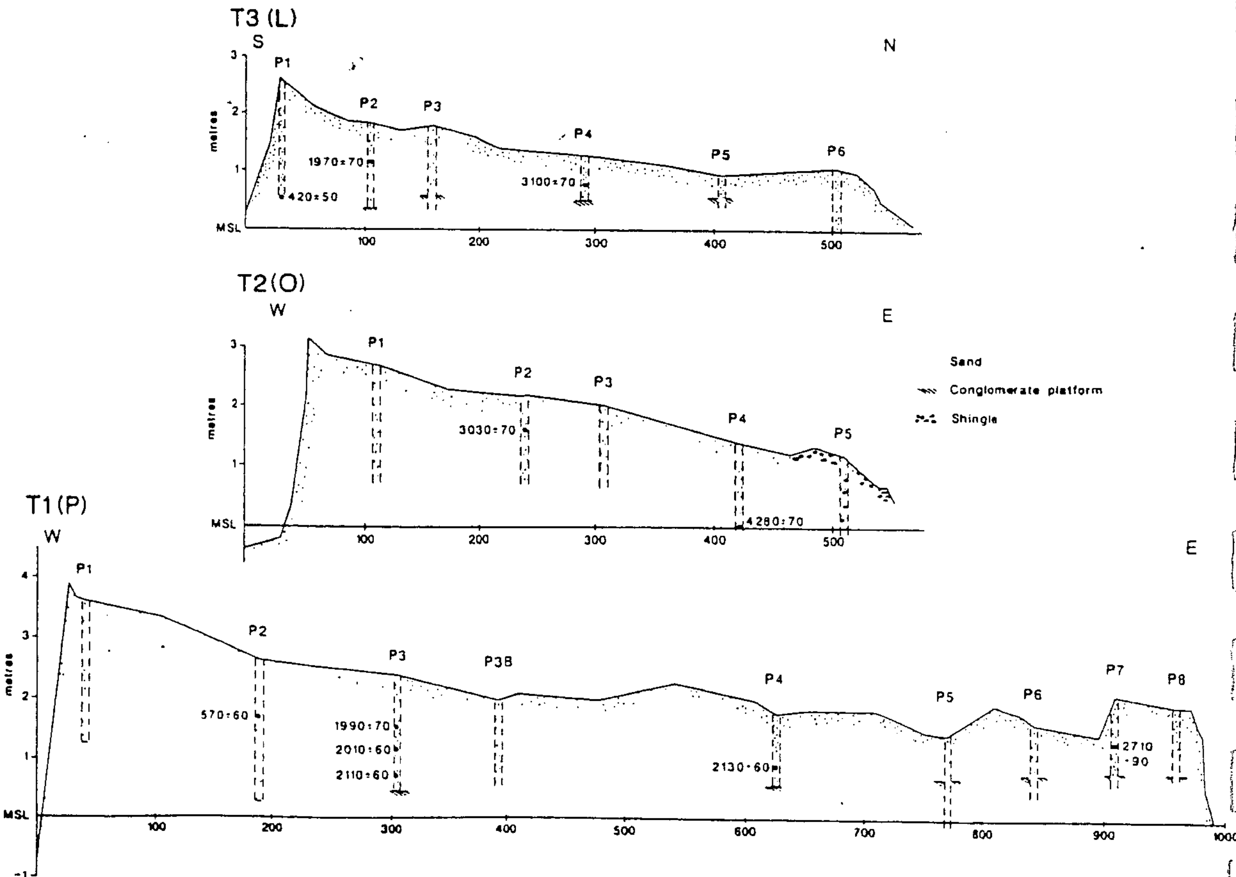


Figure 23 Cross-section and pits from three transects on West Island (Figure 27 for locations), showing radiocarbon dates.

occurs rapidly and the predominant direction of accretion is horizontal.

In the trench on Home Island the sediments were conspicuously bedded, dipping shallowly, at angles of up to 6° to oceanward. This is a much gentler dip than the present beach, which is sandy but rubble-covered. The second trend apparent from the limited dating is that West Island gets younger towards the ocean. Although favouring the oceanward accretion mode of development the dates are not consistent enough to indicate whether the accretion is regular, accelerating, or decelerating. Indeed the pattern may be episodic, though the spread of ages across the last 3000 years would seem to indicate that there was not any single most important episode of reef island formation.

The pattern of sea-level change during this period of island formation was one of gradually falling sea level. This is indicated from radiocarbon dating of fossil microatolls at points around the atoll (see Figure 21).

4.2.2.3 Implications of future sea level rise for atolls in general

On a number of Pacific atolls a rise of 30 cm would mean that the sea was no higher than it had been in mid-Holocene, and although there is no evidence of islands at that time, the cemented conglomerate platform provides some protection for the present islands, and where such a platform exists would slow the rate of erosion of those islands. Islands in storm-free areas may be slower to grow than those where storms act to supply sediment, despite the marked destructional role that storms play. It seems unlikely however that islands would have an infinite capability to maintain themselves in the face of sea-level rise. While a 1 m rise would bring the sea roughly to where it had been in the mid-Holocene, any greater rise would mean that islands were accumulating further and further above any stable base, and their continuation would depend upon natural cementation of sediment, as with the formation of beachrock, or stabilistation artificially.

A more rapid rise would almost certainly exceed the potential for islands to keep up, and would result in very altered energy conditions at the shoreline. While much of many islands would still be above water, it is extremely doubtful whether sand cays with no consolidated sediments on them could remain in the face of the higher energy wave conditions which would cross reef crests and reef flats under these circumstances. Most susceptible would be those islands which are not based on lithified deposits, and therefore have no firm base that acts as an anchor. Long linear islands on atolls may be particularly susceptible because they are narrow, and the sediment can be swept into the lagoon. Reef-top islands (table reefs) would appear less susceptible because there is no obvious route by which they may lose sediment.

The implications of these general observations for the Cocos (Keeling) Islands are summarized in Section 4.3.

4.2.3 Effects on groundwater

On small islands the freshwater lens is an important resource and on Cocos groundwater is the primary source of potable water. Figure 24 is a typical cross-section through an atoll reef island which shows subsurface stratigraphy and freshwater lens configuration schematically. A cross-section of the lens on Home Island is portrayed in Figure 25.

Small islands composed of unconsolidated calcareous sediments represent a porous medium through which ground water permeates. The first approximation of the freshwater lens of a small island is provided by the Ghyben-Herzberg principle which is based on density differences between rainwater and seawater; the lower density freshwater floats on the underlying higher density salt water.

