c) Pemphis scrub

Pemphis acidula forms dense thickets on many islands, particularly on the lagoonward shores of atolls and in comparatively sheltered inland locations on reef islands (Woodroffe, 1991). It occurs either on the dissected conglomerate platforms of the reef islands, or on an infrequently inundated substrate of medium angular coral rubble or coarse sand. Pemphis grows to 4-5 m tall, forming either a continuous fringe up to 30 m wide, or a discontinuous belt of individual shrubs.

d) Mixed Tournefortia (Messerschmidia, Argusia), Scaevola and Guettarda scrub

This mixed scrub is a form of Scaevola scrub in which other shrubs are also dominant.

e) Seagrass flats

Seagrass flats are dominated by Thalassia. There are extensive areas of the lagoon over which there is no Thalassia, or only very sparse seagrass. Little seems to have been done on the ecology of these areas (Zann, 1982), though they are important areas for the production of shellfish such as Anadara.

2.3. Socio-economic information

Table 4 summarises the economic profile of Kiribati. These data are examined in more detail in the next section in relation to development factors. Kiribati currency is the Australian dollar, and this currency is used for comparative costings in this report.

Table 4. Summary of the Economic Profile of Kiribati (1988 - 1991) Macroeconomic indicators (in millions of Australian dollars).

	1988	1989	1990	1991
Gross Domestic Product (Factor Cost)	40.4	42.0	39.1	40.7
Nominal GDP	44.2	46.5	44.4	46.9
Real GDP (% Change)	16.4	-0.2	-8.8	0.4
Balance of Trade	-21.5	-22.2	-30.7	N/A
Imports	28.2	28.6	34.4	N/A
Exports	6.7	6.4	3.7	N/A
Copra	1.6	2.6	1.0	N/A
Fish	1.6	2.6	1.0	N/A
Seaweed	0.0	0.1	0.7	N/A
Retail Price Index (% Change)	3.8	6.1	5.1	N/A
Goverment Revenue	19.4	18.1	25.0	22.8
Revenue Supplementation from RERF	8.0	5.0	7.9	7.5
Government Expenditure	18.3	20.0	22.1	22.8
Value of RERF	176.1	200.9	220.4	228.1

2.4. Land use values

It is important to distinguish between urban land, which is only found in South Tarawa, and non-urban land, upon which subsistence is practised.

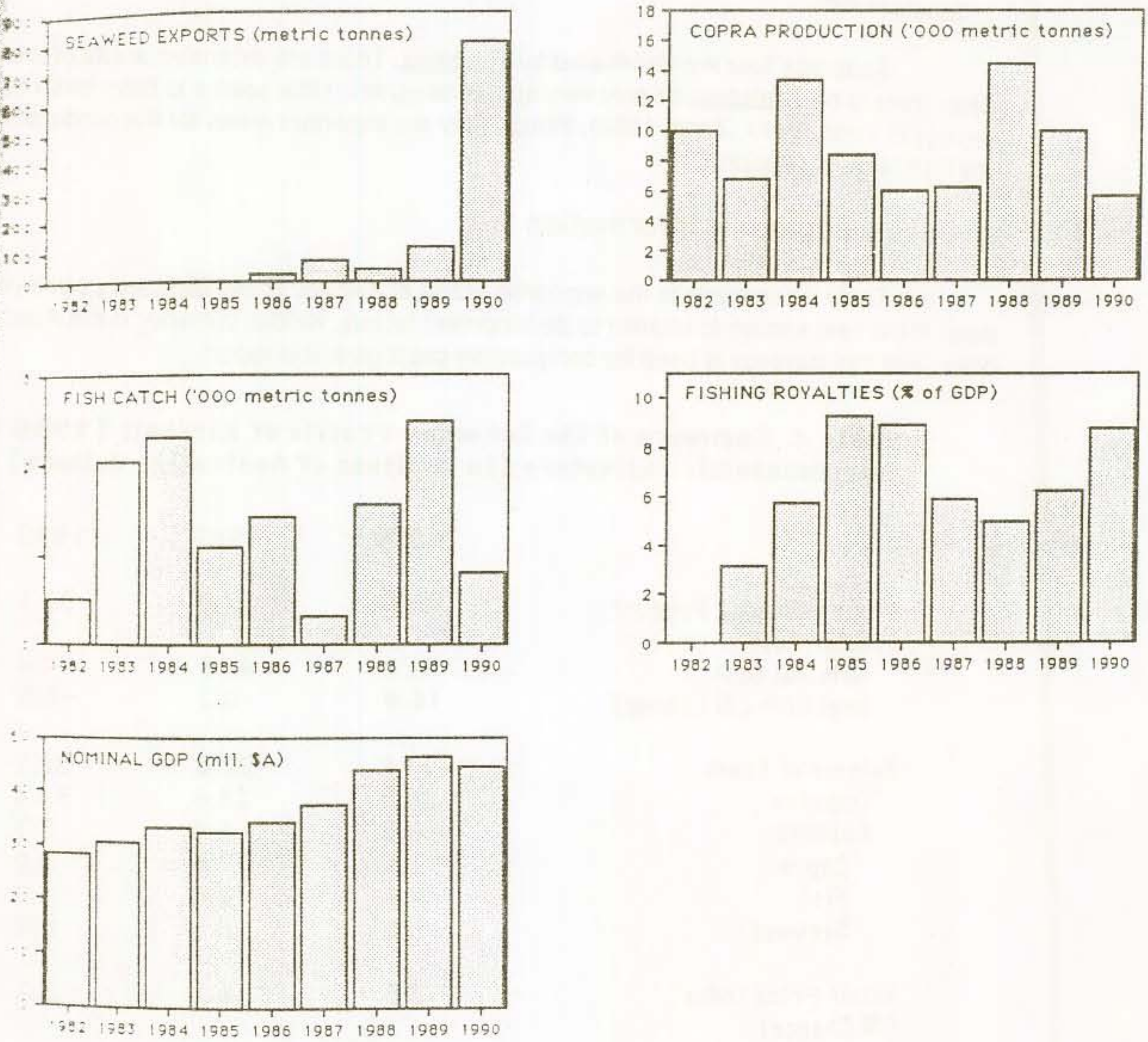

Figure 13. Kiribati economy: production, exports and GDP, 1982-1990.

2.4.1. Capital value

All land in Kiribati, except land that has accreted as a result of causeway construction, is owned. Land can be passed on through the family in either a patrilineal or matrilineal way. Much of the land in South Tarawa is leased to the Government. On the other hand all land in the Line and Phoenix Islands is owned by the Government, which bought the remaining land that it did not own only a few years ago for a rate of \$1000/acre (approx. \$2500/ha). This figure can still be used for areas of the outlying islands including North Tarawa. There has been an increasing trend towards individual freehold sale of formerly owned land, especially in South Tarawa.

