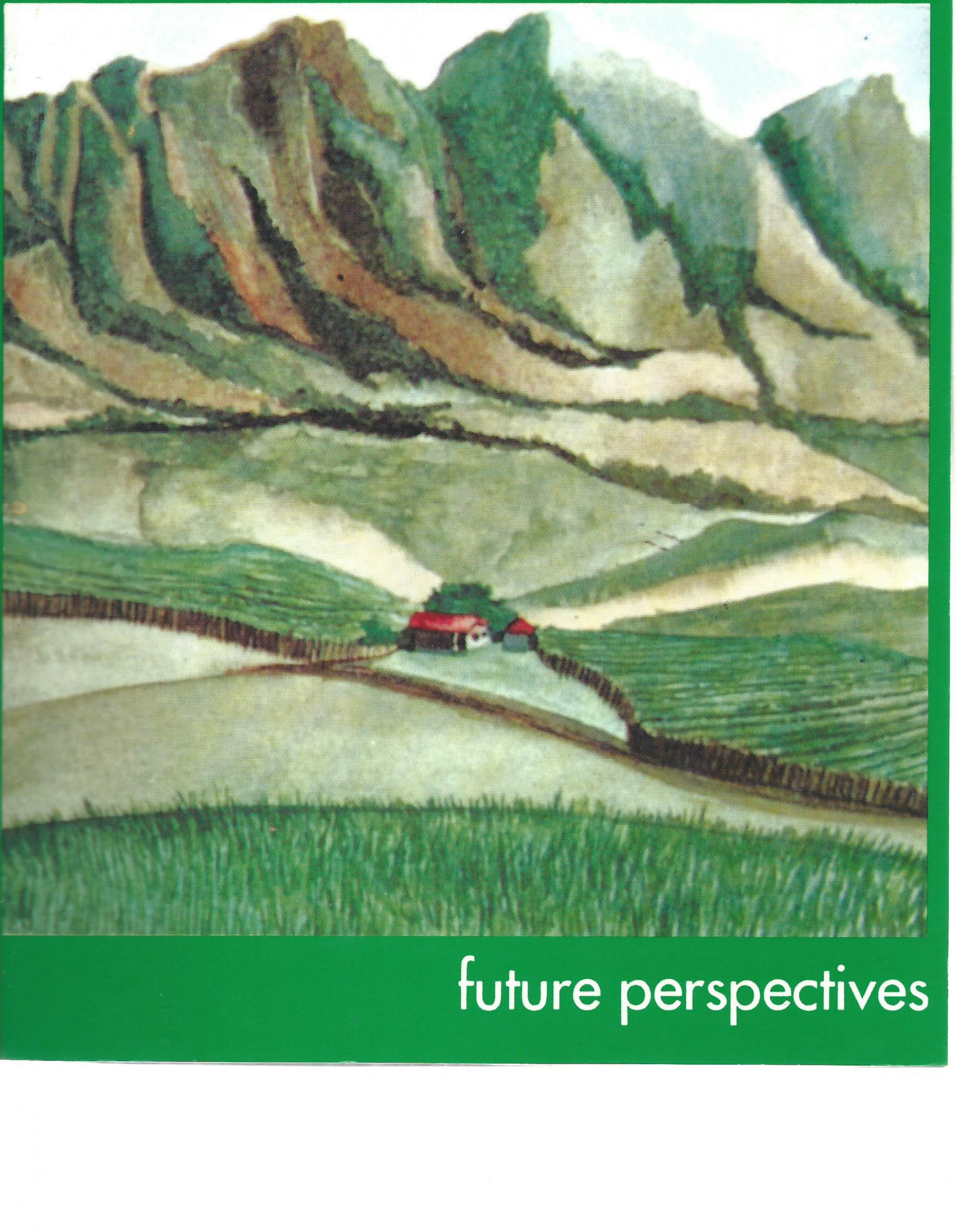
Climate & Agriculture in the Pacific Islands



future perspectives

Climate and Agriculture in the Pacific Islands: Future Perspectives

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Preface

A majority of Pacific Islanders rely on subsistence farming and fishing for their survival. These sectors are also major foreign currency earners in a number of countries. In cultural terms, the very existence of Pacific peoples is inseparable from the land.

Although the risks to the physical survival of many Pacific islands as a result of sea-level rise have been widely publicised, it is agriculture and marine and terrestial ecosystems that are likely to be affected greatest in the next century. It will be adverse effects on these systems that will probably render many areas uninhabitable long before they are totally inundated if they ever are. The lower limits of sea-level rise in the next century predicted by the International Panel on Climate Change support this hypothesis.

With this in mind the Fiji Institute of Agricultural Science and the University of the South Pacific Climate Change Researchers' Group organised a joint symposium in March 1991 with the theme of climate change and its effects on agriculture and ecosystems in Fiji and the Pacific. Although a number of regional and international meetings had been held concerning climate change, meetings at the national level had been lacking. Yet such meetings are critical if grass-roots awareness is to be increased and Pacific populations are to be made amenable to the changes and sacrifices that will have to be made to counter the negative impacts of future climate change.

The papers presented covered a range of topics. In his keynote address, Professor Ravuvu set the geographical and cultural background which needs to be considered in discussing responses to climate change. He also outlined and Dr Nunn spoke in more detail about the evidence for recent warming and sea-level rise in the Pacific. Dr Aalbersberg spoke in general about the ways in which climate change affects agriculture and also how agricultural practices can themselves affect the magnitude of climate change. Methods of lessening the negative effects were suggested.

The other presentations focused on more specific issues. Professor Willatt discussed the hydrological implications of climate change. It is likely that the stresses of both flooding and drought on agriculture will become greater as climate changes. Ms Jokhan discussed the mechanism by which increased carbon dioxide in the atmosphere can increase plant growth. Dr Wigglesworth gave an overview of information available on the genetic resources of major Pacific crops. Such resources are critical for breeding programmes to develop

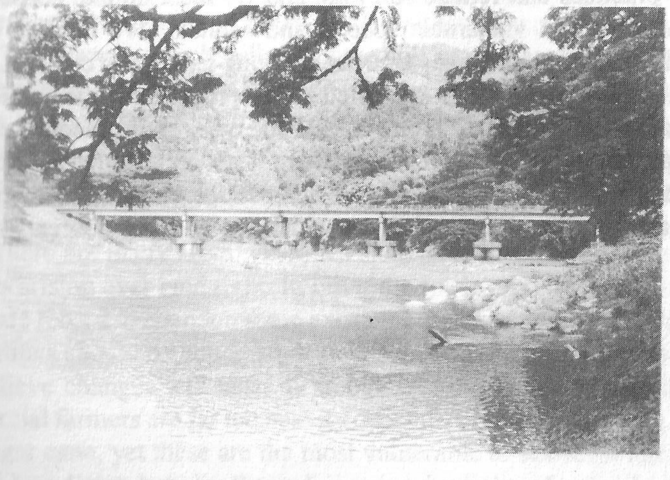

Plate 2. The bridge spanning the Wainimala River at Matainasau in central Viti Levu (Fiji) was washed away in a flood associated with the passage of Tropical Cyclone Kina in January 1993. Both the size of the cyclone (hurricane) and the magnitude of the flood were reportedly without precedent and may indicate the nature of the storms to which Pacific island peoples will have to adapt in the future.

Plate 3. The usually broad floodplain of the Wainimala River at Lutu is used intensively by the people for cultivation. Low areas in narrow valleys like this may become regularly flooded with increasing frequency, rendering them unreliable for agriculture in the future.

2

Recent warming of the Pacific region*

Patrick D. Nunn

Introduction

The Earth's climate is a topical issue at present, largely because of concerns about how the "greenhouse effect" may change the environment and its suitability for human occupation. This paper is an attempt to remove some of the misunderstanding which surrounds this subject by showing what evidence there is to support the belief that the South Pacific region has been warming recently, to what causes this may be attributed, and what the consequent implications are for the region's future.

The "Greenhouse Effect" and global warming

The greenhouse effect is a temperature-regulating mechanism which involves long-wave heat radiation from the Earth's surface being absorbed by "greenhouse gases" in the lower atmosphere, then being emitted (re-radiated) back to the Earth's surface. The greenhouse effect has existed on Earth for millions of years; without it, the Earth would experience extremes of cold. What most of the present concern is about is the 'human-enhanced greenhouse effect'. This involves concentrations of greenhouse gases in the lower part of the Earth's atmosphere increasing as the result of a number of human activities over the past 150 years or so. These activities include the combustion of fossil fuels, deforestation, increases in wetland rice farming and ruminant animals, and the manufacture of certain artificial coolants.

The increase in the lower atmosphere of greenhouse gases, principally carbon dioxide, methane, nitrous oxide, tropospheric ozone and chlorofluorocarbons (CFCs) has caused an increase in the amount of heat re-radiated back to the Earth's surface which has caused it to warm progressively over the last few decades (Bolin et al., 1986; Nunn, 1988). Even then, it should be remembered that global warming has not occurred everywhere in the past few

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* A modified version of the paper which appeared in the 1990 Journal of Pacific Studies.