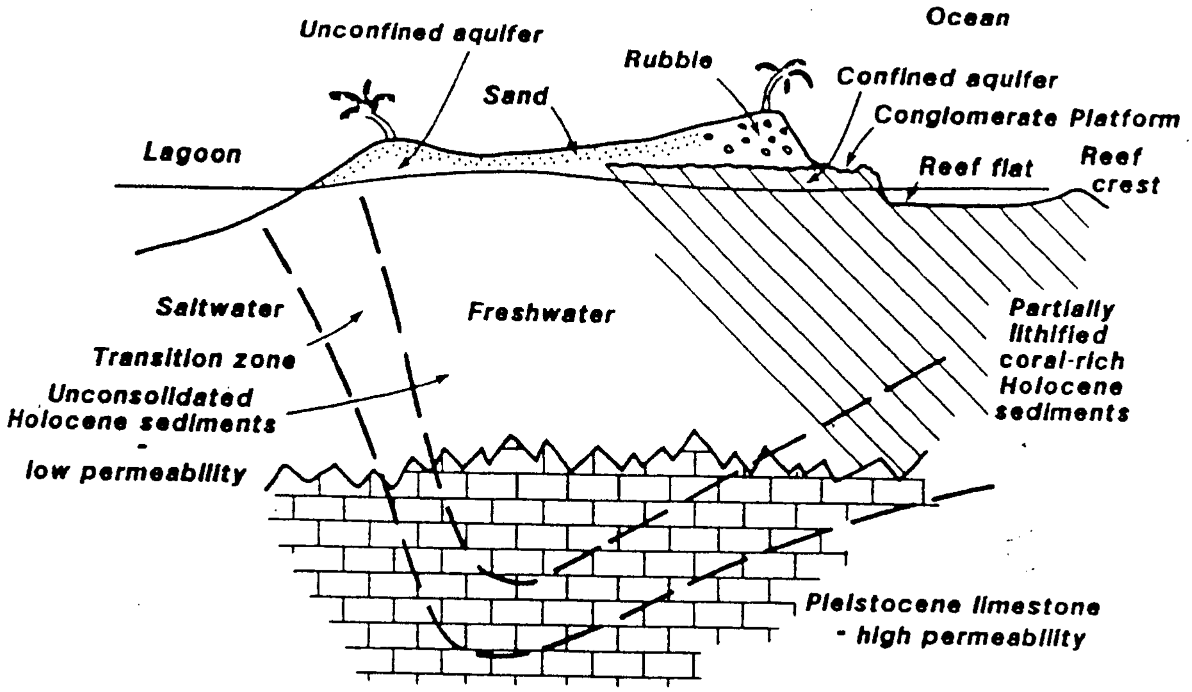


Figure 24 Typical morphology, stratigraphy and freshwater lens configuration for an atoll reef island (after Woodroffe and McLean, 1992a).

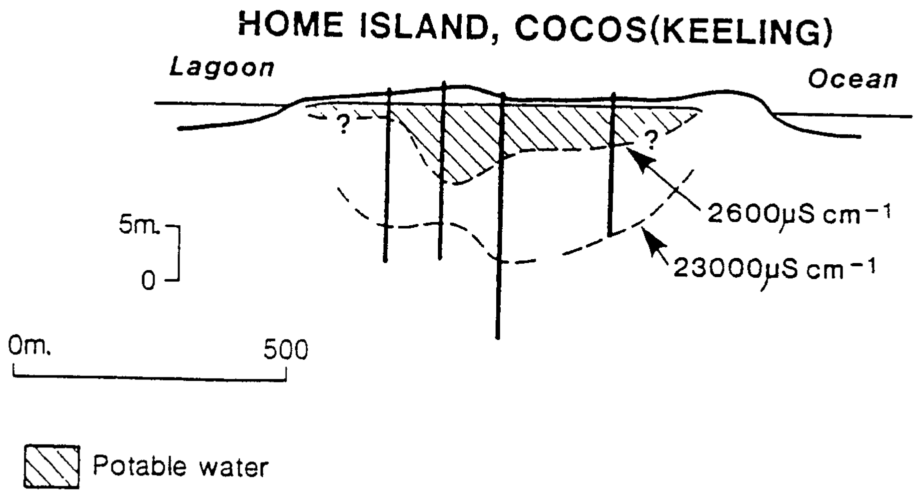


Figure 25 Freshwater lens beneath Home Island, Cocos (after Falkland, ARB).

The elevation of the freshwater lens above mean sea level is 1/40th of the depth of the lens beneath mean sea level according to the Ghyben-Herzberg principle which assumes a homogeneous substrate, uniformly recharged, and without variations of the sea surface to mix waters. However, on small islands where outflow is not likely to be large, the ideal Ghyben-Herzberg lens is not found and there is a thick brackish transition zone. Moreover, the assumptions of horizontal flow and tidal propogration have recently been questioned and it has been suggested that the freshwater lens is actually vertically coupled with a more permeable aquifer at depth (Buddemeier and Oberdorfer 1989). The older, last interglacial limestone found at depth is considerably more porous than the overlying younger limestones, and gives rise to this suggestion of a dual aquifer (Figure 24).

If the sea rises the freshwater lens will be affected. The size of the lens is closely related to island width. The response of island width to sea-level rise depends upon which of the above models of island response outlined in Figure 17 is the most valid.

Salt can intrude into the aquifer by overwash, also called freeboard washover. If storm waters overtop the seaward beach ridge then the seawater will flood the swale behind the ridge and percolate down to the water table, increasing the lens salinity (Sullivan and Pernetta 1989). Frequent overwashing may result in increases of salinity which cause death of the vegetation, with at high concentration death even of coconuts (Cloud 1952). These would then be replaced by more salt-tolerant species or remain unvegetated.

One feature that is clear in each response in Figure 20 is that the rise in water table level is going to be most noticeable in the low-lying interior of the islands. In many cases the water table will rise above the ground surface and an open pool will result. The exact response of the lens to sea-level rise depends on assumptions made in the model adopted to predict lens behaviour. The traditional Ghyben-Herzberg model is particularly sensitive to alterations of island size, and there have been a number of predictions of considerable loss of island area and consequent diminution and eventual demise of the freshwater lens (Miller and Mackenzie 1988; Roy and Connell 1990; Roy and Connell 1991). On the other hand modelling using the dual aquifer approach, has suggested that if recharge and island width remain constant then freshwater lenses on reef islands may actually increase in size with a rise in sea level because of the larger volume of freshwater which can then be stored in the less permeable upper (Holocene) aquifer (Oberdorfer and Buddemeier 1988; Buddemeier and Oberdorfer 1989).

The effect of sea-level rise on the freshwater lenses on Cocos is likely to be of secondary consequence in relation to other factors that affect lens quality and quantity. In the case of Home Island the present water resource is already limited, partly because the island is relatively small and demand high and partly because of the danger of recharge contamination. In the medium term it is far more likely that demand for water will exceed supply, irrespective of any minor changes in lens volume as a result of sea-level rise, or that quality will deteriorate to such an extent that the water is no longer potable. In the case of West Island the lenses go through natural cycles with rainfall recharge and extraction variations and it is likely that such cycles will exceed the magnitude of lens change that could be expected from a rise in sea level.

The water resources of Cocos have been described in detail by Falkland (ARB) who points out that there are large untapped freshwater lenses on South Island. Falkland argues that if freshwater is ultimately pumped from South Island to supply Home Island, or Direction Island which has no lens, it will be because of the pressure of demand. Sea-level rise is unlikely to have any appreciable effect on the size of the lens.

4.3 Vulnerability of Cocos Islands to Sea-Level Rise - Summary

On Cocos a sea-level rise of 30cm (ASLR 1) would mean that mean sea level would still be lower than it was 3-4000 years ago and a rise of 100cm (ASLR 2) would mean that the sea was roughly around (or slightly above) the position it was during the phase of conglomerate platform formation and incipient island development. Clearly conditions on Cocos at that time were quite different from what they are today since the major phase of island building and relative sea-level fall post-dates that period. Nevertheless, our geological observations indicate that islands began to form when sea level was higher than it is at present, and we would expect sediment to still be added to some islands under higher sea-level conditions in the future. We make no allowance for the likelihood that the sea would continue to rise in the 22nd century.

Figures 26 and 27 show profiles that we have surveyed across reef islands, and which have been reduced to a common datum, mean sea level. The oceanward shore can be seen to consist of one of a number of different landforms. On some parts of several islands there is a well-developed dune (profiles D on Home Island, and I and J on South Island), consisting of wind-blown sand. Dunes rise up to 11m MSL (at the 'Gunong' on the south western corner of South Island), but are not likely to be stable in the long term; where vegetation is sparse, there are already blowouts.