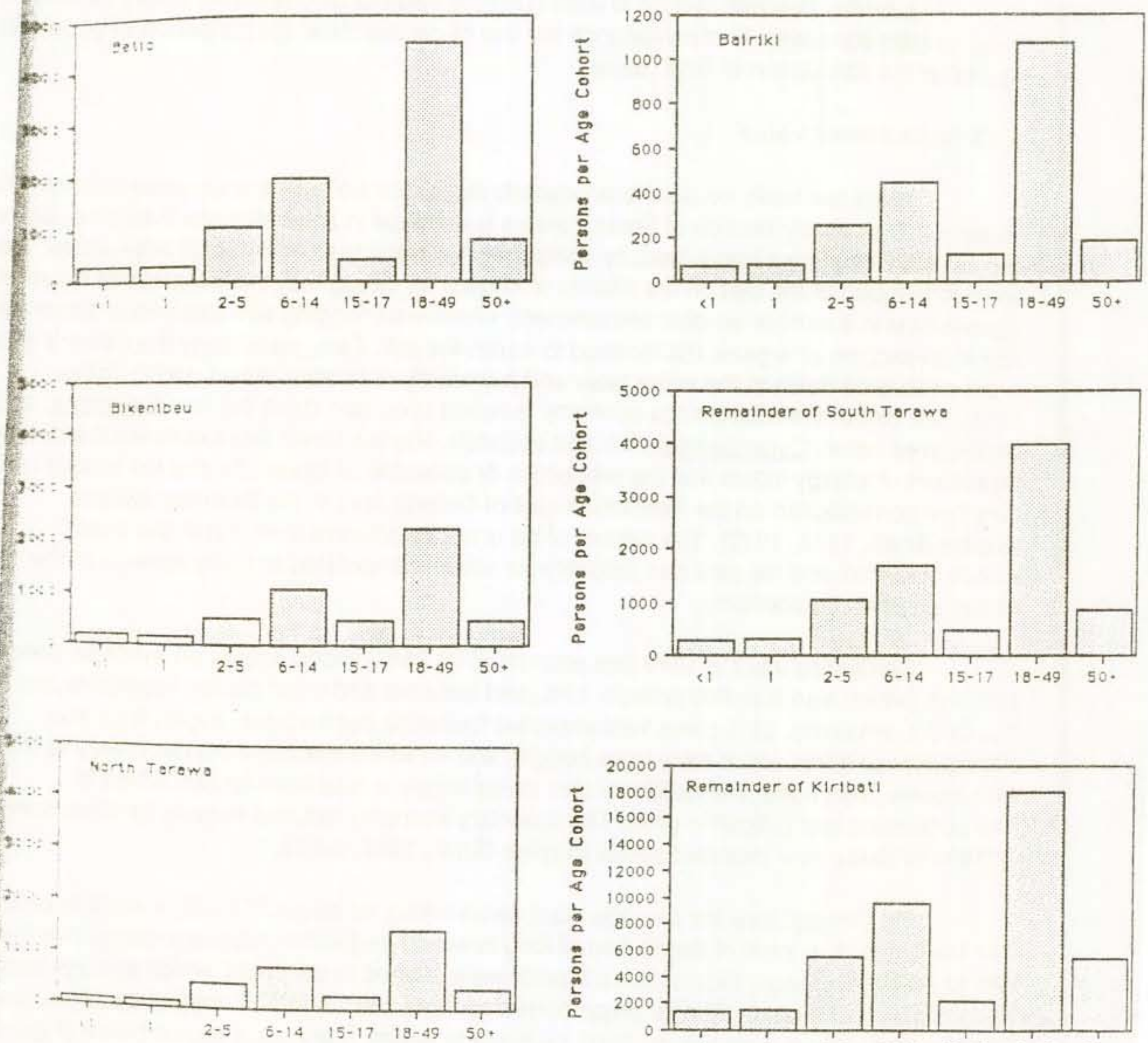

Figure 14. Age structure of population for urban Betio, Bairiki and Bikenibeu, and for the remainder of South Tarawa, compared with that for North Tarawa and the remainder of Kiribati.

Some land prices have risen as high as $4165/acre (approx $10,290/ha). This figure is based upon the Government lease value of $500/acre, capitalised taking the current interest rate of 12% into account.

Another approach towards calculating the value of land, is to value it in terms of the coconuts it supports (the principal cash crop). The value put on an individual coconut tree, should compensation be paid for loss of palms, as with Australian Government infrastructure development projects, is $25. Coconut densities are characteristically 80-150/ha, representing values of $2000-3750/ha. Coconut densities as high as 231/ha have been reported from Bikenibeu, and as high as 321/ha on Abemama (Thaman, 1990), corresponding to values of $5775/ha and $8025/ha. This, of course, assigns no capital value to other plants or resources on the land, despite as will be emphasised below, their role in the subsistence economy.

A further problem related to assessing the value of land is that in South Tarawa several areas contain squatters. This compounds the use of census data; the projection of population figures; or the calculation of land values.

2.4.2. Subsistence value

There are really no data to adequately represent the subsistence value of land. The majority of the country outside of South Tarawa is engaged in a subsistence livelihood. Some aspects of this can be summarised, by comparison with studies of other atoll economies. Taro is an important part of the diet on the islands of Kiribati, as throughout the low atolls of Polynesia. It grows best in a semi-anaerobic environment, where waterlogging with freshwater slows the rate of breakdown of organic matter used to mulch the soil. Taro, particularly the babai is grown in pits excavated down to the water table and intensively cultivated (Small, 1972; Tofiga, 1985). The diet of the subsistence economy is based upon taro (both the taro Colocasia, and the large-leaved babai, Cyrtosperma), fish and coconuts. Bayliss-Smith has examined the detailed breakdown of energy inputs into the production or collection of foodstuffs and the energy gained from their consumption on the Polynesian atoll of Ontong Java in the Solomon Islands (Bayliss-Smith, 1973, 1982). The pattern of life is not so different from that in the outer islands of Kiribati and his data can probably be safely extrapolated to many aspects of the Kiribati subsistence economy.

On Ontong Java in 1970 taro accounted for 29% of food energy on average, coconut 21%, fish (which also supplied protein) 19%, and bananas and other garden vegetable and fruit 3%. Of the remaining, 25% came from imported foodstuffs such as rice, sugar, flour and biscuits. These items which have to be bought, and for which it is therefore necessary to have a cash income, also upset the traditional diet, being largely a substitute for taro which is time-consuming and difficult to grow. The monetary economy induces scarcity by stimulating a demand for these new imported goods (Bayliss-Smith, 1982, p.60.).

On Ontong Java the average adult was working for about 27 hours a week to produce their foodstuffs. A system of distribution of food between and within families ensured that there was no shortage of food. 84% of those islands were planted to coconuts, which through copra brought in 94% of income. Similar proportions may have been true of Kiribati at that time, but the value of the copra crop has declined markedly in recent years, as is shown below (Figure 13), and coconuts occupy a different relative position now to that which they held then. A further element in the Kiribati outer island system is the pigs and chickens which are kept to supplement the diet.

There are some data on the subsistence economy of Onotoa (Ward and Monsell-Davis, 1990). Of the small cash income (annual average of $263 per capita in 1989), this was divided into 49.3% from copra, 14.2% from wages and salaries, 22.1% from wages and salaries directly involved in construction of causeways on the atoll, 10.3% from overseas remittances, 3.9% from the sale of produce, and 0.2% from the sale of handicrafts.