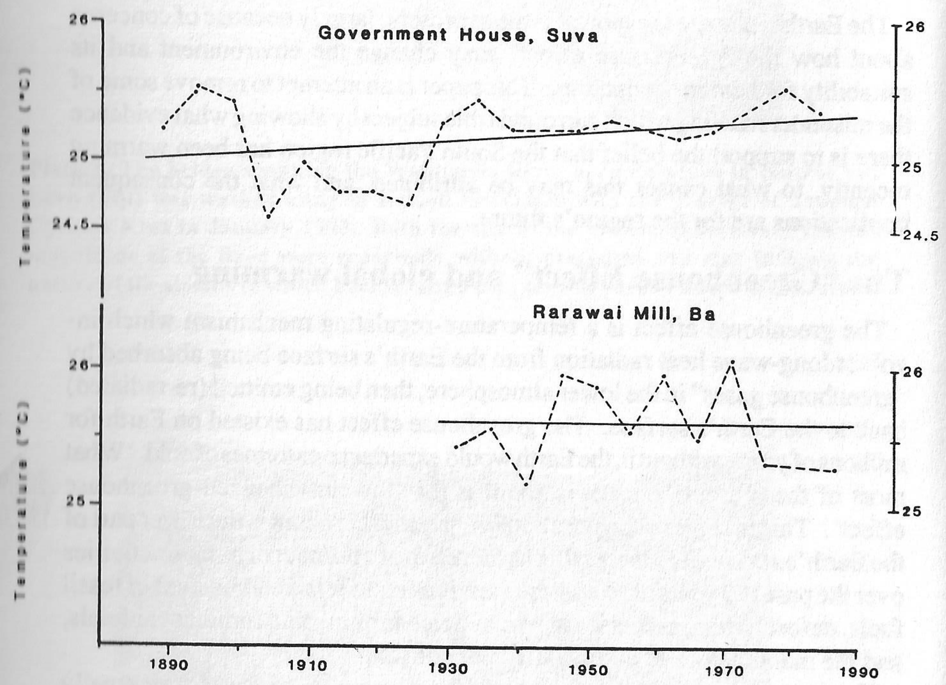

Figure 2.1. Long-term temperature data (5-year means) and trends for two stations in Fiji. Upper graph shows mean annual temperature 1887-1986 at Government House, Suva (r=+0.326, significant at 0.1% level). Lower graph shows mean annual temperature 1929-1988 at Rarawai Mill (no significant correlation).

decades and may not occur everywhere in the future. Nevertheless, the overall or global trend is clear.

Evidence for global warming

Most of the evidence for global warming over the last 100 years or so has been derived from compilations of long-term temperature data (Hansen et al., 1981). A major criticism levelled at such analyses is that their data bases have strong geographical biases towards the industrialised northern hemisphere. Such criticisms have led some people to conclude that the increasing temperatures indicated by such analyses are the direct result of increasing industrialisation, particularly heat-island effects over urban areas. Such objections were effectively annulled by the compilation of Jones et al. (1986) who derived a temperature trend for each representative sector of the earth's surface which broadly confirmed the phenomenon of global warming.

Hansen et al. (1981) concluded that global temperature has risen 0.4° C in the preceding 100 years. Jones et al. (1986) found an average global increase of about 0.5° C since 1860, which comprised "little trend in the nineteenth century, [then] marked warming to 1940, [then] relatively steady conditions to the mid-1970s and a subsequent rapid warming...the warmest 3 years have all occurred in the 1980s" (1986:430). In parts of the northern hemisphere, the summer of 1989 was the warmest on record.

Evidence for warming in the South Pacific

Long-term surface air temperature data in the South Pacific are comparatively few, and many records have large gaps in them. As with other meteorological data, trends (such as warming or cooling) cannot be identified if recording has not been going on continuously for 30-50 years at least. For the island Pacific this criterion is insisted on increasingly since the discovery of short-period climate oscillations such as that associated with the El Niño - Southern Oscillation (ENSO) phenomenon.

One of the longest-term air temperature records in the South Pacific comes from Government House, Suva, Fiji, where observations began in 1884. Raw data were collected for this study from the Fiji Meteorological Service archives and 5-year means were calculated. A positive correlation of +0.326 indicating a warming trend was obtained. This is statistically significant at the 0.1% level (Figure 2.1). This is the first analysis of data of this kind from the region of study known to the author and suggests that the warming trend experienced in areas peripheral to the region has also occurred within it.

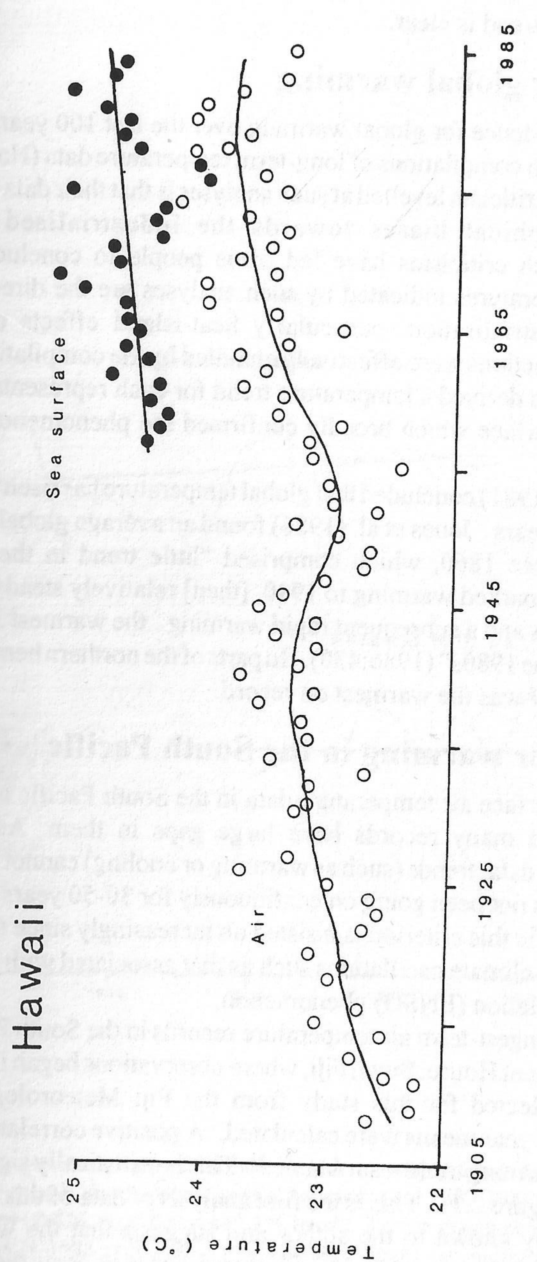

Figure 2.2.Trends of historical air and sea-surface temperature data for Hawaii (Nullet, 1989). Open circles indicate air temperature data; filled circles indicate sea-surface temperature data.

For comparison, data from Rarawai Mill, Ba, on the drier northwest side of Viti Levu, are also plotted in Figure 2.1 and show no significant trend. This is likely to be a function of the comparatively short time over which data have been continuously recorded there.

The gradual rise of temperature at Government House in Suva over about the last 100 years is not necessarily an indication of regional (South Pacific) warming although mid-ocean islands are generally excellent places to seek indications of short-term climate changes on account of the uniformity of controls on their weather (Nunn, 1987). In the case of the windward sides of the islands of Fiji (where Suva is located), the weather is dominated by the southeast trade winds. Any significant trend from such places is therefore much more likely to be representative of a larger area than places on continental margins, for example, where controls on weather are much more complex and changeable.

To overcome such problems, many analyses of trends over the last century have been derived from temperature measurements made from high-altitude balloons in the troposphere. Such radiosonde data have been collected continuously at three stations in the South Pacific since 1950. Between 1950 and 1985, tropospheric air temperatures above Fiji increased 0.7°C; above New Caledonia, they increased 1.05°C; and above Tahiti, they increased 1.4°C (from data in Karoly, 1988). These results are believed to reflect accurately surface air temperature trends in the region.

Adjacent to the South Pacific region, many longer-term surface air temperature data have been collected over much smaller areas and, consequently, the conclusions are much more convincing. This is manifested in the way in which they have influenced government policy in the major Pacific Rim countries. The results of Nullet's (1989) analyses of Hawaiian temperature data are shown in Figure 2.2 and demonstrate that a warming has occurred there over the last 75 years or so. A similar picture has emerged in New Zealand where a rise has "been experienced throughout the whole region during 1935-1970, temperatures climbing by 1°C over these years" (Salinger and Gunn, 1975:397).

Critics of such conclusions commonly believe that urban heat-island effects are largely responsible for increased temperatures because most monitoring equipment is located close to urban and/or industrial areas. Data from Taiwan in the central western Pacific effectively dismiss this explanation. Surface air temperature data exist for the period 1896-1987 for five stations, four industrialised and one, an uninhabited island 50 km off the north coast of the main island. The four industrialised stations show temperature rises of 0.67°C

(Hengchun), 0.63° C (Taichung), 0.89° C (Tainan) and 0.75° C (Taipei) for this period while the other (Pengchiayu) shows an increase of 0.78° C (raw data from Chiang et al., 1989). There is clearly no significant variation between stations in industrialised and non-industrialised areas in Taiwan.

The rise in sea-surface temperature around Hawaii (Figure 2.2) is shared by the whole South Pacific region according to the survey of Folland et al. (1984) which found a rise of 0.5-1.0° C since 1912.

From such data, it is reasonable to conclude that for around 100 years, the South Pacific region has experienced an increase in land- and sea-surface air temperatures comparable with that calculated for the whole globe (see above).

Possible causes of warming

It should be stressed more often by those writing about recent climate changes that such changes have not been uncommon in the history of the Earth: in fact, the Earth's climate might usefully be regarded as having been continuously changing.

For example, between 750 and 1300 AD, a slight warming (+0.5-1.0° C above present temperature) occurred, a period known as the Little Climatic Optimum (LCO), evidence for which has been noted in many parts of the world (Lamb, 1977). In the Pacific, it has been argued that the LCO provided favourable conditions for long-distance ocean voyaging which can help explain the period of rapid Polynesian migration (Bridgman, 1983). The LCO was followed by the Little Ice Age (LIA) during which temperatures fell 1.5° C on average below LCO temperatures.

It may be that the recent global warming is nothing more than an indication of the end of the LIA. Alternatively, the strong correlations between global temperature increases and increases in the proportions of greenhouse gases in the atmosphere over the past few decades have led most commentators to conclude that recent warming is anthropogenic: in other words, it has been caused directly by the increase in "greenhouse gases" in the lower atmosphere, an increase which has led to the enhanced greenhouse effect.

Effects of South Pacific Warming

The hydrological cycle and ENSO

It has been argued that warming in the southern hemisphere led to an intensification of the hydrological cycle in the period 1949-1979 (Flohn and Kapala, 1989) which means that evapotranspiration, precipitation and (river) runoff would all have increased recently. In the South Pacific, the few records of such parameters do not confirm this suggestion because of the influence of other factors, particularly the ENSO phenomenon.