The conglomerate platform, characteristically around 0.5m above MSL, but in places up to 1.0m MSL is exposed along much of the oceanward shore of islands on the eastern rim of the atoll, as well as forming an important anchoring role on other islands. As shown by excavations on several profiles in Figure 26, the conglomerate platform also underlies islands, and it represents one of the most effective natural defences protecting islands.

Beachrock occurs on some profiles (eg profiles I, South Island, Figure 26, and profile N, West Island, Figure 27). On profile N, it rises up to nearly 3.0m MSL, where it must have been formed under a higher sea level, and forms the crest of the beach preventing inundation of low-lying ground in the vicinity of the Quarantine Station. Although not as extensive or as well-lithified as conglomerate, it nevertheless endows the shoreline with some stability in the immediate future.

Shingle and rubble beach crests are predominantly unlithified (eg profile H, South Island, Figure 26, and profile Q, Horsburgh Island, Figure 27), but can exceed 4m MSL. They form on high energy coasts which occasionally experience wave energies sufficient to move rubble of more than 50cm diameter. While this energy has served to construct such features in the past, increased energy under a higher sea level, although generally serving to add further to the ridges, could breach them, or substantially reshape them. These shores may be less stable than those that are lithified.

The commonest oceanward shore type is a beach ridge of sand, or sand and shingle. The general trend is for these to exceed 3m MSL, and to continue to accrete material, building upwards and outwards under recurring moderate storm conditions. The response of this shoreline type to higher sea-level conditions remains uncertain and has been reviewed at length in the previous section (4.2.2).

Figures 26 and 27 also illustrate three patterns of cross-island profile (see Woodroffe and McLean, ARB). The simplest is one in which there is a prominent oceanward ridge crest, and the reef island gets progressively lower towards the lagoon shore (eg profiles J, South Island, Figure 26 and L and O, West Island, Figure 27). The second type of profile is basin-shaped (as illustrated in the schematic profiles, Figures 18 and 20), with a prominent oceanward ridge which slopes inland to a central depression before rising to a lower lagoonward ridge. This profile is characteristic of Direction Island (profiles A, B and C Figure 26), and part of Home Island (profile E, Figure 26), and several profiles lie between these two types (eg profiles O and H). The third profile type is

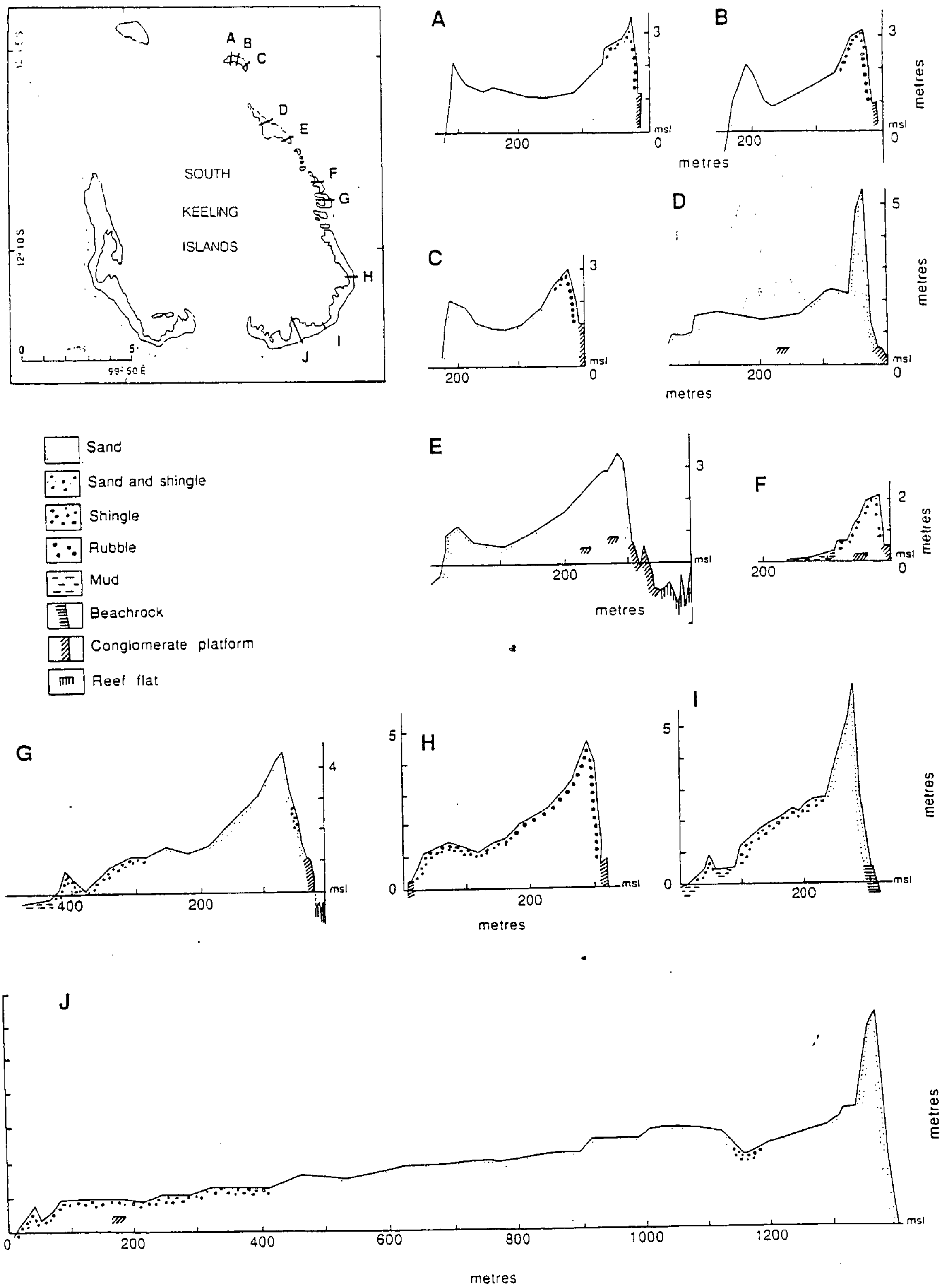


Figure 26 Surveyed sections across islands on the eastern atoll rim.