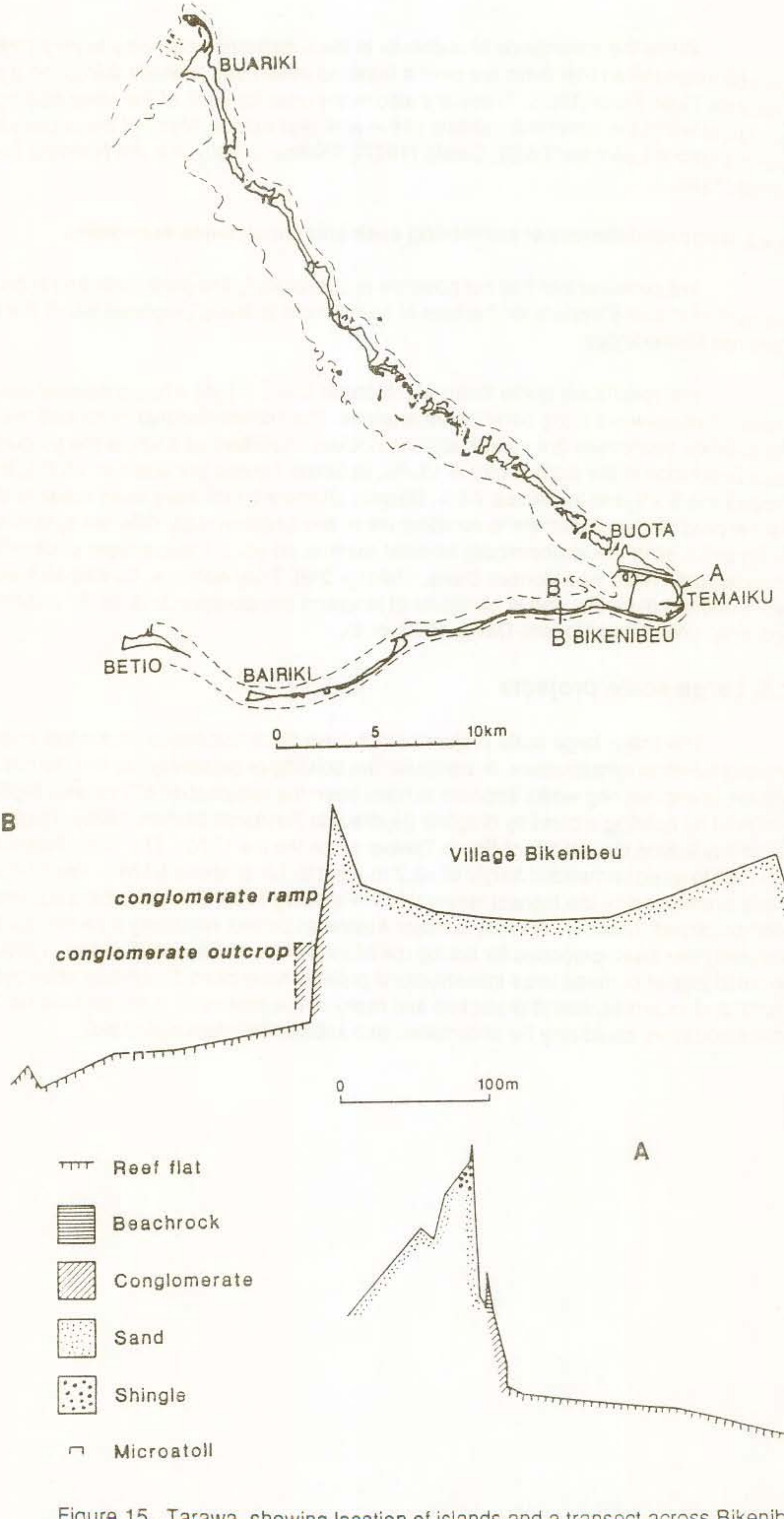

Figure 15. Tarawa, showing location of islands and a transect across Bikenib

While the importance of coconuts in the subsistence economy is very cle also be emphasised that there are over a hundred other uses to which the coconut (National Task Force,1992). There are also many uses for each of the other major are found within the terrestrial habitats of the atoll reef islands. Many of these uses summarised in Luomala (1953), Catala (1957), Thaman (1990) or in the National Ta report (1992).

2.4.3. Inappropriateness of combining cash and subsistence economies

We consider that it is not possible to successfully integrate cash and subsis economies into one system for the type of benefit/cost analysis proposed within the IP Common Methodology.

We specifically quote Ward and Monsell-Davis (1990) who considered asses impact of causeways using benefit/cost analysis. They concluded that 'in Kiribati the ca subsistence economies are inextricably interlocked. In Kiribati as a whole the proportior adult population in the cash sector is 19.4%. In South Tarawa this soars to 35.7%, but i Tarawa it is 6.9% and in Onotoa 7.6%. Despite attempts which have been made to do s neither possible nor legitimate to combine these two fundamentally different systems int which behaves in the 'economically rational' manner on which the premises of benefit/co analysis rest' (Ward and Monsell-Davis, 1990: p. 2-3). They continue, 'In Kiribati there is lack of statistical series, and in particular of longterm comparative data for the subsistenc economy' (Ward and Monsell-Davis, 1990: p. 3).

2.5. Large scale projects

The major large scale projects which have been undertaken in Kiribati involve improvements to infrastructure, in particular the building of causeways to link islands. The first major engineering works appears to have been the reclamation of Temaiku Bight. This achieved by building a bund by dragline (Hydraulics Research Station, 1976). There has b causeway linking the islands of South Tarawa since the the 1970s. The Betio-Bairiki cause was built to a recommended height of +3.7 m , that is 1.8 m above MHWS. We note howev it was overtopped by the highest spring tide in February 1992. Several other causeways ha been proposed. There is presently a major Australian project rebuilding a causeway on Ono causeway has been proposed for linking the islands of North Tarawa (Colman, 1989). It sho be noted that all of these large infrastructural projects have been dependent upon overseas capital and expertise. Island protection and many of the measures to be considered under accommodation, could only be undertaken with substantial international aid.

3. Identification of relevant development factors

It is clear that vulnerability has most meaning in relation to human activities. In this section the Kiribati economy and socio-economic factors are summarised.

Up until 1979, the year in which Kiribati gained independence, it was receiving a reliable income from phosphate mining on Banaba, which contributed 85% of export earnings, 45% of GDP and 50% of government revenue. Investment of the income from phosphate in a fund called the Revenue Equalization Reserve Fund (RERF) remains the country's principal external asset. Since independence the annual rate of growth of the economy has been low, <1%, with in the last few years a decline in per capita income. The Gross Domestic Product (GDP) in 1991 was $40.7 million (Australian dollars, see Table 4). It has been, and remains, an aim to increase the sustainable rate of growth, and it is aimed at a 5% per annum growth over the next few years.

Two prime constraints to growth have been recognised, firstly the lack of entrepreneurship, resulting from a shortage of skilled manpower, despite a rapidly increasing population. Secondly there is a lack of capital. In addition the remoteness of Kiribati, from world markets and supply routes, its fragmented population, and its limited natural resources are significant constraints.

Kiribati produces three main exports, copra, fish and seaweed. Copra, marketed through the Copra Co-operative Society, has been the traditional export; however, its contribution to the balance of payments decreased markedly in 1990 as a result of low rainfall and hence poor coconut production; aging trees, and a low market price. In fact the decline in copra earnings resulted in a 5% reduction in nominal GDP, and a 9% reduction in real GDP (Table 4).

Fishing is also an international money-earner, but the capability of the Kiribati fishing fleet is limited. There are 4-5 pole and line vessels, and fishing is principally close-to-shore. In 1990 activites of the fishing company Te Mautari were suspended while the boats were refitted, and there was a 69% fall in the value of the catch. Both fish catch and coconut crop are affected by the year-to-year El Niño oscillations in climate (Figure 13).

A growth area over recent years has been the cultivation of the exotic eucheuma seaweed Eucheuma cottonii, which is being marketed in a joint venture with a Danish company, for use in food processing and pharmaceuticals. Indeed income from seaweed now exceeds that from copra (Figure 13).