It has been noticed that, in those years when the tropical Pacific Ocean off western South America is significantly warmer than average, anomalous climatic effects are experienced elsewhere. A Southern Oscillation Index (SOI) based on normalised pressure differences between Papeete in French Polynesia and Darwin in Australia (Trenberth, 1976) has been used to characterise the Southern Oscillation. In parts of the western Pacific such as Fiji, recent droughts have been coincident with negative SOI displacements (El Niño events) and periods of unusual wetness with positive SOI displacements. In the equatorial western Pacific, the situation is sometimes reversed. Western Kiribati experiences a seasonal rainfall increase when the SOI is negative and drier times when the SOI is positive and easterly winds are more dominant.

The strong relationship between the SOI and synoptic climate elements such as precipitation in the Pacific islands probably accounts for the absence of any clear rising or falling trend in such data. Those from Tarawa in Kiribati illustrate this point well (Figure 2.3).

Tropical cyclones

The frequency of tropical cyclones in most parts of the Pacific has also increased recently (Grant, 1981; Thompson, 1986; Nunn, 1991a). Tropical cyclones develop when the South Pacific Convergence Zone lies over places where sea-surface temperatures (SSTs) exceed 27-28° C. A recent increase in SSTs has been noted (above) and this is likely, at least in the central South Pacific, to have been responsible for the recent increase in the number of tropical cyclones experienced in the region recently.

For example, 12 tropical cyclones with hurricane-force winds (hurricanes) affected Fiji between 1941 and 1980 (an average of 3.1 per decade), yet 10 occurred between 1981 and September 1989 (an average of 11.4 per decade). Tropical cyclone frequency in the Tuvalu region is shown graphically in Figure 2.4: an abrupt increase is clear after 1975. Part of this increase may be due to improved detection and reporting of cyclones but this is unlikely to account wholly for such large increases.

Sea-level rise

One of the most talked-about effects of global warming is sea-level rise. It is argued that ocean water undergoes (thermal) expansion as temperatures rise

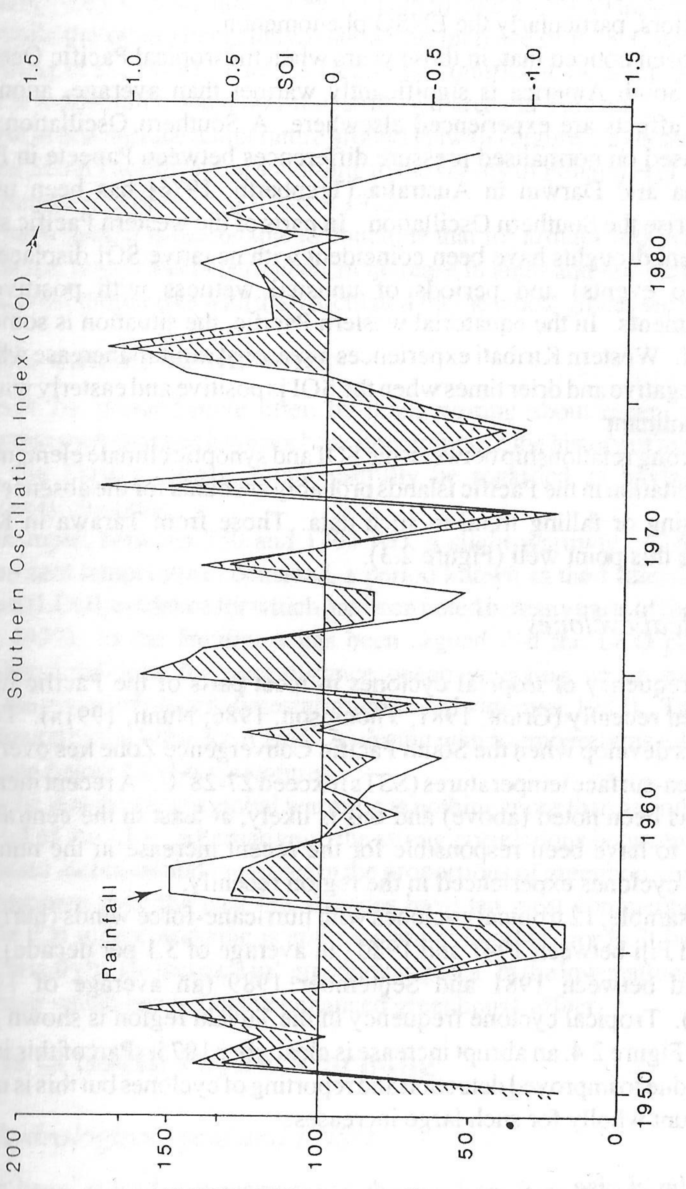

Figure 2.3. Annual rainfall and Southern Oscillation Index (SOI) values for Tarawa, Kiribati 1951-1980 (from Burgess, 1987).

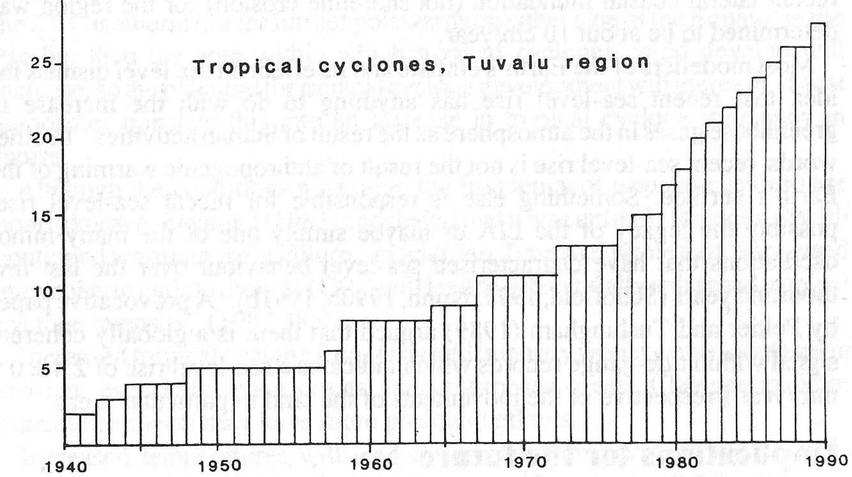

Figure 2.4.Cumulative frequency of tropical cyclones in the Tuvalu region, January 1940 - August 1989 (data from Thompson, 1987, and S. Tusi, personal communication, 1989).

and that long-term warming inevitably causes a sea-level rise resulting both from this and from melting of land-grounded ice.

Analyses of long-term sea-level records from many of the world's coasts suggested to Gornitz et al. (1982) that a truly global sea-level rise of around 12 cm had taken place in about the last 100 years. Marginal to our region of interest, rising sea-level trends have been identified from tide gauges at Honolulu, Hawaii (+1.5 mm/year since 1900 - Pirazzoli, personal communication, 1989) and at Wellington, New Zealand (+1.6 mm/year since 1900 - Hannah, 1988). The longest-term record in the South Pacific, at Pago Pago, American Samoa, although only 30 years in duration, also shows a rising trend of about +2 mm/year (from data in Pirazzoli, 1986).

A recent study of 59 coastal settlements in the South Pacific from Solomon Islands in the west to the Cook Islands in the east showed that at those places which were not tectonically rising (81%), sea level had probably been rising for at least 90 years (Nunn, 1990a). The vertical magnitude of this rise could not be accurately determined from this study although the average rate of recent lateral coastal inundation (not shoreline erosion) for the region was determined to be about 10 cm/year.

Most modellers of the Earth's climate and its effect on sea level dismiss the idea that recent sea-level rise has anything to do with the increase in greenhouse gases in the atmosphere as the result of human activities. In other words, recent sea-level rise is not the result of anthropogenic warming of the Earth's surface. Something else is responsible for recent sea-level rise; possibly the legacy of the LIA or maybe simply one of the many minor oscillations that have characterised sea-level behaviour over the last few thousand years (Schofield, 1977; Nunn, 1990b, 1991b). A provocative paper by Peltier and Tushingham (1989) argued that there is a globally coherent signal within tide-gauge records which indicates a sea-level rise of 2.4 ± 0.9 mm/year irrespective of the movements of the land in particular areas.

Implications for the future

A likely scenario

Even if emissions of greenhouse gases were stabilised immediately, the recent warming trend would continue for decades to come and is predicted to increase in rate. The projected increase of 1.5°C-5.5°C by the year 2050 (Bolin et al., 1986) reflects the uncertainty, and at least one respected commentator has emphasised the potentially disastrous consequences of not knowing enough about the workings of the Earth's atmosphere to be able to make more precise predictions (Broecker, 1987). The view of the International Panel on Climate Change (IPCC), based on a projected doubling of atmospheric carbon dioxide by 2050, is that average earth-surface temperatures will rise by 1°C by 2025 and by 3°C by 2100 (Houghton et al., 1990).

The most recent predictions by the Australian CSIRO Division of Oceanography involve an average warming of the Earth's surface by 3°C by the year 2050 which will cause a sea-level rise of 30 ± 20 cm by 2050. The rate of sea-level rise "would continue and possibly accelerate beyond 2050 unless global action is taken to greatly reduce the emission of greenhouse gases" (Pittock, 1989:2). The IPCC predict that sea level will rise 18 cm by 2030 and 44 cm by 2070.

Implications for climate in the South Pacific

If the present warming trend continues, tropical cyclone frequency is likely to continue to increase in the central south Pacific (Holland et al., 1988). Tropical cyclone frequency will not increase linearly with increasing temperature. As the 27°C isotherm moves further polewards on either side of the Equator in the Pacific, then the area within which tropical cyclones could develop will increase, so the potential for tropical cyclone development will increase. Most authorities translate this into an increase in tropical cyclone frequency in future.