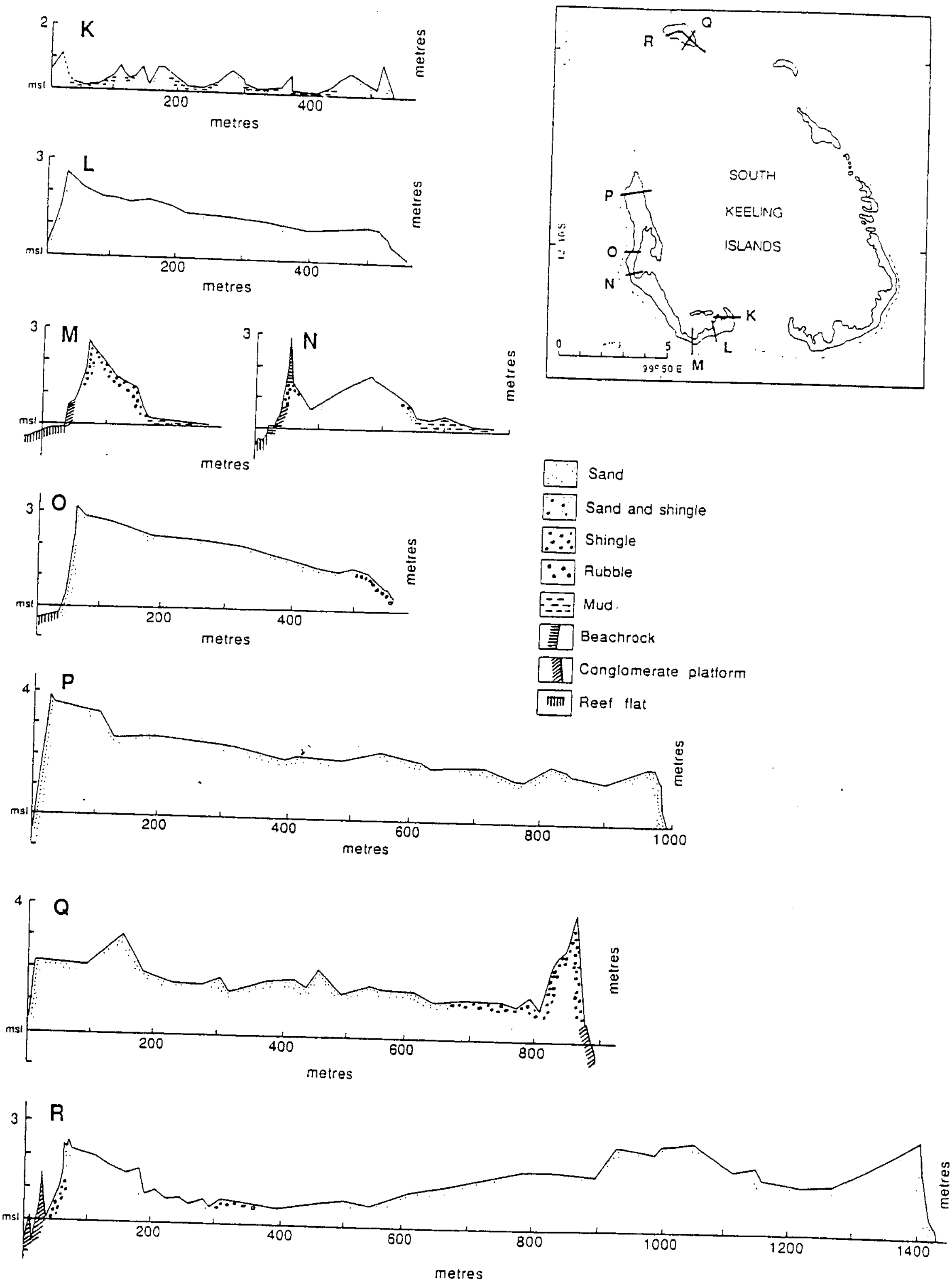


Figure 27 Surveyed sections across West and Horsburgh Islands.

more complex being composed of a series of subdued ridges and swales between ocean and lagoonward ridges. This form, found on Horsburgh (profiles Q and R, Figure 27) indicates a complicated accretionary history.

The impact of sea-level rise on each profile type is likely to differ. The first type will experience increasing encroachment of lagoon waters on the lagoonward shore. The second type is better protected on the lagoon shore, but may be more prone to flooding in the interior either from occasional overtopping of protective shoreline ridges, or as a result of elevated water tables. The third type, though not always reaching a great height at the present shoreline, is generally at a greater elevation than the other types in the island interior, and may offer a greater resilience to erosion because of this.

Inspection of Figure 26 and 27 gives a good indication of where the higher sea levels would intersect the present shoreline and the nature of the substrate which would be covered and exposed. Note that with a 30cm rise low tide level would still be at a lower elevation than the mean sea-level datum shown in the cross-sections, and the highest still water level is likely to be about 60cm above the new mean sea level (with wave conditions meaning that, in practice, inundation frequently exceeds that level).

Along the oceanside of most islands natural protection is presently afforded by the presence of the solid conglomerate platform, outcrops of cemented beachrock or a high shingle and rubble ridge. We envisage that such protection would generally be maintained with a higher sea level. Thus, before any substantial shoreline retreat could occur these barriers would need to be eroded or overtopped. Such erosion is unlikely as a result of tradewind-generated swell conditions under ASLR 1 but may be possible under ASLR 2. It might occur as a result of one exceptionally catastrophic storm even without any sea-level rise. However, as noted in Section 4.1, despite the destructive effect of storms, they also have the ability to deliver reefal materials to island shores and, with a higher sea level, to build up storm ridges to levels higher than those presently found.

Exposed ocean shorelines that presently do not have the natural protection afforded by the conglomerate platform, high beachrock or high shingle and rubble ridge, and particularly those composed of sand, are potentially more vulnerable to sea-level rise as at-shore wave energy and the magnitude of beach profile change can be expected to increase as a consequence of increased water depth over the reef crest while build-up of stony coral growth on the reef flat will be slow.

Three possible responses to sea-level rise were previously identified (Section 4.2.2) as (1) shoreline erosion; (2) redistribution of sediment along the shoreline; and (3) shoreline accretion, and which one or combination of these responses will occur in a particular area will be dependent on local circumstances. On the broad high sandy segments of the islands, such as along the southern shore of South Island (Figure 26, profile J) and along the northern part of West Island (Figure 27, profile P) long-term sustained erosion is unlikely and a combination of (2) and (3) more probable as these areas have been net sediment sinks during the period of island formation. Moreover, if erosion did occur, the erosional products would be moved downdrift to compensate for the loss, with movement towards the west on South Island and towards the northern tip of West Island.

For the extensive low sandy areas of recurved accretionary spits which form the western section of South Island and the eastern section of West Island, we have already suggested that increased flooding is likely under a higher sea level (profile K, Figure 27). Similarly around the perimeters of the embayments (teloks) on the lagoonside of West Island and South Island flooding will be enhanced. Because these are in low energy environments they are more liable to inundation rather than erosion at least on the lagoonside. However, increased inundation, if not compensated for by increased sedimentation, may result in further narrowing the distance between the ocean and