Foreign income (in addition to use of the external asset of the RERF) comes from royalties for fishing in Kiribati waters (and seizure of vessels), and remittances from workers overseas (Table 4). Most remittances come either from workers on Nauru, or seamen. In 1985, of 10093 households, 630 received some remittance from workers on Nauru, and 1000 received money from seamen with South Pacific Marine Services (SPMS). The other large source of foreign income is aid. Almost all aid comes on grant terms from friendly donor countries and multilateral agencies, with only modest borrowing from Asian Development Bank concessional window. These sources of foreign funds mean that GNP exceeds GDP by more tha 50%.

The development objectives spelt out in the 6th National Development Plan (1987-1991), are likely to be continued in the 7th plan which is soon to be issued. It is aimed to stimulate growth in small industries (such as fish processing and canning, fruit and vegetable growing, coir industry based on copra, and handicrafts). Growth is planned through four strategies: i) promotion and expansion of domestic production and concentration on resource-based industries; ii) privatisation (public administration presently represents a third of GDP), and establishment of an industrial estate on Betio (industry presently accounts for only 2% of GDP); iii) developing skills (especially through joint ventures); and developing the Line and Phoenix Groups, (there is already a resettlement scheme for the northern Line Islands, using the Government owned land on Kiritimati, Teraina and Tabuaerai). Kiritimati has the only established tourism in Kiribati, based upon fishing and bird-watching for tourists from the U.S.

Capital projects are restricted to projects that are covered by external aid. Aid has been sought in particular to develop infrastructure, especially roads, airstrips, causeways (connecting islands), communications and water and electricity supply.

The population in the 1990 Census was 72298 (Population statistics are summarised in the Appendix). This is unevenly spread; 96% live in the Gilbert group, with over a third on urbanised South Tarawa, where there is a population density of 1596 persons/km^2. On Betio the population density is >5500 persons/km^2, and increasing at a rate which suggests that it will rival Hong Kong or Singapore by the turn of the century. Crowding is a problem on South Tarawa; young people from the outer islands are attracted to the urban facilities offered on Tarawa and the median age is 20 in South Tarawa. 40% of the population is under 15 years of age, and there is an average of 7.4 persons per household in comparison with an average of 5 elsewhere in Kiribati (Figure 14).

The natural rate of population increase is 2.4%. Emigration is 0.3%. There does not seem to be firm data on the out-migration from the outer islands into Tarawa. On the outer islands there is largely subsistence. Of the 11,142 people reported to be in cash employment, most are on South Tarawa.

The people of Kiribati generally enjoy a good standard of living. They are healthy, and have an adequate dietary intake, at least in terms of calories per day. Medical care, family planning and education (at least in the lower level) is free. Health and education spending represent 16% of GDP.

The most likely development scenario for the next 30 years is continued urbanisation and population growth on South Tarawa, with urban development spreading north inot North Tarawa as access improves. This is likely to be accompanied by out-migration from the outer islands into Tarawa which will be increasingly expressed in the population age structure. The major infrastructure developments are likely to come about through causeway construction and better communications.

4. Assessment of physical changes and natural system responses

4.1. Morphological development of the shoreline

It is important to stress that reef islands are naturally dynamic. The sediment that makes up islands is continuing to be produced, so there is not a finite sediment supply as there may be on many continental beaches. Sediment, as well as being produced, is also lost through breakdown or dissolution.

Reef islands can be divided into a number of types (Stoddart and Steers, 1977). On atolls there are often sand islands with shingle ridges on the more exposed rim; these are often known by the Polynesian term 'motu'. In more sheltered situations cays built entirely of sand are formed. The location of islands on atoll rims is usually a subtle but balanced outcome of patterns of wave and current activity. Reef-top islands (also termed table reefs) such as Tamana, Kuria and Makin, are a special form of island where one single island occupies a large proportion of the reef platform (see Table 2). Few data are available on these islands from Kiribati, though McLean (1989) reports preliminary observations on the topography of Kuria.

The principal features of a typical reef island are shown schematically in Figure 11. Conglomerate platform where it is found, generally underlies the oceanward side of an island; elsewhere the beach directly overlies the reef flat. A feature of many of the islands in the Gilbert group is that this conglomerate platform forms linear extensions like groynes across the reef flat; these serve to slow sediment exchange along the reef flat. The seaward beach is often coarser (shingle or rubble) where there is a conglomerate platform, and the platform and these coarser sediments provide some stability to the shoreline. There is often a lagoonal ridge of finer sediment, and a central depression (McLean and Hosking, 1991b). It is in this central area that excavations for babai pits are made (Plates 1c and 1d). A typical transect across the linear island of Bikenbeu is shown in Figure 15, demonstrating the central depression.

The geomorphological history of reef islands has been outlined above. Islands are geologically extremely young; probably not having existed for more than 3500 years. It is less clear what the pattern of sediment accretion on islands has been over those 3500 years. At least three different possibilties exist; firstly islands may have accumulated uniformly over that time, and thus be continuing to build up at the same gradual rate; secondly islands may have formed initially around 3500 years ago as conditions were first favourable for supratidal accumulation, and then have received progressively less sediment with time; thirdly islands may have accreted during one or more episodes within that period. It would be extremely useful to know which, if any, of these simplified models of island growth was appropriate, as it would give an insight into modern and future island dynamics. On the Great Barrier Reef, one of the few studies using extensive radiocarbon dating, has demonstrated that shingle islands appear to have accreted uniformly over the last few thousand years (Chivas et al., 1986). That study however comes from a high-energy reefal environment where cyclones are important and cannot be readily extrapolated to the much lower-energy largely sandy islands of Kiribati. It is most likely that different processes are dominant on different islands, and that individual islands are in different stages of evolution.

Evidence for the natural dynamics of Kiribati reef islands comes principally from monitoring of effects of the Betio-Bairiki causeway. Each of the geologists who have examined the issues related to the impact of causeways has stressed the natural dynamics of the shore (Gauss, 1982; Howorth, 1982, 1983a, 1983b; Burne, 1983; Carter, 1983; Harper, 1987, 1989a, 1989c; Howorth et al., 1986; Colman, 1989; Howorth and Radke, 1991; Byrne, 1991; Gillie, 1991).

The morphology of a reef island can be thought of as in an equilibrium with the processes which operate to move sediment. On some islands there may be a stable equilibrium,