Although the conditions governing the frequency of tropical cyclones are poorly known, Emanuel (1987) concluded that it was unlikely to diminish with continued warming in the future. In addition, Emanuel wrote that "increased atmospheric carbon dioxide (CO_2) will lead to substantially enhanced tropical cyclone intensity" (1987:485).

Increased tropical cyclone frequency and intensity would cause increases in erosion, especially along coasts and in exposed areas. Changes in other climatic elements may have more profound effects.

Increased temperatures will lead to increased evaporation and possibly increased annual precipitation levels on Pacific islands. While this may benefit those areas which presently suffer from aridity, it may amplify the effects of processes such as sheet wash and runoff which are major causes of soil erosion and land degradation in many parts of the Pacific islands region. Increased precipitation may also alter the hydrological regimes of many rivers presently used for irrigation and hydroelectric power generation.

Increased temperatures and precipitation will allow a variety of crops to be grown on certain islands where they could not be grown before. Yet the attendant increase in humidity may make living on tropical Pacific islands less comfortable than at present.

Implications for Pacific Island coastlines

The economic well-being of most Pacific nations derives mainly from activities carried out in the low-lying coastal zone. Many Pacific islands are wholly low-lying. The effect of recent and future sea-level rise is therefore a problem which needs to be seriously addressed by decision-makers in the region.

The most threatened islands are obviously those with no high ground. Most of the islands in the nations of the Marshall Islands, Kiribati, Tuvalu and Tokelau rise no more than 3 m above mean sea level. Yet the threat of direct inundation is not the most serious in the short term. Since these islands (and many higher ones) are composed solely of permeable rocks (sand and limestone), they contain a freshwater lens resting on top of saltwater. The surface of this lens (the water table) is dome-shaped and sometimes breaks the ground surface in the low parts of islands. As sea level continues to rise, the surface of the freshwater lens will also rise causing an increase in the amount of standing water on the island surface. Groundwater is more likely to be contaminated by salt-water overwash during storms.

Larger higher islands composed of a greater variety of rock types will be less seriously affected by sea-level rise, although this should not be a reason for complacency. Most of the major urban centres on Pacific islands will experience a substantial amount of inundation if the sea level rises by half a metre in the next 100 years. Several case studies were presented by Nunn (1988).

Conclusions

Many people regard the effects of future climate change and sea-level rise as too far in the future to warrant immediate concern. Few people reading this paper are likely to witness the sea level rising half a metre but many of their children and grandchildren might. The uncertainty surrounding what other changes may occur as the result of continued warming is a point continually emphasised by scientific commentators (Broecker, 1987; Schneider, 1988, 1989).

What can be done? The simple answer is something not nothing. As Schneider (1988) argued, to decide now not to do anything, is to make a decision which, in his view, is wrong. There are several groups of responses which policy-makers can make now (Schneider, 1989).

The first of these involves engineering countermeasures, purposeful interventions in the environment to minimise the potential effects of future climate change and sea-level rise. This could range from building-up low-lying areas of land to levels where they would not be inundated or flooded to encasing whole islands with impermeable sea-walls and living, as the Dutch do, largely below sea level.

The second involves adaptation by society, and this is the most appropriate response for most Pacific Islanders. This means that the implications of various scenarios for future change should be examined in detail and appropriate preparations made. For example, both sea-level rise and increases in temperature and precipitation will cause changes to the pattern of agriculture. If the agricultural economy is not to suffer serious disruption, plans for diversification and testing of new crop strains tolerant of higher temperatures should be made now. The need for future resettlement of lowland and low-island dwellers because of water shortages and inundation can also be discussed now.

The third group of responses are preventative. At a global level, this means that the use of CFCs must be discontinued; the rate of forest removal must be slowed and that of forest renewal accelerated; and fossil fuels must be phased out in favour of less-polluting or non-polluting energy sources. In the Pacific islands, the coastal environment should be effectively conserved and the processes operating there better understood.

Dealing with the threats posed by future climate changes is largely the responsibility of policy-makers and decision-makers in national governments. In his opening address to the first intergovernmental meeting on the subject, President Amata Kabua of the Marshall Islands eloquently articulated the fears and hopes of many Pacific Islanders. He said,

> It is truly frightening to think that our ocean will turn against us. We have been sustained by the ocean for two millennia. It has been bountiful and continues to yield to us its bounty. We have learned that this harmony may be interrupted by the action of nations very distant from our shores. I hope that the appeal of the peoples of the Pacific can help convince the industrialised nations to discontinue their profligate contamination of the atmosphere.

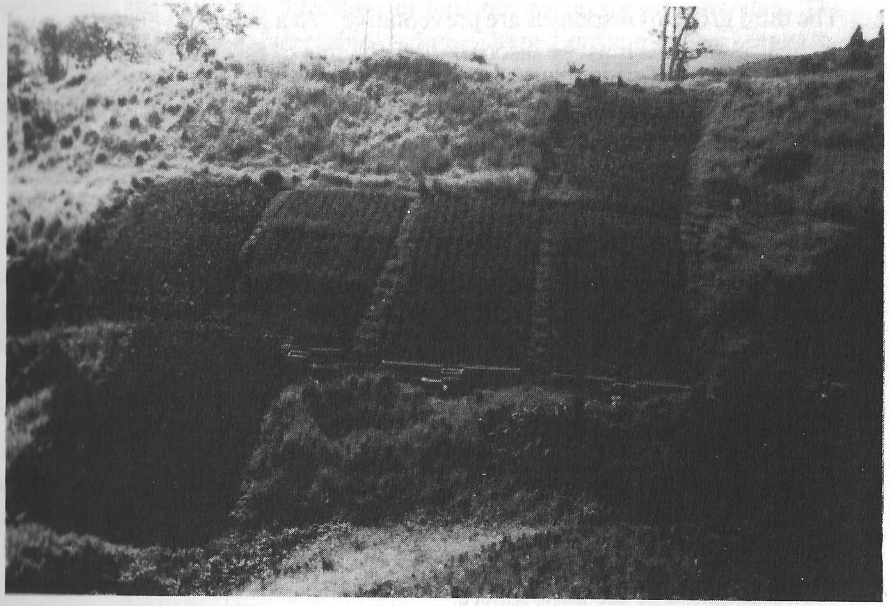

Plate 4. A proper understanding of how future climatic changes will affect Pacific island environments and their agricultural potential first requires some information about the rates of soil erosion and runoff under different crop combinations. These are experimental runoff plots established at Waibau near Suva on Viti Levu (Fiji) where the amount of sediment washed downslope is regularly monitored for rainstorms of varying intensity.

3

Agriculture and climate change: Double feedback

William Aalbersberg

Introduction

Feedback is a commonly used word in the discussion of climate change. As global warming causes some change, this change in turn may affect the amount of warming. This is a feedback. For example, warming temperatures will mean increased evaporation and increased water vapour in the atmosphere. Since water vapour is a greenhouse gas, the result of its increase will be additional warming. This is a positive feedback. Another example is the effect of clouds. Depending on the amount, height, types and time of occurrence of clouds, there may be either an increase or decrease in warming. The feedback might thus be positive or negative. The uncertain effect of changing cloud patterns is one of the main reasons why there is such a wide range (1.5-4.5° C) in the anticipated average global warming in the next 50 years.

In the same way, agricultural practices can either increase or decrease the amount of global warming. This aspect of the relationship between climate change and agriculture has not been widely discussed in the Pacific. A second feedback is the converse; that of climate change on agriculture. This will be the main focus of this paper. In addition to the discussion of these two feedbacks, possible appropriate responses to lessen their negative impact will be suggested.

Agriculture's contribution to global warming

People who think of global warming as being caused by increased production of carbon dioxide by industries and automobiles will be surprised to learn that more than a quarter of the enhanced radiative forcing comes from increases in greenhouse gases (methane, nitrous oxide and carbon dioxide) due to agricultural, forestry and livestock practices. Deforestation, biomass burning, and increased land clearing release these gases into the atmosphere. Methane is also produced by wetland rice production and ruminant livestock. The use of nitrogenous fertilisers results in enhanced nitrous oxide emissions into the atmosphere. One might argue that the agricultural contribution of Pacific islands to the overall production of these greenhouse gases is insignificant. Yet I would argue that it is nonetheless important to consider how the production of these gases can be limited in our region without affecting productivity and sustainable development. There are two reasons for this.

One is that small island nations, especially because of their vulnerability arising from the sea-level rise that is expected to accompany global warming, have an important role to play on the international stage to pressure the more industrialised countries to limit their greenhouse-gas output. This moral high ground will be even more influential if these threatened island states can show that they are taking serious steps to reduce their own output of greenhouse gases.

The second reason is that discussions aimed at bringing about these changes in agricultural practices will help make farmers aware of the climate change issue. As a consequence they may be more receptive to other government initiatives necessary to counteract the effects of global warming.

Much research is currently being undertaken to determine ways to reduce greenhouse gas outputs from natural systems. Generally, the solution is improved technology along with improved agricultural techniques. For reducing methane emissions from domestic animals, for example, feed additives can increase yield per animal as well as reduce methane produced. In general, any practice that increases the yield per animal will be of use. The same is true for wetland rice. If yield per area is increased, less methane will be produced. Use of rice varieties with high yield potentials and proper fertilisation can increase productivity. Removal from the field of plant residues, aeration of the paddy, and a shift to upland rice production are all possible solutions to reduce methane production.

Nitrogenous fertilisers added to the soil are partly broken down to nitrous oxide, a greenhouse gas. This process can be lessened by the use of slow release fertilisers or by their deep placement in the soil. The use of composted material instead of chemical fertilisers is another possible solution.

Biomass burning is a common practice in "slash and burn" shifting agricultural systems frequently practiced in the tropics. From an agricultural point of view, there is debate as to the efficacy of this practice. From an ecological point of view, it is disastrous, releasing large amounts of carbon dioxide, nitrous oxide and methane into the atmosphere. Rather than the wasteful burning of such material, other uses of it, such as for animal fodder, compost material or firewood should be encouraged.