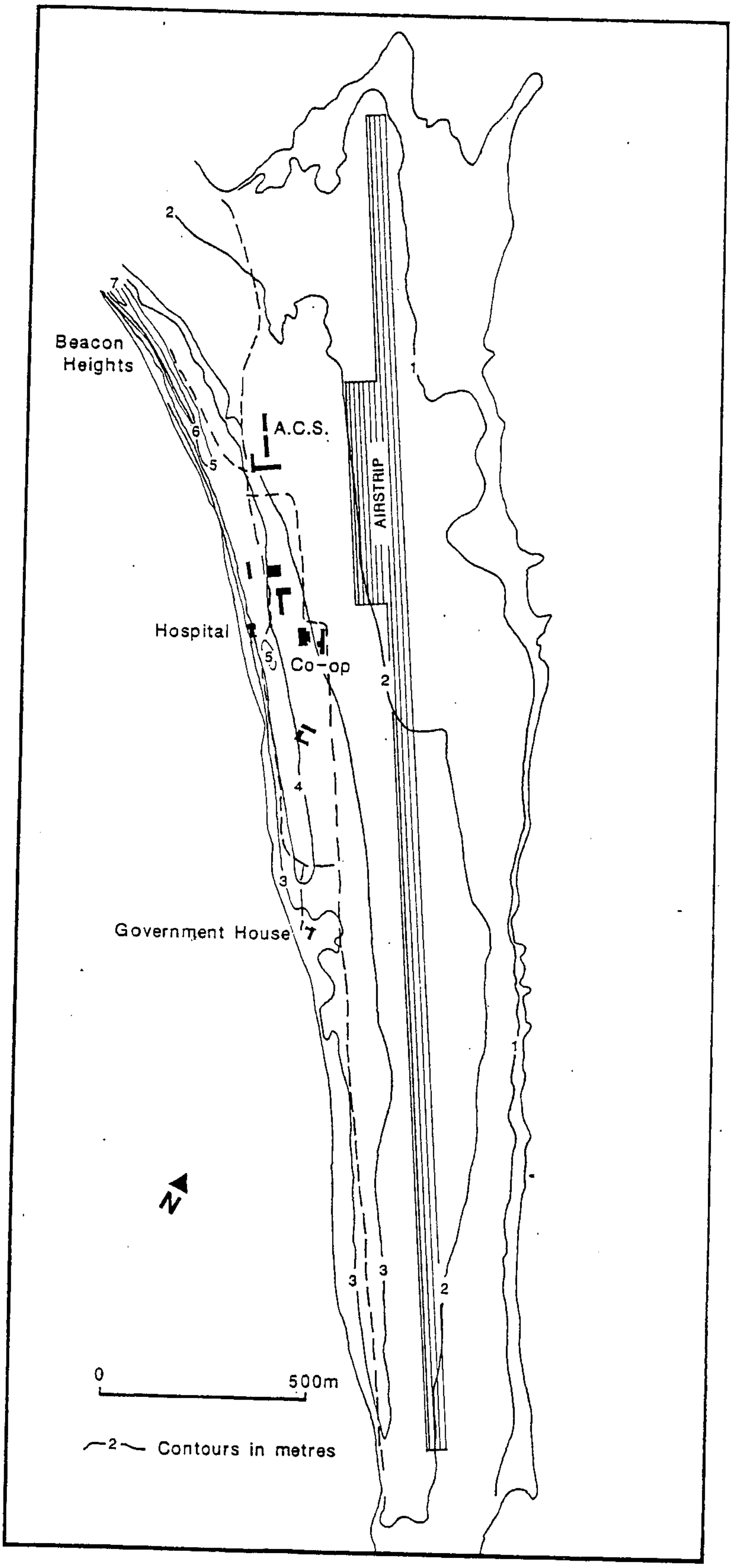


Figure 28 Survey data on West Island

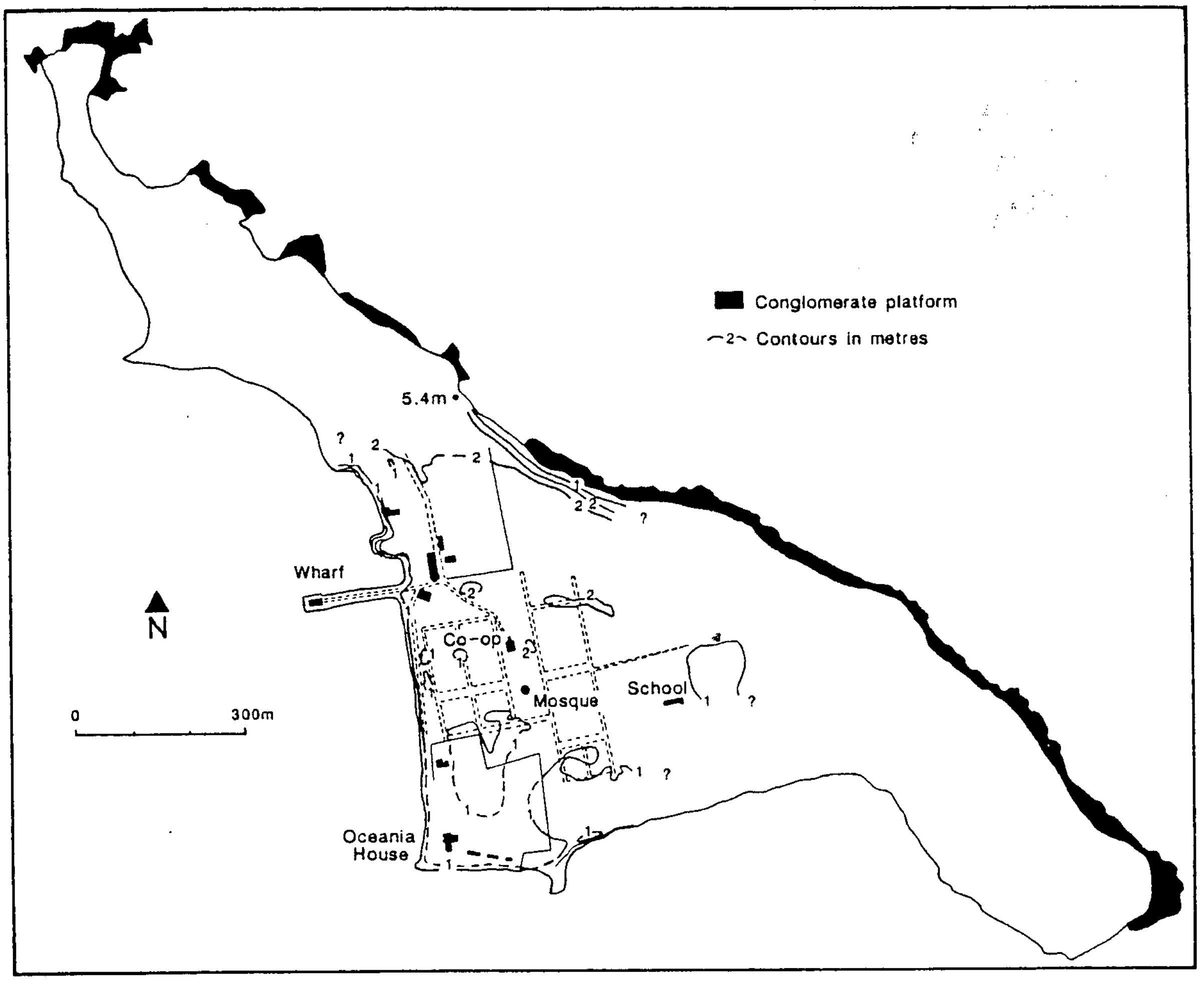


Figure 29 Survey data on Home Island

lagoon shores. In some locations this distance is presently less that 200m and in such places the possibility of island breaching must be considered. Possible breach sites can be identified on West Island at the southern end of the airfield (Figure 28) and further to the east, near the aerial receiver site to the north of the settlement, and around the Yacht Club at the eastern end of the island. The vulnerability of some of these sites to contemporary erosion has been already recognized and a variety of formal and informal shore protection structures have been installed. Without maintenance and further attention to design, these are likely to exacerbate rather than inhibit erosion with a higher sea level.

Much of Home Island is of low elevation. Figure 29 summarises the contouring (undertaken at 20cm intervals on the survey sheets) through the kampong area. Although it is protected along some of its oceanside by conglomerate platform and a high ridge, the platform is not continuous around the island and the ridge is mainly composed of sand which is not as stable as shingle or rubble. While we do not envisage that a sea level rise of 30cm would have much affect on the island, a rise of 100cm would certainly result in some flooding of the lower parts of the island. It is also possible that the combination of higher sea level and higher wave energy on the oceanside would result in erosion and be particularly concentrated in the northern half of the island in those areas not protected by the conglomerate platform and where the sand ridge has been quarried and lowered for reclamation purposes to the northeast of the kampong.

Housing and community buildings on West Island are generally above 3m MSL and are unlikely to be subject to direct inundation (Figure 28). The greatest threat on West Island is to the ends of the airstrip, and that localised erosion of the oceanward beach may undermine buildings which have been built on or close to the ridge crest. We do not envisage substantial long-term erosion, but the sweep zone, within which erosion and subsequent accretion occurs, may broaden if greater wave energy crosses the reef crest and reef flat. Shoreline response along this crest may also be altered because of the structures (groynes and seawalls) which presently modify the natural pathways of sediment movement.