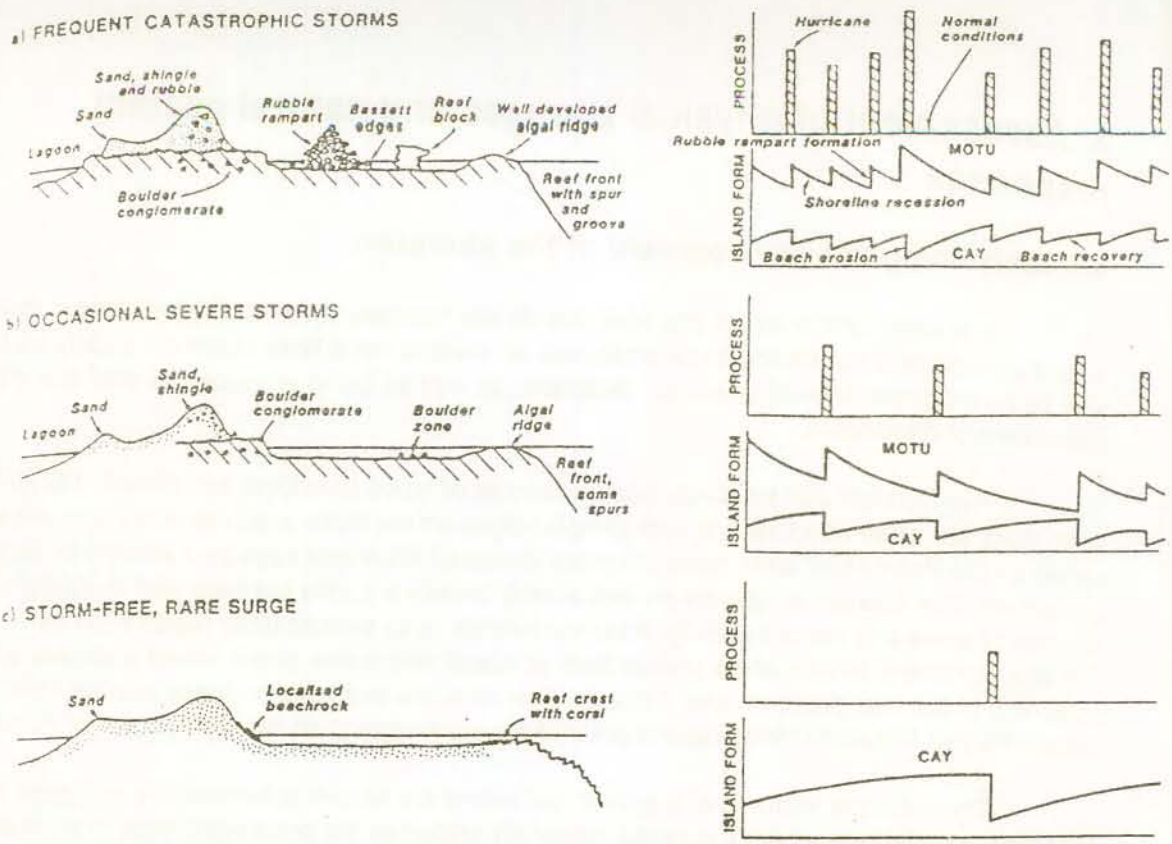

Figure 16. The morphology of reefs and reef islands in areas of different storm occurrence, and the response of form to process (based on Bayliss-Smith, 1988; modified by Woodroffe, 1989b).

while on others sediment is added and lost from islands over time, and there is a dynamic equilibrium between inputs and outputs. Catastrophic storms play an important role in both construction and destruction of many islands in seas which experience hurricanes (Stoddart, 1971), though the effect of these episodic but high magnitude events is also likely to differ on different types of island. Motus, which are sand and shingle islands typical of high-energy settings of atolls which experience storms, are built up in part by rubble-sized material which cannot be moved by regular processes; storms are obviously instrumental in moving this coarse material, and large reef blocks, onto the reef flat (i.e. Hurricane Bebe in Tuvalu, Maragos et al., 1973). It has been shown, however, that regular less severe storms break down and redistribute the storm rubble landwards (Baines et al., 1974; Baines and McLean, 1976a, 1976b; Bayliss-Smith, 1988). Rubble is usually an important constituent of a well-developed conglomerate platform beneath islands, a legeacy 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.

Not all islands are affected equally by storms and the morphology of islands differs accordingly (McLean, 1980). Figure 16 illustrates the morphology of islands in different categories of storm occurrence. It is schematic, and represents a generalisation that is not universal; other processes associated with strong tradewinds outside hurricane belts can also serve to modify islands, as in Kiribati 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 of the high-energy reef flat; the algal ridge is well-developed, 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).

Figure 16 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 to an 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 tsunami, or a rogue hurricane, can cause devastation on these islands, and such catastrophes will require a long time for recovery (Figure 16).

There are insufficient data to determine the principal patterns of sediment production, movement and deposition for reef islands in Kiribati. The best data exist for Tarawa; the initial study of lagoonal sediment type and probable movement by Weber and Woodhead (1972), has been extended by several studies, particularly in relation to existing or potential causeways (Colman, 1989; Byrne, 1991). Coral contributes less to the sediment with distance away from the western reef crest across the lagoon, and the contribution of the alga Halimeda, and molluscs, both produced within the lagoon, increases in the finer-grained muddy sediments of the lagoon west of Temaiku. The patterns of sediment movement on Tarawa are still not clear, while the situation on other atolls remains unknown. Sediment samples collected on Maiana for this study serve to demonstrate that molluscs represent a disproportionately large component of the lagoon beach sediments and suggest considerable variation in patterns of sediment production and movement.

Many of the beaches in Kiribati show signs of recent erosion. Erosion however, may be short-lived in some cases, or severe in others. By and large, in South Tarawa, and on Abaiang, the oceanward beaches appear to be accretionary, still growing from the accumulation of reef flat sediments, while 'lagoon shorelines were shown to be considerably more dynamic than ocean shorelines in terms of erosion/accretion cycles' (Harper, 1989b). Seasonal reversals of sediment movement; or reversal of general trends, such as the return of sediment back along lagoon shorelines under westerlie winds, (Byrne, 1991), play important roles in sediment redistribution. These movements are natural, and are important as they are the way the beach adjusts to fluctuating processes. Seawalls and other engineering structures interrupt these movements, which in turn can have detrimental effects on the downdrift shoreline.

It is also important to stress the great variability of conditions at present in Kiribati, both geographically, and from year to year. There are large fluctuations in rainfall related to El Niño, which serve to put large stresses on the economy of several islands in drought years. There are also large fluctuations in sea level from year to year, also related to El Niño. Indeed the smaller ASLR1 scenario represents a total rise by the year 2100 that is less than the range within which the sea presently fluctuates. In other words the mean under that scenario will be at a level which was experienced as a mean for several months in late 1982. Of course, it is important to recognise that the fluctuations are likely to continue, so that vagaries like that in 1982, will result in a mean sea level for a time that will be 30 cm or so above that experienced in 1982 (i.e. 60 cm above the long term mean). This will lead to inundation of more extensive areas, overtopping of low beach crests, and probably shoreline erosion in some places. Nevertheless the fact that the sea has.been to these levels for short periods should serve to dispe notions that such a rise will be immediately accompanied by catastrophic erosion.

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, on the reef islands and on the groundwater. However, we should point out that the processes which are acting daily on the shorelines of Kiribati are not fully understood nor is it presently possible to accurately predict the impact of structures such as causeways, and it is clearly going to be very difficult, therefore, to forecast what changes will occur under accelerated sea-level rise.

4.2.1. Effects on reefs

Massive corals can grow at rates of up to about 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 only a few reefs kept up. Drilling of reef on the Huon Peninsula, New Guinea has suggested that that reef kept up with sea level (Chappell and Polach, 1991). Other reefs seem to have been catching up with sea level (Neumann and Macintyre, 1985). Exceptionally a reef may accumulate at up to 16 mm/yr, where storm accumulation has occurred and branching corals comprise the matrix. However 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 have occurred in water depths of around 5m (Hopley and Kinsey, 1988; Buddemeier and Smith, 1988). On atolls reef growth rates up to 5 mm/yr are characteristic, with rates of up to 8 mm/yr recorded (Marshall and Jacobson, 1985). Under these circumstances Kiribati reefs could keep up with ASLR1, but would eventually lag slightly behind ASLR2.