The "slash and burn" method usually results in total land clearance. The baring of the soil which results facilitates the release of greenhouse gases and increases erosion and evapotranspiration. Farmers need to be educated as to the benefits of minimum soil tillage.

The issue of deforestation and amount of land clearance is a difficult one to solve as it is often the result of economic factors. An improvement in the economic status of rural people can lessen the urgency of cutting down rain forests or clearing additional land for cash cropping.

It is possible to replant all deforested land and this practice should be encouraged at individual, village and governmental levels. Commercial logging companies should be required to replant areas that they deforest. Another critical factor in subsistence land clearance is efficiency of land and wood usage. If maximum productivity is to be gained from the land, firewood should be used efficiently so that there is less need to cut down forests.

As discussed by Watkins (this volume), coral reefs are a major "sink" for carbon dioxide. We must therefore limit damage to reefs by agricultural and marine chemicals and by sedimentation from soil erosion.

It needs to be stated, in conclusion, that the root of many ecological problems is population growth. The need to grow more rice, raise more cattle and clear more land is largely due to the need for more food as population increases. Policies that encourage stable or slow-growth population are therefore critical to lessen global warming.

The effect of global warming on agriculture

In spite of what might be done to reduce greenhouse gas emissions, global warming will still be a reality in the next century. The following section will focus on how we can plan for these changes in the south-west Pacific islands. It is important to start this process now even though serious effects may be decades away.

Many papers in this volume discuss how global warming might affect agriculture in the southwest Pacific. To summarise these points:

1. Increased temperatures will cause heat stress on many plants. Increased evaporation may lead to increased drought, especially in drier areas during the dry season.
2. Increased atmospheric carbon dioxide will increase plant growth, although this will be less pronounced for sugar cane and maize. Faster growth will also lessen time to maturity. This could decrease yields and perhaps food value. The sugar content of cane could, for example, be lessened. Yet for

rice, this could permit an additional crop per year. Weeds will also grow faster, competing with plants for water and soil nutrients.

3. Different climate models give different results for precipitation patterns for our region. It seems likely that there will be increased rainfall with greater intensity but that this will occur mainly during the wet season. This would lead to increased erosion, flooding and leaching of nutrients from the soil. It is also predicted that hurricanes will be more frequent.
4. Areas of agriculture will shift. Warming upland areas could be planted with crops that previously could not be grown there. Sea-level rise will claim coastal land that is currently used for agriculture through inundation or salinisation.
5. Other factors affecting agricultural output may change in a warmer, more humid south-west Pacific. The occurrence of agricultural pests may increase causing lower yields and increased loss during storage.
6. The human factor also needs to be considered. Farmers are likely to be less productive as temperatures and humidity increase.

What can be done?

Many of the negative effects on agriculture that are expected to accompany global warming can be countered. Advance planning is necessary. There are several possible responses.

1. Collect and evaluate agricultural data

In order to make intelligent decisions, data must be available. We need to know the yields of crops and cultivars under conditions likely to be predominant in the future. This can be done both in the field and at experimental stations. In addition, crop modelling is also possible. Computer programs are available that predict yields based on critical agricultural parameters. Dr Upendra Singh is an expert in this field and has analysed maize and rice yields in Fiji under a variety of possible climate conditions. A model for taro is currently being developed. This work needs to be continued and expanded to other crops and the results considered for future planning. Studies also need to be made of coping strategies that farmers currently employ in time of drought, for example.

2. Network internationally

The issues we are discussing are global ones. Research is going on throughout the world to find cultivars that are less sensitive to heat, salt and drought stress. In the south-west Pacific, we need to be aware of these experiments and participate in them as appropriate. Agricultural planners need to keep abreast of technological developments that may help us address these problems.

3. Water management

The likelihood of both more rainfall and the greater possibility of drought means that the economics of food control and irrigation infrastructure need to be re-evaluated. It was upsetting to read a recent report from overseas consultants saying that irrigation of sugar cane farms was uneconomical. That may be true under current conditions but may not be if average temperatures were two degrees warmer. Government should insist that such studies include consideration of possible future changes due to global warming.

4. Encourage good agricultural practices

Good agricultural practices are always important but even more so in times of stress. We have seen that climate change will probably lead to greater moisture stress, soil erosion, nutrient depletion of soils, and pest and food storage problems. Thus such practices as minimum tillage, wind protection, irrigation, contour and strip planting on slopes, and the sensible use of fertilisers and pesticides will be critical simply to maintain present yields in the future. Land tenure policies need to be considered in terms of this. Many farmers are short-term leaseholders and are unlikely to spend money for the long-term conservation of the land unless long-term usage is guaranteed.

Conclusion

The fact that global warming will occur over an extended period of time allows planners time to minimise its negative impacts. For the islands of the south-west Pacific, one of the main areas of impact will be agriculture. It is important that professional societies, such as the Fiji Institute of Agricultural Science (FIAS), do everything possible to see that governments start to make necessary decisions before it is too late. We must remember that the changes we have discussed for the next 50 years may double in the following 50 years unless drastic action is taken now. A wait-and-see attitude can be very dangerous.

Plate 5. Conservation of Pacific island coasts is a sensible procedure to adopt in the face of rising sea level. Yet seawalls need to be adapted to local conditions if they are not to cause more problems than they solve. An impermeable seawall built along the front of a tourist resort resulted in the removal of the beach and exposure of the underlying beachrock. Destruction of the seawall in one place (foreground) resulted in the return of the beach but continued erosion of the resort frontage.

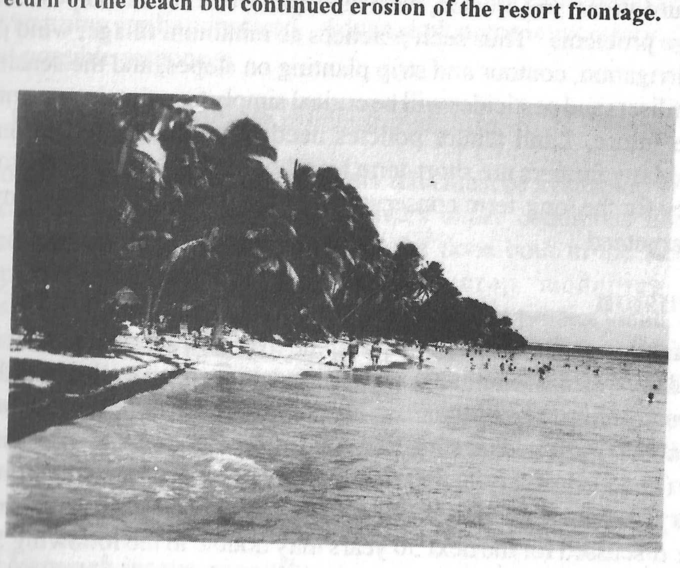

Plate 6. A permeable seawall with a less abrupt profile has been constructed (left foreground) and is helping conserve sand along the front of this resort.

4 Carbon dioxide and plant growth

Anjeela Jokhan

This review is mainly concerned with looking at some of the physiological effects of carbon dioxide (CO_2) enrichment on plants. The importance of CO_2 is known to all. It is best known as a substrate for photosynthesis.

The temperature of the globe is increasing slowly. It is predicted that, with a doubling of the concentration of CO_2 in the atmosphere, global temperatures will rise by 2-3° C (Acock, 1990). Yet, with such a slow rise in CO_2 concentration over many generations, plants are likely to become genetically adapted to the rise.

When looking at the effects of CO_2 on plants perhaps the most important aspect to look at would be its effect on stomata. Stomata are pores formed by a pair of specialised cells, the guard cells, which are found on the surface of the aerial parts of most higher plants (Willmer, 1983). Stomata open and close to control gas exchange between a plant and its environment. Whatever CO_2 enters the plant does so through its stomata. In general, as ambient CO_2 increases over the physiological range (atmospheric CO_2 is about 350 ul l^{-1}), stomata close while, as CO_2 decreases over the same range, stomata open. Thus high CO_2 can close stomata, even in the light, while CO_2-free air can open stomata, even in the dark (Willmer, 1983).

The opening and closing of stomata is a very simple physical process. Stomatal structure is such that an increase in turgor inside the guard cells (due to water pressure) causes the opening of the stomatal pore. Lack of turgor results in the closing of the stomatal pore (Raschke, 1975, 1976). To increase turgor inside the guard cells, water needs to be drawn into these cells. To draw water in, the solute potential (osmotic potential) inside the guard cells needs to be lowered. For this there must be an accumulation of solutes/ions inside the guard cells. Potassium ions are actively taken up by a H^+/ cation exchange pump located at the plasmalemma of the guard cells. This exchange pump works in such a way that for every 10 potassium ions moved into the guard cells, only 9 protons are moved out. This to some extent helps in the maintenance of electroneutrality inside the guard cells. To achieve this fully, malic acid is synthesised inside the guard cells. This provides the anion

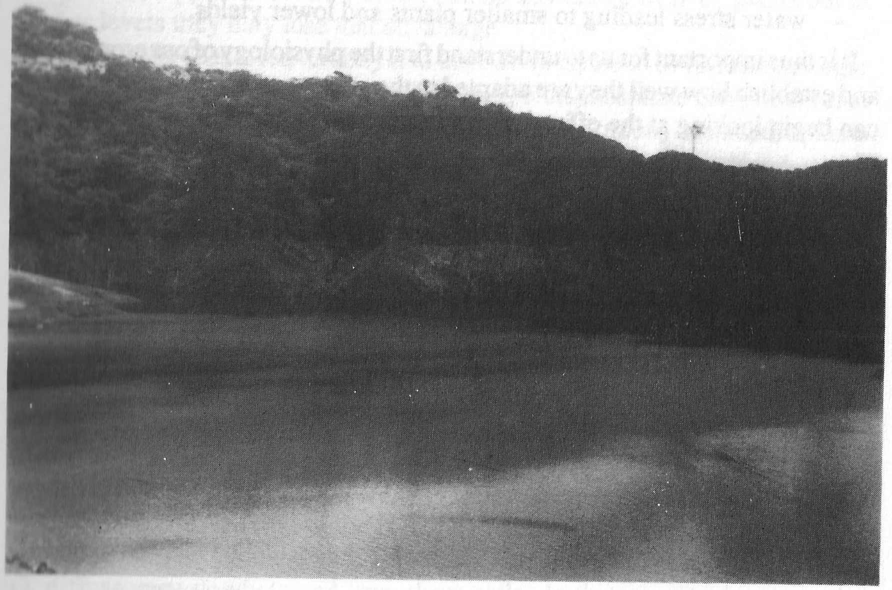

Plate 7. Prolonged droughts such as those associated with El Niño events in the tropical southwest Pacific islands may have longer-term consequences for human existence. This view shows the low level of the Monasavu reservoir in central Viti Levu (Fiji) in 1991 during a lengthy El Niño event. Water from the lake is used for power generation: alternative sources of power are much more costly.