5. FORMULATION OF RESPONSE STRATEGIES AND ASSESSMENT OF THEIR COSTS AND EFFECTS

Four possible response strategies to ASLR are outlined in the RSWG (1992) Common Methodology as: a) no response b) retreat c) protect and d) accommodate. These are examined in turn below and assessed in terms of their effects. We have not attempted to determine their separate costs quantitatively.

5.1 No Response

This is regarded as the reference situation and represents the 'do nothing' option or the situation at present. Erosion and flooding are presently problems in certain areas of South Keeling, and particularly on West Island (see Section 4.3), and these will continue to be problem areas whether the sea level rises or not. NCPA-DASET (1992) note that erosion on the seaward side of West Island is evident, that several houses and the hospital are close to the beach, that the road at the southwest corner of the airfield is in danger of encroachment and that the seawall in front of the settlement "is deteriorating and is not an appropriate design to arrest erosion in the long-term" (p. 7).

Elsewhere on the islands shoreline erosion is apparent. Geomorphological evidence in the form of stranded beachrock outcrops (eg. at the southern end of Horsburgh and south side of Direction Islands) and historical evidence as described initially by Darwin (1842) indicate shoreline erosion. But whether such erosion represents a permanent trend rather than a temporary phase is less clear. Certainly there has been substantial sedimentation around the atoll since Darwin's time. There are two implications of this. First, that erosion (and deposition) has taken place in the absence of sea-level rise. And, second, if sea level were to rise 30cm (ASLR 1) it would be difficult to attribute any erosion specifically to that cause rather than to normal natural variations in wave energy, sediment supply etc.

A 'no response' scenario for a sea-level rise of 100cm (ASLR 2) is also difficult to assess because of the many interacting factors involved (eg rate of reef growth and productivity, rate of sea-level rise, storms, bleaching events etc). However, assuming that such a rise did take place and also assuming that there was no change in reef and island geography during the 100 years of rising sea level, then extensive flooding of low-lying areas on the lagoonside of most islands and extensive erosion and inundation on the oceanside could be expected assuming the Bruun erosional model applied (Figure 20b). However, such simplified assumptions are not realistic, as inevitably changes will take place during rising sea-level, and the equilibrium response model, involving sediment redistribution, is likely to be a more apposite model than that of Bruun.

Moreover, while there may be 'no response' specifically to ASLR, we can expect that the community would respond to shoreline erosion and flooding in those areas where it interacted adversely with the human use system or had the potential to do so, irrespective of whether the cause was accelerated sea-level rise or not. That is, a combination of reactive and proactive responses to these problems can be expected regardless of the 'cause' of the problem.

5.2 Retreat

Even on low elevation islands such as Cocos, there are important variations in height and topography (see Figures 26 and 27) and it may be possible to identify local areas of high ground to which retreat is possible. However, we are reluctant to map such refuges because the present areas of high ground (eg on Horsburgh, Direction, West and South Islands) may be subject to change over the next several decades; some may be lost and other new areas of high ground created.

Total disappearance of all of the islands seems most unlikely even under the ASLR 2 scenario and the time frame considered here. But if this did occur there is little doubt that the entire population could be removed to the Australian mainland (or Christmas Island) either temporarily or permanently, just as they could if the islands were completely devastated by a cyclone.

5.3 Protect

The full protection option is one that is to be reviewed for each nation as a part of the Common Methodology. This option is evidently viewed as the construction of protection works, principally seawalls, around all or selected areas of land. On Cocos there is a disproportionately large length of shoreline (120km) to land area (14km^2) and with 22 islands, the wholesale protection of these would be an enormous and expensive task. Perimeters of individual islands are summarised in Table 3.

Complete protection is also an unrealistic option. Settlement and capital investment is concentrated on Home and West Islands and it is unlikely that extensive protective works could be justified, or would be necessary, elsewhere. In our view, artificial protection around the entire perimeter of Home and West Island would also not be necessary given the natural protection afforded by the conglomerate platform along the oceanside of both islands. However, as noted earlier, that natural protection is not continuous and there are areas, particularly on West Island that are presently subject to erosion or are vulnerable to erosion. These may need protection. Similarly with flooding and inundation along parts of the lagoonside of West Island. With higher sea level, low-lying areas, such as along the airfield and around part of the teloks, as well as the lagoonside of Home Island, may well need protection over the long-term.

Australian Construction Services (1992) has provided some estimates of the cost of sea wall construction in Cocos. For sloping revetments with Seabee units, which would be appropriate for oceanside protection, indicative costs range from $3000 to $4000 per linear metre. Protection of the West Island Medical Centre alone is estimated as in excess of $1 million. The cost of appropriate lagoon-shore protection is not known but is likely to be less than the above figures.

5.4 Accommodate

This option is not well defined in the Common Methodology though examples of regulating building developments in the coastal zone and changing land use from land-based activities to aquaculture with rising sea level are cited (RWGS, 1992). On Cocos the accommodation strategy has been a traditional response to storm inundation and flooding in the past and with few exceptions buildings and facilities have normally been set-back some distance from the shore in anticipation of such events. The raising of buildings has not been a common practice but some buildings have been moved (the older residences on West Island were brought from Direction Island on closure of the cable station).

While there has been some reclamation along the lagoon shore of Home Island and some structures and facilities have been built relatively close to the shoreline on both Home and West Islands, such developments are not extensive. Indeed, pressure on the coastal zone of Cocos has not been great in comparison with that on many other atolls, which are either densely settled, support intensive developments or large urban areas (eg Majuro, Marshall Islands; Male, Maldives, Tarawa, Kiribati). This, combined with the fact that most of the land on Cocos has been under single ownership, initially the Clunies-Ross family and now the Islands Council, has meant that it has been relatively easy to control and manage developments on an atoll-wide basis. It also means that there are good prospects for 'accommodating' sea-level rise into planning and management of Cocos in the future.

5.5 An Integrated Response Strategy

In our view none of the four strategies by themselves is appropriate for Cocos. Rather an integrated response strategy is proposed; one that we believe is more realistic for the Cocos situation and one that may have application to other atoll states and territories.

Integration can take place at various levels. First, projected ASLR needs to be integrated with other environmental factors that may result in island erosion, flooding, overtopping, groundwater deterioration, etc. Such factors include cyclones and hurricanes, interannual variations in mean sea level, storm waves from far distant sources, coral bleaching, land use and other human induced changes, which singly or in combination may have greater direct or indirect impact on the islands than sea-level rise per se. Impact and response to ASLR will not be independent of the impact and response to these other factors.

Second, is geographical integration which requires recognition of the fact that atolls comprise many habitats and environments that interact with one another. It also implies that all of the islands are not equally vulnerable to ASLR; nor are their socio-economic values at risk equal. Instead there are important spatial variations in vulnerability between islands and around single islands; similarly with the socio-economic values at risk. For some areas a single response strategy may be appropriate, though in most cases a combination of strategies would be more effective. What is important is that a chosen response option(s) in one location should not create or exacerbate problems in another place. Rather there should be geographical complementarity.

Third is temporal integration. This involves recognition that atoll islands have formed and changed through very recent geological and historical time and that they will continue to do so in the future regardless of whether sea-level rises, falls or remains stable. It also accepts that quick responses to contemporary erosion or flooding problems may be short-term palliatives only. There are many instances on atolls where seawalls have been constructed and their very presence has inhibited natural shoreline recovery in the longer term. Planners of solid protection structures, in response to storm erosion or projected ASLR, should be aware of the dynamics of shorelines not only in terms of contemporary sediment supply, transport and loss, but also in terms of the way reefs and islands have developed and interacted in the past. Integrating an understanding of contemporary processes within the context of past geomorphological changes should provide the necessary basis for forecasting the general magnitude and directions of change over the medium and long-term. It should also provide data on whether or not it is possible to complement natural processes rather than confront them, the purpose being to work with nature rather than against nature wherever possible. In coastal erosion situations this may mean adopting 'soft' (eg beach nourishment, vegetation planting) rather than 'hard' solutions.