Little change will 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 will be the recolonisation of extensive areas of presently bare reef flat by coral (Hopley and Kinsey, 1988). The poor condition of reef flats, particularly in Tarawa, was noted by McLean (1989).The bare reef flats typical of Gilbert Island atolls 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). There is a general absence of coral or coralline algae over reef flats along the southern margin of Tarawa, and extensive areas of green algae suggest a highly eutrophied condition. Under these circumstances coral re-establishment might take considerably longer, if indeed it can occur, than where the reef flat is more healthy. Thus those reefs which are most needed to protect the urban environment are perhaps the least likely to respond by vigorous growth. If there is no reponse on the reef flat then water depth will increase resulting in greater wave energy reaching the shore, and altered patterns of wave refraction, which may then accelerate erosion.

4.2.2. Effects on reef islands

Flooding of the lowest-lying parts of islands is likely to occur under higher sea level. The areas which are lowest lying at present are often subject to extensive inundation at exceptional high spring tides or by storms or surges. These areas are consequently dominated by salt-tolerant vegetation, often mangroves or scrubland of _Pemphis acidula_. These areas will be flooded more often when the sea is higher, and mangrove and _Pemphis_ will become established further landwards in areas that were previously beyond inundation but are now flooded. Many reef-top islands will flood from the interior, with water tables rising in babai pits.

However, it is not clear whether reef islands will erode, or whether sediment from the reef flat might contribute to continued growth of islands. There are at least three responses of islands which can be envisaged as a result of sea-level rise. These are illustrated in Figure 17, and consist of i) the Bruun response, ii) the equilibrium response, and iii) continued growth.

a) _Bruun response_

The Bruun rule applied to the response of sandy beaches to sea-level rise indicates that the beach will erode and retreat (see Figure 17b), and that sediment will be deposited over the reef flat area in front of it (Bruun, 1988). It should be emphasised that rising sea level is not the only cause of beach erosion, nor indeed is it necessarily the most dominant, and beaches elsewhere show long-term trends of erosion and recovery significantly related to factors such as rainfall, storms and El Niño. Nor does the Bruun rule appear to hold over long-term sea-level rise, such as the Holocene marine transgression, where in some instances landward reworking

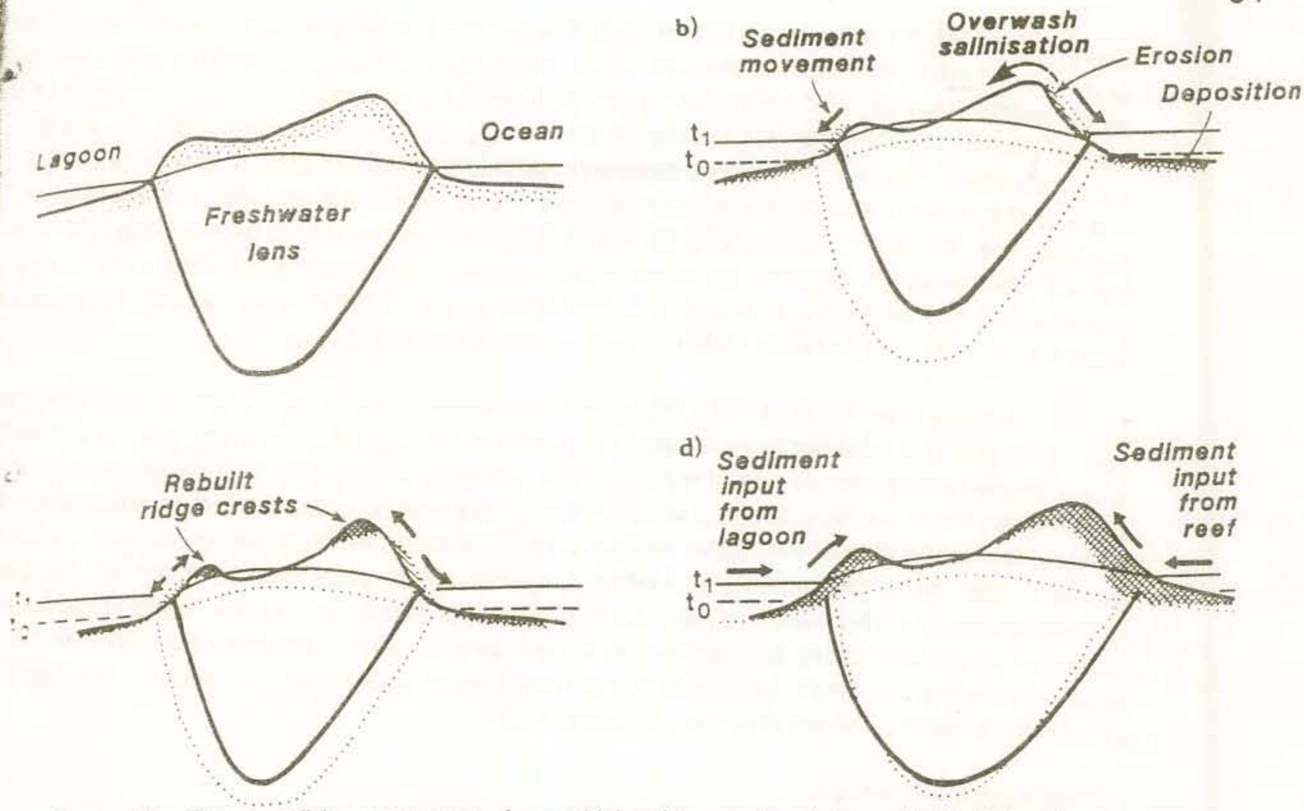

Figure 17. The possible responses of a reef island to sea-level rise: a) initial island morphology: b) the Bruun response: c) the equilibrium response, and d) continued growth. Details are discussed in the text.

of sand, 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.

b) Equilibrium response

An equilibrium response is shown in Figure 17c. It differs only slightly from the Bruun response. The beach undergoes erosion, but some of the eroded sand is deposited on the ridge crest, building it up and maintaining a profile in balance with the processes dominating the shoreline. Reef islands generally have a form that is low in the middle with a pronounced ridge on oceanward and a small ridge on lagoonward shores (McLean and Hosking, 1991b). These ridges prevent the majority of storms from overwashing into the island, and are presumably built up by frequent small storms. Reef island form therefore appears to be in equilibrium with processes operating on it (Stoddart et al., 1978; Bayliss-Smith, 1988). If sea level rises at a rate that is not too fast, this equilibrium will be maintained at higher sea levels (Figure 17c). Erosion of material from the beachface will occur and some retreat of the shoreline is likely, although as the angle of the beachface is generally steep, this is unlikely to result in 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 permit the equilibrium to re-establish.

c) Continued growth

The third view of island response to sea-level rise is one of continued growth through sediment accretion (Figure 17d). 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). This is the view favoured by McLean (1989), and described in some detail in that study. 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, is likely to build the shoreline up into a new equilibrium form. On several islands a rise of 50 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 (ASLR2) 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 than ASLR2 (for example more than 50 cm above present by the year 2050) 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 will 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.

d) Choice between models

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 todays reef islands. We presently have no way of knowing which will occur in the future, and it will also be extremely difficult to determine which has happened without careful monitoring by surveys and aerial photographic records.

4.2.3. Effects on groundwater

If the sea rises the freshwater lens will be affected. The size of the lens is closely related to island width, but it has already been suggested that we are unsure of the response of islands themselves to sea-level rise; they may decrease or increase in width.