5

Potential effects of global warming on coral reef systems

Anni Watkins

Introduction

Predicting the future may seem an impossible task but that is the challenge that this meeting proposes. Global warming will affect the natural world in many ways, and it is in our interest to try and assess what those effects will be in order to be able to take action where necessary and possible. The problem is that we can never know what will happen; we can only make informed guesses. In many cases, the informed guess we make depends on other predictions and as we balance one informed guess against another, the predictions we can make invariably become less and less precise.

There is a reasonable consensus of opinion on what degree of warming we can expect: recent estimates suggest that there will be an overall increase in average temperature of about 1°C in the tropics (with a greater increase in temperate regions), by the year 2025. There is a range of predictions concerning the rise in sea level, largely owing to thermal expansion of ocean-surface waters that will result from this temperature increase. Estimates vary, but recent predictions are about 5 mm/year. Predictions of the effects of this on global weather systems are less clear. Different models give very different answers. For example, it seems likely that evaporation will increase in a warmer world (Flohn and Kapala, 1989). Therefore rainfall should increase, but where will this extra rain fall?

The responses of the natural world to all this are even less obvious. The interactions both within the biotic environment and between ecosystems and climate are complex. In addition, biologists must consider the possibility of evolutionary change in response to environmental change. Thus, we are dealing with a complex array of interacting organisms, each with a different lifestyle, each of which is also subject to change. In this paper, I propose to look at just one natural ecosystem - tropical reefs - and to try to predict what is likely to happen, based on current climate change predictions.

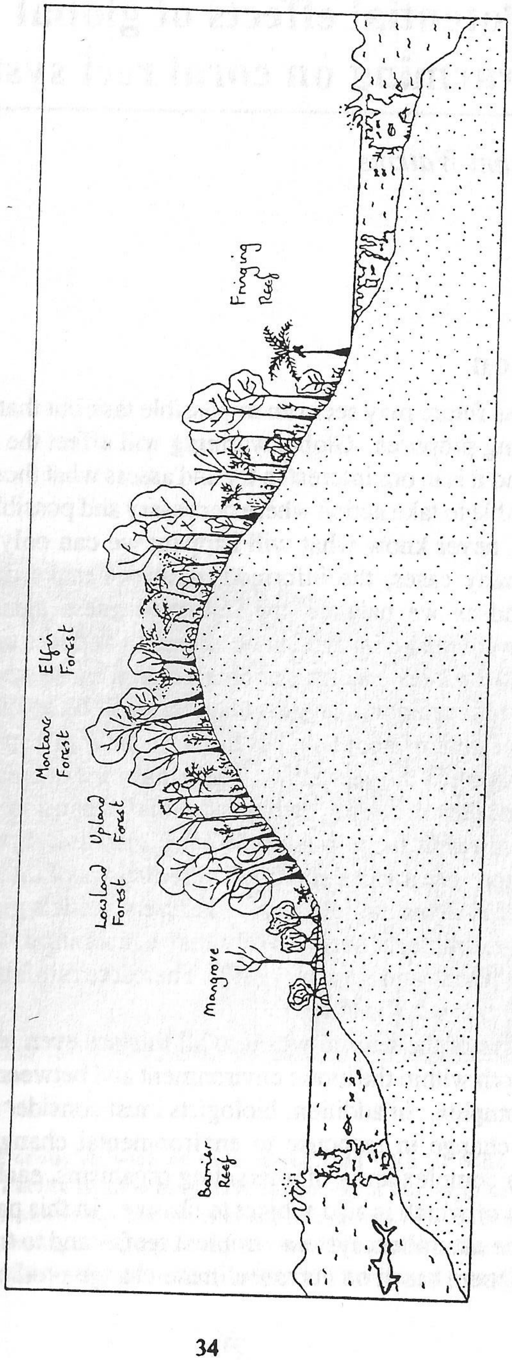

Figure 5.1: Profile diagram of a typical tropical island, showing habitats that may be affected by global warming.

Reef Importance

Before considering specific effects, it is appropriate to consider the importance of coral reefs, both in terms of their place in the natural world and their direct contribution to human well-being. A diagram of some of the associated ecosystems is shown in Figure 5.1.

Mechanical protection

Reef systems have an enormous capacity to absorb wave shock, giving us the placid lagoonal waters that are so characteristic of the tropical Pacific region. Without this protection, more coastal erosion would occur. To give some idea of the value of the reefs as a mechanical barrier, it is worth considering the cost of replacing the reef with a man-made structure capable of doing the same job. In the Maldives, where this has been done, the costs are such that a barrier reef can be valued at over F$12,000 per metre of their length (Wells and Edwards, 1989). This figure is simply for construction and does not include maintenance costs, thus a *living* reef would be worth considerably more.

Ecosystem interdependence

The absorption of wave shock by the reef allows the existence of the mangrove ecosystem that might otherwise be unable to survive. The mangrove forest acts as a filter, removing solids and many excess nutrients which would either clog up the corals or encourage a blanket of green algae to grow over the reef (Buddemeier, 1988). Thus, the two systems are interdependent and any damage to one is likely to have 'knock-on' effects. Both these ecosystems interact with the open ocean, particularly in that they are used as nursery areas for many open water fish. Fish, sea urchins and various molluscs perform an important role in grazing the reefs. This grazing removes green algae which would otherwise grow over the reef, preventing light from reaching the corals and other reef components. A complex system of food webs, homes and hiding holes, nutrient flows and chemical changes is, therefore, dependent on the reef system.

Economic importance

Most people of the south Pacific are dependent on their ocean harvest, because the majority of the island nations have very little land. Added to this, the productivity of tropical waters is low (Buddemeier, 1988). The importance of the reef as a nursery for open water fish and as a source of economically valuable organisms should be taken into consideration by those involved in planning the future of island coasts. There are already many examples of problems of overfishing and overcollecting leading to the necessity for managing legislation: the examples of *Trochus* shells and bêche-de-mer have received some publicity in recent years.

Carbon dioxide absorption

At a global scale, the reefs of the world are important as a carbon dioxide (CO_2) sink. An average figure for the deposition of calcium carbonate on reefs is 2.4 kg/m^2/year at present rates of growth. When we consider that there are some 617,000 km^2 (6.17×10^{11} m^2) of reef worldwide, it may be seen that reefs have an enormous capacity for sinking carbon dioxide although the figure could rise 4-9% if reef growth increased to its maximum potential (Kinsey, 1991).

Climate and sea-level change

When making informed guesses as to what will happen to ecosystems, what information do we have to help us? There are two main sources of information: fossil records of past changes and our knowledge of the biology of the species concerned gained from experimentation. I will be presenting a review of the work of many different scientists to support my guesses.

Change is not uncommon in the natural world. In the past there have been many profound changes; indeed, climate is constantly changing. There have been big bursts of extinction and evolution during the past. Biological systems are capable of adapting to change. The critical thing is not that there will be change, but how fast those changes will occur. It is the *rate* of change that is important. Will species be able to respond fast enough? It has been suggested that the future changes will be occurring 10 to 40 times faster than during the warm-up after the last ice age (Schneider, 1988).

The potential responses of biological systems to the associated sea-level rise have been popularly summarised by the phrase "keep up, catch up or give up" (Neumann and Macintyre, 1985). There is evidence of all three of these responses occurring in different parts of the South Pacific region in the past.

Features of climate change (and the resulting physical effects) having the potential to affect reefs can be summarised as follows:

1. sea-level rise,

2. increase in average temperature,
3. air pressure and sea current changes,
4. changes in storm frequency and severity, and
5. changes in rainfall patterns.

It should be noted that it is not just the absolute changes or the average changes that are important. There will also be changes in the range of values experienced. For example, the range of temperature experienced through the day, or through the year, is very narrow in the tropics. Tropical species are not adapted to extremes.

Rates of change

Looking at rates of change in the past gives some idea of the capacity of biological systems to adapt. Corals have been in existence for the past 650 million years. Thus, although the patterns and species may have changed, this biological system has survived dramatic changes. Some of these changes have been quite rapid. Figure 5.2a shows an estimate of sea-level changes over the past 400,000 years: approximately 100 m of sea-level rise occurred in 11,000 years. This can be compared with Figure 5.2b which gives the estimated sea water temperature in the tropics over the same time period. The temperature varied by as much as 6°C (approximately) but never very rapidly. The maximum rate of temperature change indicated by this graph is maybe 1°C in 1000 years.

Figure 5.3 gives a more detailed look at that last warm-up period. A rise in sea level of 100 m in 11,000 years is equivalent to an average rise of 9 mm/year. However, it can be seen from Figure 5.3 that this is a misleading average. Some parts of the graph show a much steeper incline, equivalent to perhaps 40 mm/year.