Rarely in atoll environments is there sufficient understanding of contemporary process regimes or of retrospective changes to provide a firm basis for prospective evaluation. The time frame for ASLR however does give the opportunity to redress this situation.

Fourth, is the need to integrate traditional and modern technologies wherever possible. Such an approach acknowledges that many atoll communities have experienced very substantial environmental changes during their history and they have made adjustments to, or adapted to, those changes. This may be less applicable in the case of Cocos than on some of the older societies in Micronesia and Polynesia where there is for instance a strong tradition in building appropriate structures to alleviate erosion and flooding. Traditional adjustments are usually more flexible, use local resources, involve individuals and community decision-making, respect cultural and environmental values and optimise local priorities for both amenity and protection. They may also be more cost-effective in the long-term. Similar traditional responses could be expected to an on-going gradual rise in sea level. Such responses should not be ignored or dismissed lightly before less flexible, single-purpose, capital intensive and physically extensive protection measures are proceeded with to combat ASLR.

Finally an integrated response strategy considers all possible responses to ASLR (and other environmental processes) without prejudice. It is not biased towards any one of the four options proposed. Nor should a 'no response' option be automatically dismissed. It may be the most appropriate one in some circumstances.

5.6 Towards an Integrated Response Strategy for Cocos

Cocos now has in place the basis for an integrated response strategy which can accommodate the four response options of the Common Methodology as well as incorporate some elements of the above discussion. Fundamental to this is the planning scheme which has just been adopted and which provides the legislative and statutory structure for considering future developments in both the short- and long-term, as well as some indication of the likely scale and impact of those developments. The intent of the planning scheme is

> to direct and guide the control of activities and developments in the Scheme Area so as to promote and assist in safeguarding the natural and cultural resources and values of the Scheme Area and the health, safety, convenience and economic and general welfare of its inhabitants
>
> (NCPA-DASET, 1992, p.32)

The Scheme Area includes all of the islands and waterways, including the lagoon and reefs, within the Territory.

Although the question of ASLR is not specifically addressed the sensitivity of island shorelines, freshwater lenses, reefs and lagoon to development and other activities is acknowledged.

In this context several types of Reserved Land have been identified in the plan (Tables 9 and 10) within which proposals for any use of land or work of any kind should have regard to the objectives of the reserve and to the purpose for which the land is reserved. Foreshore protection reserves have been identified on West Island and Home Island as a strip of land, generally 20m wide, around islands. Foreshore protection reserve occupies 12% and 13% of the total land area of West Island and Home Island respectively. The plan also recommends that this practice could be adopted as an option for the other islands particularly if pressures arise for developments near the foreshore.

Among the objectives for land set aside as Foreshore Protection are those that aim:

- to minimize erosion;
- to control activities and works such as tree and shrub removal, material winning and other excavation, indiscriminate and uncontrolled rubbish dumping, vehicle use and public utility services which could disturb the natural form of the foreshore; and
- to protect remnant vegetation species near the foreshore.

Broadly similar objectives are also included in other types of reserves and land use zones including those for Nature Conservation, Common and Recreation, while included in Marine Protection are objectives specifically aimed "to control activities likely to deplete or damage the marine life of the lagoon and reef flats" and "to protect the reef flat of South Island as a source of replenishment organisms of the lagoon".

Thus, in the context of ASLR and the four response options, the planning scheme can be seen as having elements that are both proactive and reactive. An example of the former is the foreshore protection reserves which provide buffer zones that could "accommodate" some of the natural changes that may occur with sea-level rise. An example of the latter is coastal engineering works that may serve to "protect" the land from erosion or flooding. Decisions to institute such works are clearly embedded in the planning process which involves extensive public consultation.

While the planning scheme has an important statutory role, NCPA-DASET (1992) also recognize the need for it to be complemented by specific management plans. They foreshadow, for example, a plan for the management of the lagoon and reef-flats and a management plan for the foreshore in general as well as site specific plans such as for the foreshore of West Island near the settlement. It will be through the development of such plans that response strategies to ASLR are formulated and their costs and effects assessed.

The scientific basis for management plans is not yet adequate. Our data on contemporary process regimes, particularly those linking reef flats to island shorelines, is presently incomplete though a start has been made on understanding the hydrodynamics of sediment transfer through inter-island channels from the ocean side into the lagoon (Kench, ARB).

6. ASSESSMENT OF VULNERABILITY PROFILE

The Cocos (Keeling) Islands, in our view, should be considered one of the most vulnerable parts of the Australian coastline to the ravages of the sea, not only because they are so low-lying, but also in view of their unique strategic and cultural values. There are lower-lying islands off the Australian coast, such as the sparsely vegetated sand cays of the shelf atolls of Rowley Shoals or of the Great Barrier Reef, but these are generally uninhabited, or occupied by tourist facilities rather than an indigenous population. There are similarly strategically or territorially important islands, such as Ashmore and Cartier Reefs, but again these are uninhabited. The cultural significance of the Cocos (Keeling) Islands though of less antiquity has some similarities to that of the Torres Strait Islands, but the latter are less susceptible, as a whole, than Cocos.

However, despite their vulnerability, we find the vulnerability analysis as proposed within step 6 of the Common Methodology largely inappropriate for the assessment of Cocos, and at best misleading in the comparison of Cocos with other places. The issue has been complicated by what we consider to be grossly exaggerated suggestions that all land is likely to disappear from the coral atolls of the world in the near future. In relation to Cocos, with its status of a Territory of the Commonwealth and with its administration in the process of transferring to the State of Western Australia, the strictly economically rational approach can hardly be applied. In any case, we have demonstrated above that there is no consensus between reef scientists as to whether islands will show net erosion (Bruun model), redistribution of coastal sediment (equilibrium model), or net accretion (continued growth) in the event of sea-level rise.

The Common Methodology contains two stages within step 6; the first stage considers the susceptibility to physical changes imposed by ASLR and the related socio-economic and/or ecological impacts, and the second stage is involved with the implementation feasibility of response options.

6.1 Socio-economic and/or Ecological Impacts

This stage of the Common Methodology is based upon the premises that it is possible to put an economic value to a unit area of land, and that it is possible to forecast the area of land lost under any particular sea-level rise scenario. We have demonstrated above that neither of these can be done with confidence for Cocos.

Within the methodology, socio-economic values are to be calculated as loss, at risk and at change, and may be expressed either as capital value or subsistence value. In the case of the Cocos (Keeling) Islands, we are unable to derive meaningful economic values because of the unusual nature of land tenure (most being vested in the Cocos Island Council), and the history and present transition of administration on the islands. There is not a realistic basis upon which to set the benefit-cost analysis advocated in the methodology, particularly as this is intended for comparison with other areas of the nation and other nations.

Nor can subsistence values be placed upon the land, as most of the land is not used for subsistence, (excepting horticultural plots), beyond the collection of firewood or free-ranging chickens. Indeed the marine resources of the reefs and lagoon perform an important; if not more important, subsistence role. When the Cocos (Keeling) Islands were operated as coconut plantation with export of copra, it may have been possible to have placed a value in terms of economic production on the majority of the land area which is under coconut woodland. However, the copra industry was finally declared to be unprofitable in 1987, and export of copra from Cocos has ceased.