Salt can intrude into the aquifer by overwash, also called freeboard washover (Roy and Connell, 1989a, 1990). 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. These would then be replaced by more salt-tolerant species. The lens also shrinks during periods of low rainfall. At times of drought 'rainfall is insufficient to maintain a fresh-water head, permitting invasion of salt or brackish water through the pervious island sediments and rock foundation. The ground water in the narrower parts of the islands is soon contaminated, with the resultant death of breadfruit and eventual death even of coconut trees' (Cloud, 1952). The lens will expand again when more rainfall is received; the rapid extension of the lens on Kiritimati has been recorded, after 2000 mm of rain was received between July 1982 and February 1983 (Falkland and Brunel, 1989).

One feature that is clear in each response in Figure 17 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. On many reef islands the central depression is an important area for the intensive cultivation of taro (Colocasia and Cyrtosperma) in excavated pits. Taro is sensitive to salt, and will be killed by saltwater from excessive overwash. Cultivation of taro is a labour intensive activity already, and the rise of the water table is unlikely to be a problem which cannot be managed locally in individual pits.

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 freshwate lens (Miller and Mackenzie, 1988; Roy and Connell, 1989a, 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 aquifer (Oberdorfer and Buddemeier, 1988; Buddemeier and Oberdorfer, 1989).

4.3. Summary

The reef islands are naturally changing systems, existing in a dynamic equilibrium between processes of sediment production, accumulation, lithification and erosion. It is not as yet possible to predict how shorelines will change under stable sea level conditions, and so it is too early to forecast what responses reef islands or the freshwater lens will undergo in repsonse to ASLR. Monitoring of these changes now will be important in order to determine the direction of change as early as possible.

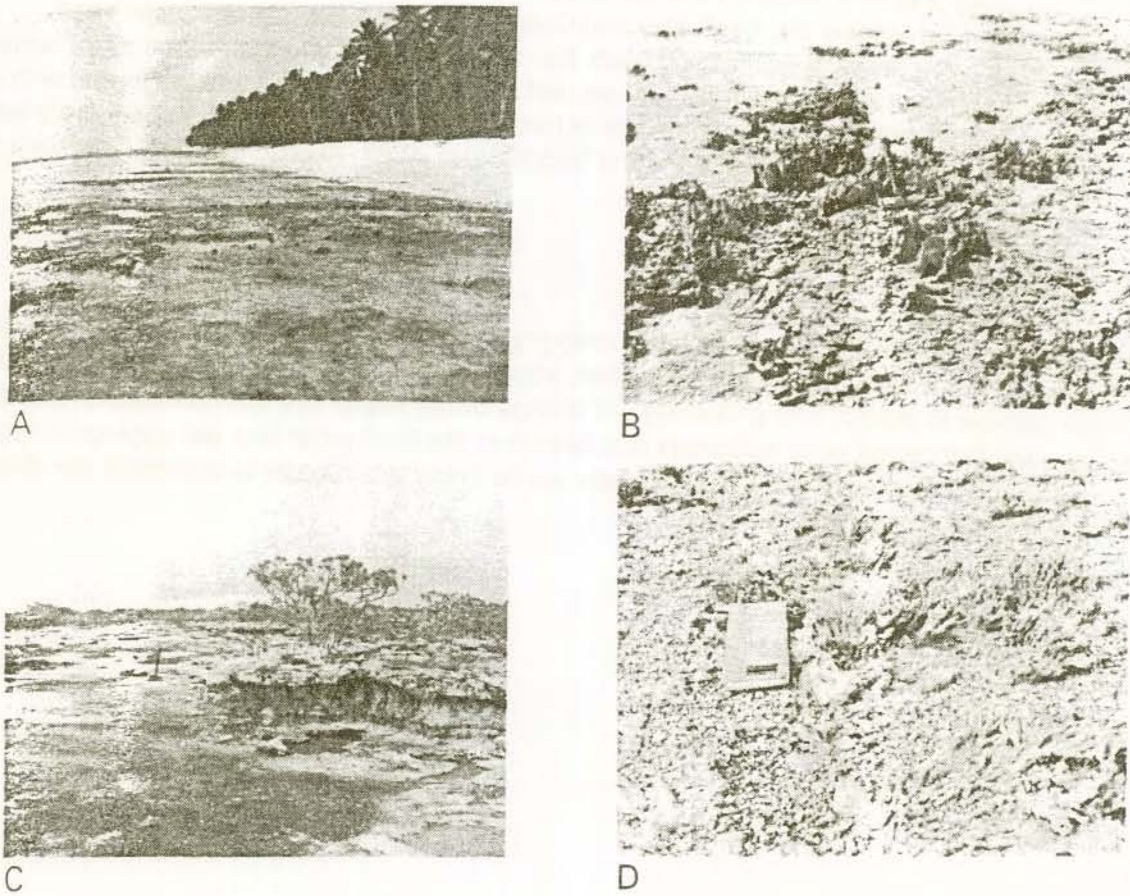

Plate 2 Fossil corals indicating that the sea has been higher than present in the past. A) Fossil Heliopora reef, north west Abemama. B) Individual fossil Heliopora coral in its growth position, north Abemama. C) Outcrop of heavily cemented limestone in the interior of Kiritimati. D) Fossil corals in their growth position, central Kiritimati, formed when the sea was higher.

5. Formulation of response strategies and assessment of their costs and effects

Four response strategies are outlined in the IPCC Common Methodology, a) Do nothing, b)Retreat, c) Protect and d) Accommodate. These are examined in turn below.

5.1. Do nothing

No measures is the IPCC reference situation and represents the situation at present. However, there are erosion problems on most of the islands of Kiribati at present, and these are to be expected given the way that islands form and change, and the variability in water levels and wave energy that occur as a result of natural environmental perturbations, such as El Niño. The coastal protection, principally seawalls that are there at present are there not to protect against ASLR, but nevertheless they would decrease the vulnerability of those areas in the event of sea-level rise. We have no estimate of the expenditure outlayed on construction and maintenance of existing seawalls.

5.2. Retreat

This is not a feasible option for Kiribati. There is nowhere to which to retreat; everywhere is within the influence of the sea. Banaba is the only island of elevation above 10 m, and it has been left ecologically disturbed after phosphate mining. Kiritimati, it is suggested in this report, is the least vulnerable of the islands of Kiribati and will undergo the least change under ASLR1 or ASLR2 scenarios, but its harsh environment does not make translocation of the entire population of Kiribati to that island, a realistic possibility. The retreat option exists only as an emigration option. The entire population of Kiribati might need to be moved somewhere else if the islands upon which the nation lives were to disappear (Connell and Roy, 1989). There are precedents for large scale movement of population in the Pacific, and indeed within Kiribati, with depopulation and resettlement of the Line and Phoenix groups, and migration of most of the population of Banaba to the island of Rabi in Fiji. Total disappearance of the islands seems unlikely under the ASLR scenarios and time slice considered here. The emigration response strategy is outside the scope of this study.

5.3. Protect

The full protection option is one that is to be reviewed for each nation as a part of the IPCC Common Methodology. This option is evidently viewed as the construction of protection works, principally seawalls, around all or selected areas of land.

In the case of Kiribati there is a disproportionately large perimeter for surface area for the nation as a whole (This can be seen by looking at the perimeter of atolls in the Appendix). Many of the atolls are composed of numerous small, elongate islands, and the wholescale protection of these would clearly be an enormous and expensive task. Perimeters of islands are summarised in the Appendix.