Sea-level rise

Water depth is of importance to the reef. If the reef becomes exposed above water level for a prolonged period, the reef organisms within the exposed area are likely to die. If the water becomes too deep, the light intensity reaching the reef organisms will be reduced, and there may be a similar outcome. The corals live in symbiosis with an alga which requires light to be able to function. Thus, low light intensity reduces growth and, at a certain depth, the reef will no longer be able to live. Reef flats maintain a surface a few

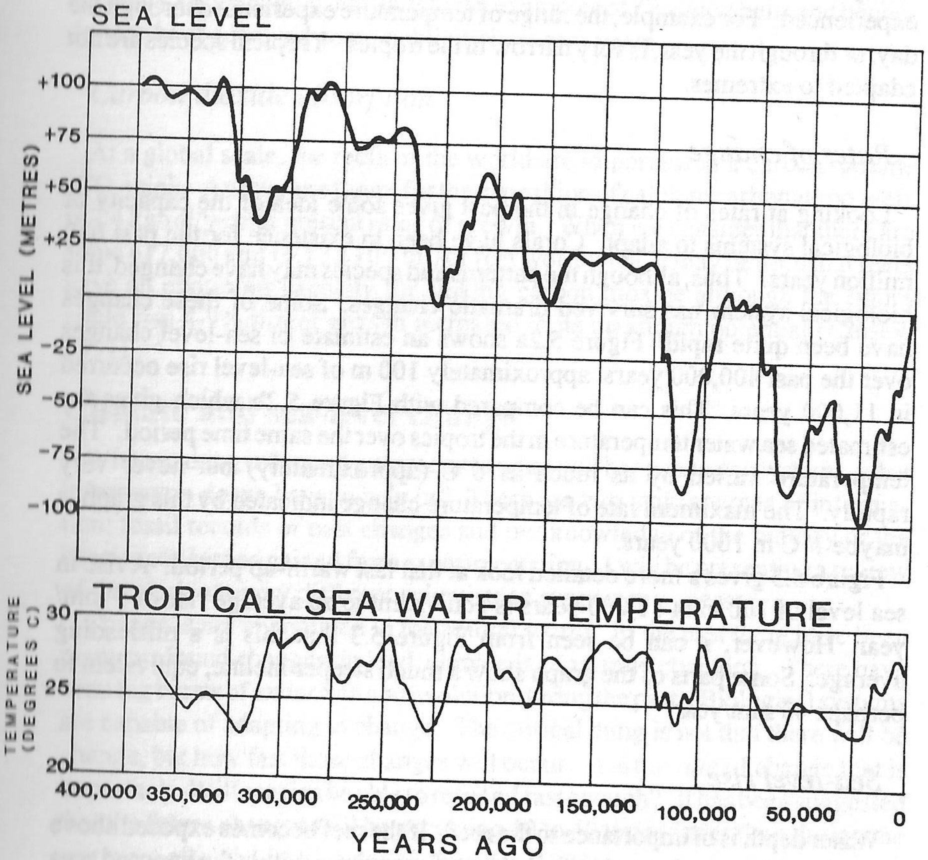

Figure 5.2: Changes in sea level and tropical sea water temperature over the past 400,000 years. (From Fairbridge, 1960).

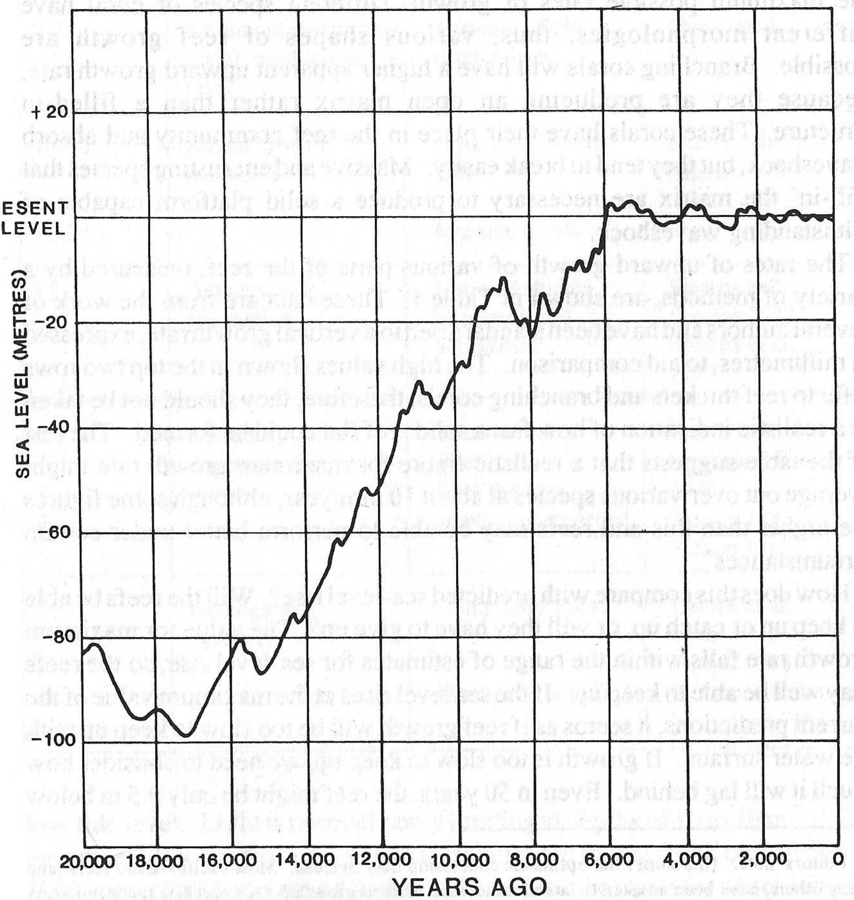

Figure 5.3: Changes in sea level over the past 20,000 years. (From Fairbridge, 1960).

centimetres below low-tide level, dying back if exposed and growing upwards if submerged. If the sea level rises, the reef flats will begin to grow upwards, but how fast can they grow? Will they be able to keep up?

Currently, reef flats may grow upwards by about 2 mm/year (Kinsey, 1991), but this figure is based on reefs that are constrained by low-tide levels. The upward growth of such reefs should speed up if submerged. We need to know the maximum possible rates of growth. Different species of coral have different morphologies; thus, various shapes of reef growth are possible. Branching corals will have a higher apparent upward growth rate, because they are producing an open matrix rather than a filled-in structure. These corals have their place in the reef community and absorb waveshock, but they tend to break easily. Massive and encrusting species that 'fill-in' the matrix are necessary to produce a solid platform capable of withstanding waveshock.

The rates of upward growth of various parts of the reef, measured by a variety of methods, are shown in Table 1. These data are from the work of several authors and have been standardised to a vertical growth rate, expressed in millimetres, to aid comparison. The high values shown in the top two rows refer to reef thickets and branching corals; therefore, they should not be taken as a realistic indication of how fast a solid reef flat could be formed. The rest of the table suggests that a realistic figure for maximum growth rate might average out over various species at about 10 mm/year, although some figures are higher than this and reefs may be able to perform better under certain circumstances*.

How does this compare with predicted sea-level rise? Will the reefs be able to keep up or catch up, or will they have to give up? The value for maximum growth rate falls within the range of estimates for sea-level rise, so the reefs may well be able to keep up. If the sea level rises at the maximum value of the current predictions, it seems as if reef growth will be too slow to keep up with the water surface. If growth is too slow to keep up, we need to consider how much it will lag behind. Even in 50 years, the reef might be only 0.5 m below low-tide level. Light is normally only limiting at depths of 10 to 20 m. Using the present figures, the reefs would be submerged to that depth only in 500 to 1000 years (Buddemeier and Smith, 1988), a period of time for which it really is not possible to make sensible predictions. Thus, there is considerable potential for the reefs to catch up, even if they cannot keep up.

Table 5.1: Estimated growth rates for coral reefs

Equivalent vertical growth rate (mm/yr)	Measured by	Notes	Sources
7-70	Estimated maximum CaC0$_3$ production rates	Assuming 50% open matrix	Chave et al. 1972
10-70	Actual growth measured	Branching corals only	Buddemeier and Kinzie 1976
10-20		Massive corals	
11	Actual CaC0$_3$ production	Detailed studies of growth and abundance	Stearns and Scoffin 1977 Stearns et al. 1977
0.6 3 7 9	Alkalinity depression in water	Shallow water Reef flats Reef thickets Maximum recorded	Smith 1983 Smith and Kinsey 1976 Kinsey 1985 Pichon 1985
10	Geological evidence	Commonly found	Davies et al. 1985 Davies 1983
14		Maximum recorded	Neumann and Macintyre 1985

It is possible, given sea-level rise, that the reefs will enjoy a burst of growth and probably a change in species composition. Faster growing species and branching forms will be favoured over those which dominate at present.

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* Editors' note. This somewhat optimistic conclusion may mislead. Most Pacific island reefs (and many others) have been adapted to lateral rather than vertical growth for the past few thousand years since sea level stabilised around its present level. The species composition of a reef which is actively growing laterally is quite different from the species composition of vertically-growing reefs. Thus in order for laterally-growing reefs to respond to sea-level rise by growing upwards, a change in the species composition is necessary. This is likely to take decades rather than years. It is also important to realise that maximum rates of upward reef growth refer to reefs in a healthy condition, not ones which (like some in the Pacific) are struggling to survive in the face of pollution, sedimentation, dynamiting, overexploitation and increasing stress from rising ocean water temperatures.