Those areas within the Cocos (Keeling) Islands for which capital values can be ascertained are some of the buildings, particularly the most recently built (see Table 8). The problem here is that on the one hand we are unable to forecast which buildings will actually be threatened, and on the other hand, we are unable to determine how much of the coastal erosion that might take place would be due to sea-level rise. Thus, for instance, the Medical Centre on West Island is threatened by erosion of the adjacent foreshore; this is a threat which exists at present and may exacerbate even without any rise in sea level.

Similarly, we have identified ecological and cultural-historical values, but cannot determine how threatened these are likely to be. A single storm under present sea-level conditions could inflict far more damage than we would anticipate as a result of sea-level rise per se. Thus the storms of 1876 and 1909 were particularly severe, the latter purportedly knocking over 90% of coconut palms and 95% of buildings. To what extent the damage would have been worse if the mean sea level had been higher cannot be determined. Cocos remains at the mercy of such catastrophic events.

6.2 Interpretation of Implementation Feasibility

The Common Methodology recommends tabulation of aspects related to the preparation and implementation of response options, with attention to four main problem categories (ie legislative/institutional/organizational; economical/financial; technical; and cultural/social). Our interpretation of these is made relatively straightforward by the coastal management provisions described above but at present several elements of policy remain to be resolved (see Section 5.6). At present, there are legislative, institutional and organizational problems, but we expect these to be sorted out relatively soon. Economic and financial constraints on responding to problems of foreshore erosion are also unclear at this time of transition. Technical problems should be minimal; though we emphasise what we see as the desirability of implementing soft engineering options, rather than extensive protection or large-scale engineering projects. Facilities and expertise for such small-scale projects are presently not a constraint on Cocos.

Finally, the unique cultural and social setting of the Cocos (Keeling) Islands has been emphasised throughout this report; not as an impediment to shoreline protection, but as an additional incentive to ensure that the Home Island community in particular accommodates any change in sea level, along with other major changes which it is presently experiencing.

We would foreshadow that the Cocos (Keeling) Islands are relatively able to implement responses when they become necessary. They have recently been provided with a state-of-the art tide gauge, adequate planning strategy, and awareness of the sea-level rise issue. If this is combined with future monitoring of shorelines, the island group could be one of the best prepared atolls in the world to respond rationally, but not precipitately, to any sea-level rise that may become detected.

Bruun (shoreline erosion) response, the equilibrium (sediment redistribution) response, or the continued growth (sediment accretion) response. Our data point toward the second and third options. However, in the case of West Island the shoreline response will also depend upon how those structures which are there already interact with the natural pathways of sediment movement. The West Island groynes and seawalls constrain the ways in which the shoreline can respond, and retention of sediment at one part of the shore (within a groyne system) may decrease supply further north upsetting the erosion/deposition balance and leading to net sediment loss from the beach.

Despite the considerable scientific information available on Cocos, and the geological studies of sediment provenance and long-term buildup, there are still insufficient data to draw any firm conclusions on how reef islands will respond to sea-level changes, or even how they are responding to the shore protection structures that are in place.

There are three approaches to increase that knowledge. First, further radiometric dating of island sediments will increase our knowledge of how islands have built up, what the sequence of formation has been, and what trends have been apparent over the last three millennia. Second, shoreline monitoring is required to record whether or not the shore is continuing to accrete. We note that a series of lagoon shore survey transects were monitored for a number of years by AUSLIG. A more extensive network of shoreline profiles around West and Home Island would represent a valuable investment of effort, which would indicate over a decadal timescale just what trends of shoreline response do occur locally.

The third approach would be a detailed study of the pathways and volumes of sediment movement along the West Island shoreline. Such a study would require the use of instrumentation and survey techniques, and is more easily justifiable, only when the first two approaches have indicated that there is a real problem.

The Cocos (Keeling) Islands are vulnerable to the ravages of the sea. We see no immediate threat as a consequence of sea-level rise, but there is time to instigate a modest programme of shoreline monitoring in order to gain a greater insight into natural shoreline dynamics, to give a clearer indication of what might occur if the sea does rise at rates likely in the ASLR 1 and ASLR 2 scenarios. We also emphasise that both the reef and its associated biota, and the coastal vegetation, will be best able to respond naturally to perturbations such as sea-level rise (but including storms and coral bleaching events) where they are healthy and where the pathways between adjacent ecosystems are maintained.

The initial foreshore protection planning tools are in place, and in that sense Cocos is well prepared within the context of the national coastal zone management programme. The response strategy should be an integrated response. Rather than major engineering works we advocate soft options, such as beach nourishment, coastal vegetation rehabilitation, and so on wherever possible though we recognize that solid protection measures may be required in places such as if the airfield and other major infrastructure was threatened. We emphasise that shoreline erosion is apparent on many shorelines which subsequently go through phases of recovery. Although there are ample signs of erosion around Cocos, the overall trend has almost certainly been one of net reef-island growth.

7. IDENTIFICATION OF NEEDS AND PLAN OF ACTION

This stage of the IPCC Common Methodology involves a plan of action which should provide the country's decision makers with appropriate conclusions, recommendations and proposals for immediate, medium and long term action in the framework of the nations coastal zone management programme.

In the case of the Cocos (Keeling) Islands we consider that the threat of sea-level rise is not so immediate as to require precipitous action. Indeed there is no evidence, either from the geomorphology of reefs and reef islands, or from the discontinuous tide gauge records, or from intertidal corals called microatolls which are constrained in their upward growth by sea level, that the sea is presently rising with respect to Cocos.

Sea-level rise, if it occurs, will be only one of a series of potential impacts on the Cocos (Keeling) Islands. The atoll remains vulnerable to devastation by a catastrophic storm, which might wreak havoc irrespective of any sea-level change. Any planning measures associated with anticipated sea-level rise need to be formulated in the broader context of coastal hazard awareness.

At the present time the nature of the coastal management of Australia's shoreline is under wider review (Resource Assessment Commission). On the Cocos (Keeling) Islands, new planning tools are being set in place through the transition from Commonwealth control to that of the state of Western Australia. As we have seen foreshore protection will be an important element of future land-use planning. These measures should enable an integrated, proactive response to sea-level rise, as and when it is needed.

Although we doubt that there has been any significant net rise in sea level relative to Cocos over the last 100 years, there are several areas where inundation is of concern under the present sea-level conditions. The West Island jetty, in particular, is presently at an elevation at which it is awash at the highest tides. The jetty is located in an area that has shown marked geomorphological change, both in terms of accretion and erosion, over recent years. It already requires attention, but it would be unserviceable under only a very modest rise in sea level.

Similarly, there is already extensive flooding at high tides in the vicinity of the Yacht Club (eastern West Island) and around teloks. This would be exacerbated if the sea rose, and the former may be accentuated by compaction of the road by vehicular traffic. While some protection for these areas could be provided by minor earthworks, a more aesthetically pleasing option might be to encourage natural vegetation regeneration (especially stands of *Pemphis*), stabilising the higher ground in these areas.

We envisage little change over a 30-year planning period with sea-level rise at the ASLR 1 rate. Under ASLR 2 conditions the atoll is considerably more vulnerable. However different shorelines will react differently, with well lithified deposits being much more stable than sand and shingle. It would be possible to devise a vulnerability index for different parts of the atoll, based upon the distribution of the different shoreline types.

We would see as major concerns, when a sea-level rise trend had been demonstrated on Cocos, i) flooding of lowest-lying land in the Home Island kampong which might occur increasingly frequently; ii) the need to protect parts of the West Island airstrip; iii) the threat that some of the low-lying corners of reef islands might be breached and converted into passages. Until such time as these threats become apparent, there is little if any need for action in these areas.

Whether or not accelerated sea-level rise will threaten the oceanward shore of West Island depends firstly upon which of the reef-island response models is appropriate: the

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