5.3.1. Cost of protection

The Public Works Department in Tarawa provided figures for the construction of three types of seawall. A coral rock seawall was costed at $174/m; a sand bag seawall was costed at $232/m and a gabion bag seawall was costed at $290/m. These costs include the costs of cement, labour and transportation. Gabion bags (or sand bags) are more resilient than vertical stone walls, and the latter can only be used in areas of low energy and even then require maintenance (Holmes, 1979, 1983; Ward and Monsell-Davis, 1990).

Table 5. **Costs of major engineering protection works**

	Cost per linear metre	Maintenance	Source
4m sloped sided causeway	$320	Low risk	Ward and Monsel Davis, 1990
Sloped sided causeway with concrete sand bag protection	$756	Very low risk	"
5m sloped sided causeway	$360	Low risk	"
Vertical sided causeway (stone packed)	$160	High risk	"
Sand bag cemented seawall	$232	Low risk	PWD, 1992
Coral rock seawall	$174	Medium risk	"
Gabion bag seawall	$290	Low risk	"

It is important to note, however, that each uses local material either a gabion bag fill, as slabs or as backfill, and the supply of this material is not taken into account. Thus if the entire coastline of Betio, for instance, was to be protected with a coral slab seawall, there wouldc be environmental problems finding a source of suitable material. The environmental acceptability of collecting fill from the lagoon, or coral slabs from the reef flat, has already been questioned (Hydraulics Research Station, 1976). We wish to reiterate that the reef flat in front of vulnerable areas must be fully protected from such mining, as alteration of the reef flat can change the energy levels received at the shore and result in further erosion. Lowering the reef flat is going to accelerate the impacts of sea-level rise, but is also likely to remove the potential sediment supply (Richmond, 1990). It should be prohibited, as should the removal of shingle and sand from beaches which are considered essential protection (see Plate 6d).

Furthermore if these figures are used as a measure of the cost of the protection optio then there should also be some cost for their repair and maintenance included. An examination the seawall structures around South Tarawa showed that almost all are in a poor state of repair and many are not performing the task for which they were constructed.

In practice, there are many more types of coastal protection than those which could t constructed by the Public Works Department. Individual land owners often choose to protect their properties, and many have constructed seawalls of their own (Plates 5 and 7). The costs (construction of these are unknown, but as family labour was presumably used, and is used in their maintenance, they must be considerably cheaper than the costs given above. In many ca they are also less successful.

Particular attention was paid to seawall construction during the visit to Tarawa. It would appear that many of the walls constructed were initially built more for the purposes of reclamation than protection, despite the need for application for reclamation under the Foreshore and Land Reclamation Act (1969) which declares ownership of the foreshore and regulates certain reclamation projects.

It needs to be asked to what extent sseawalls will be successful as protection. They be appropriate for the perimeter of highly urbanised islands, or small parts of islands (Lewis, 1990 demonstrates that construction of a wall is economically viable on one side of Nuku'alofa, Tonga), our calculations for the case study of Betio suggest that it is not viable for that island. Islands are especially porous, and construction of seawalls is not going to alter the rise, and in some cases the salinisation of the water table.

The costs of seawall construction would put the construction of the full protection option for Kiribati well beyond the level of 18.79% of GNP suggested by Tsyban et al. (1990).

5.4. Accommodate

The accommodate option is one of the hardest to define, but through elimination of the others becomes one of the more desirable. It has been the traditional response to storm inundation and flooding in the past. It is noteworthy that the houses, particularly those of local materials and which are raised above the ground are both more able to withstand inundation, and easier to move to a new location if necessary, than the more modern concrete structures which are becoming more widespread in urban Tarawa. There are a series of measures which could be introduced to plan for sea-level rise, such as building setbacks from the high water mark, planned retreat where only short term buildings are constructed in the most vulnerable locations. Planning should permit major developments only on the widest of islands. Islands at the corners of reefs are the easiest to build up with dredged material from the lagoon (i.e. the reclamation at Temaiku).

Further consideration of this option is beyond the scope of this study.

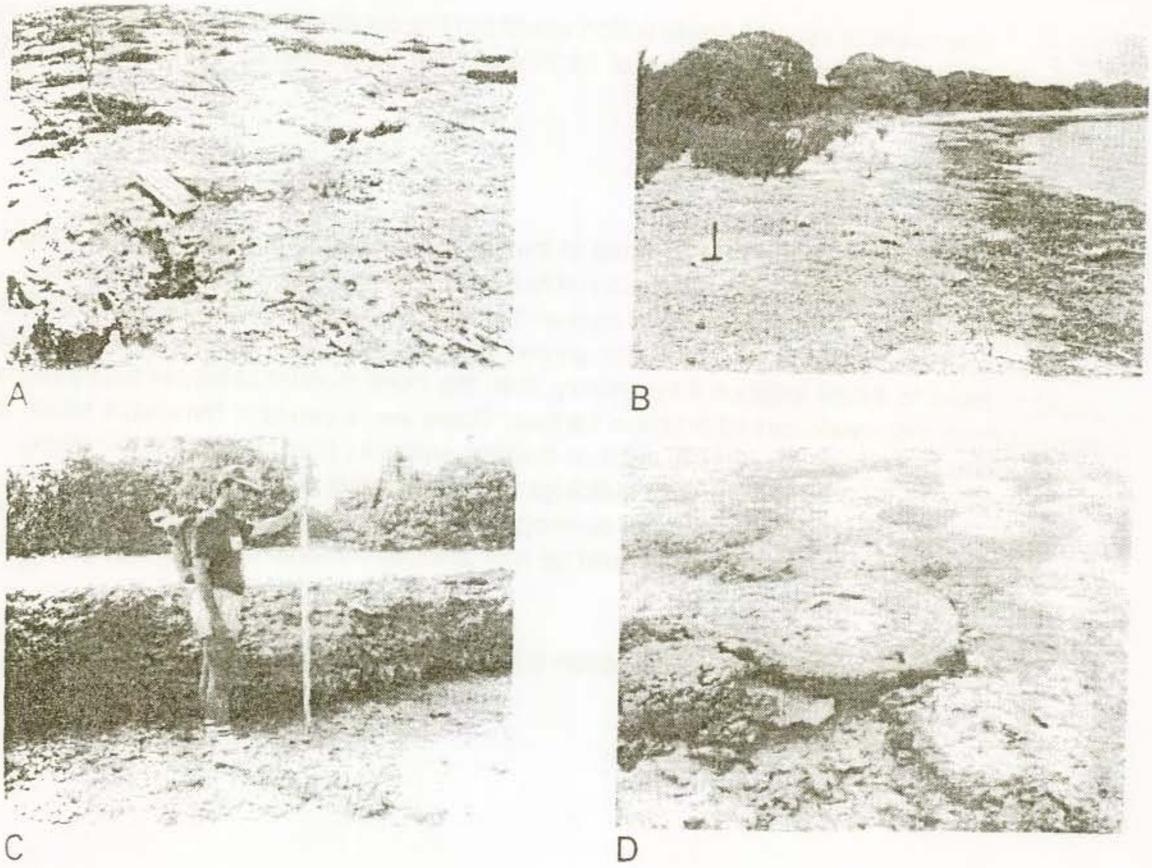

Plate 3 Microatolls, fossil and modern. A) A fossil microatoll, central Kiritimati, formed when the sea was higher. B) Interior saline lagoon, southern Kiritimati. The hammer is on a large fossil coral head, formed under conditions of higher sea level. C) Fossil Heliopora reef at the base of a conglomerate platform, northern Maiana. D) A modern microatoll living on the reef flat at Paris, Kiritimati. This specimen is more than 1.5 m across and indicates fluctuations in sea level over recent decades but no significant net trend.