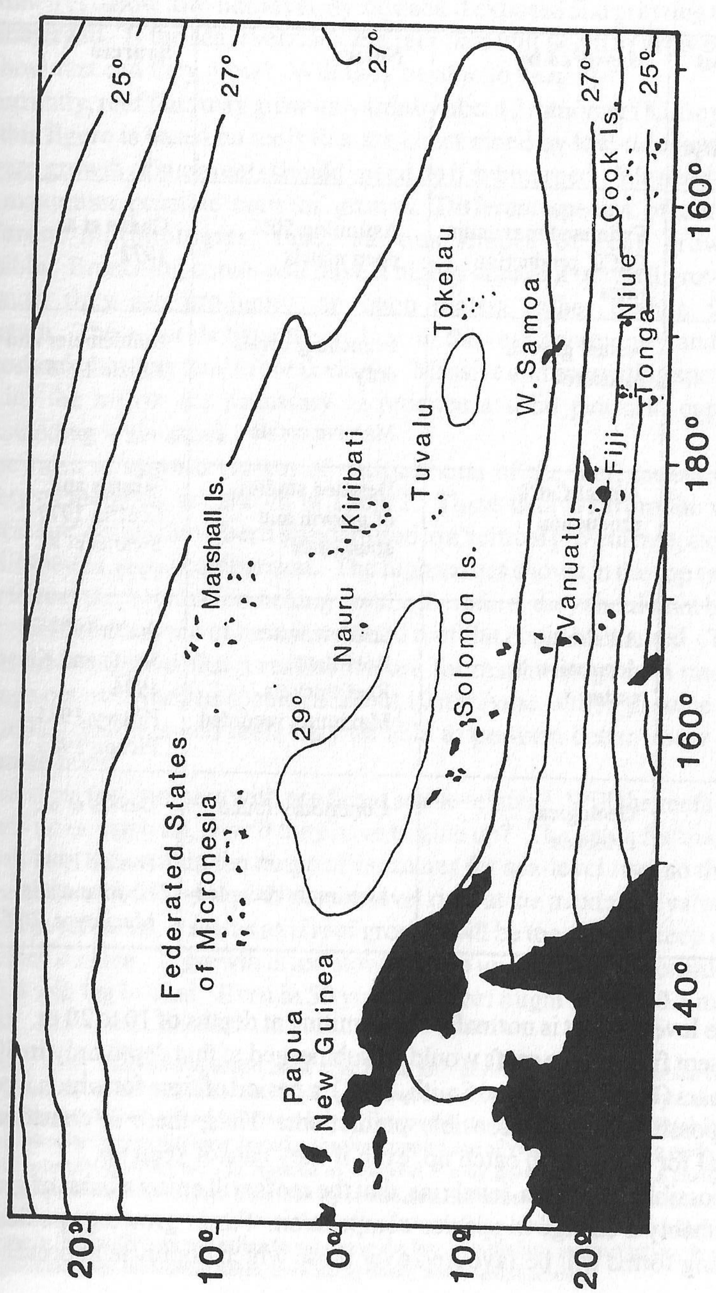

Figure 5.4: Mean summer temperature at the sea surface in the South Pacific region (adapted from Philander, 1983).

Increase in average temperature

Coral grows well at temperatures between 26-30° C. Temperatures above 30° C can cause corals to 'spit out' their algal partner. This results in a phenomenon known as bleaching, because it is the algal pigments that give the corals their rich variety of colours. Without the algae, the corals do not grow and it may take a considerable time for them to regain suitable algal cells. Evidence for the damaging effects of high temperatures comes from bleaching in the past 40 years (Goreau and Macfarlane, 1990), and from the 1982-1983 El Niño - Southern Oscillation (ENSO) phenomenon which could well become more frequent as a result of global warming. Short-term dramatic events such as these could well have more impact than overall sea-level rise.

Gradual temperature changes within the range 26-30° C would present no problems. Yet abrupt changes can cause bleaching. Such changes could result from sudden alterations in ocean currents associated with the ENSO phenomenon, for example (Philander, 1983).

Changes in storm frequency and severity

One of the conditions for cyclones to develop is a sea-surface temperature of about 28° C or more. Looking at Figure 5.4, it can be seen that a 1° C rise in temperature should increase the area of sea within which cyclones could develop, which suggests an increase in the frequency of such storms (Nunn, this volume). It is also possible that storms will become more intense as a result of global warming (Emanuel, 1987).

Reefs absorb shocks yet also sustain damage during storms. Pieces are broken off, especially from branched corals and the more open structures. This hits the fastest growing ones most severely, thus the species most likely to allow the reefs to keep up with sea-level rise are also those most vulnerable to storm damage (Smith and Harrison, 1977). In addition, if the reefs fail to keep up near the water surface, waves will go over the top of the reef flat rather than breaking at the reef edge, potentially causing more damage.

Changes in runoff patterns

The extreme sensitivity of reef systems to the turbidity and nutrient status of water means that they can be adversely affected when rainfall and runoff patterns from the land change. This is particularly true of fringing reefs, which occur next to the shore rather than barrier reefs which lie some distance offshore (see Figure 5.1). Fringing reefs also experience freshwater input and may be affected by any increase in rainfall. Lowering of salinity can cause bleaching (Goreau, 1964). Nutrients washed off the land lead to eutrophication, which results in a turf of green algae growing over the reef, killing corals and reef-building algae. This problem is exacerbated by pollution. Sewage output and runoff of agricultural fertilisers already pose serious problems of eutrophication.

Reef composition

Given that different species have different capacities and different strategies for responding to change, it seems obvious that the composition of reefs will alter. It is difficult to make anything other than very general predictions without a very detailed knowledge of the ecology of the species making up a particular modern reef, few of which have been studied in detail to date.

Drilling through the reefs of Funafuti Atoll in Tuvalu has revealed that the largest component of the reef, by biomass, is coralline red algae. Next on the list comes *Halimeda*, a calcareous green alga. Shelled protozoa comprise the next largest proportion of the biomass and only then do the corals occur.

As already mentioned, some of the reactions expected of the corals are mainly extra growth and an emphasis on the faster-growing and more branching forms. Thus, it is appropriate to look at the biology of the coralline red algae, a group which has received little attention from ecologists. Maudsley (1990) reviewed what is known about these organisms.

Coralline algae act as reef cement, filling in and holding together the 'hard core' of broken pieces of coral. They are very resistant to wave damage and can grow under very poor light conditions. They are also resistant to heavy grazing; in fact, they require a severe grazing regime to keep off other algae and settling propagules of faster-growing species that would otherwise overgrow them. The problem is their slow rate of growth, maximum rates being under 5 mm/year, average rates probably being considerably under that. They are thus unable to compete with faster-growing species except under severe conditions such as low light intensity or heavy wave action. In the event of increased storm frequency, coralline red algae may well increase in proportion, especially on the reef front. They are unlikely to be able to keep up or catch up with a rise in sea level, so the reef front may take on a gentler profile than the reef cliffs seen in many places today. Yet, because of their tolerance of low light conditions, they are unlikely to 'give up'.

Coralline red algae are likely to be a very important component of future reef systems but they are very vulnerable to damage from human activity. Pollution, leading to eutrophication, would encourage faster-growing algae. Overfishing or collecting of grazing species would allow these algae to overgrow potential reef-saving species such as coralline red algae.

Conclusion

If the problems they faced were only those of climatic and physical changes predicted by the present view of global warming, I would expect reefs to survive, thrive and to enjoy a burst of growth in most parts of the South Pacific region. There would likely be changes in the structure of the reefs: competitive relationships would be likely to change, resulting in dominance by different species.

The main threats to the reefs still remain those of eutrophication, largely as a result of pollution from human activity, and overfishing or collecting, again a human activity. It is to these areas that I would suggest our reef-saving activities be directed, especially as these seem more tractable problems, at least in terms of logistics.

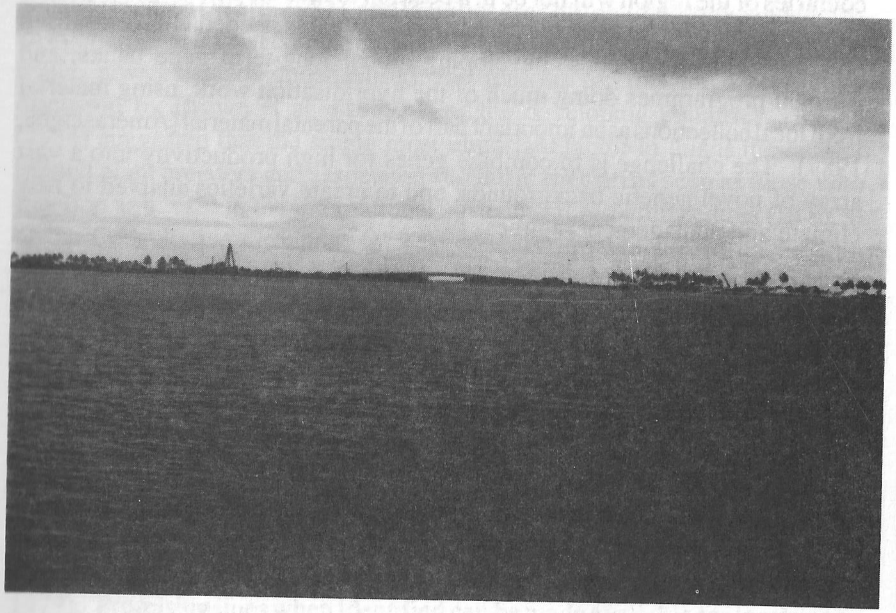

Plate 10. In terms of both future climate and sea-level rise, atolls are the most vulnerable island types in the Pacific. Majuro Atoll in the Marshall Islands rises only 5m above sea level (at the bridge in the picture). The remainder of the island is a narrow strip of largely unconsolidated sediment where supply of drinking water is a major concern and one likely to become more so in the future.

7

Recent sea-level changes in the Pacific with emphasis on Fiji

Patrick D. Nunn

Background

The level of the sea fluctuates. Every 24 hours in every part of the world, sea level passes through a cycle with distinct high-tide and low-tide stages. Daily tidal range in some parts of the world is many metres in magnitude although it rarely exceeds one metre in the South Pacific islands.

The mean sea level, that is the average position of sea level, is often thought of as being fixed. This is certainly true over periods of months, even years or decades in some places, yet over longer periods of time, mean sea level is known to vary considerably. It varies in response to external factors such as temperature and ocean water volume. For example, at the maximum of the last ice age 18,000 years ago, mean sea level in the Pacific lay around 120 m *below* its present level. This was because many of the Earth's land masses were covered with thick sheets of ice. The water used to form this ice had been drawn from the ocean so its surface - that of mean sea level - had dropped. When this ice melted, sea level rose to around its present level. Another example was the *rise* in mean sea level which ended in many parts of the world (including most Pacific islands) around 5000 years ago. This was a time when world-wide temperatures were higher than at any time in the past 125,000 years. The surface layers of the oceans expanded as the result of these high temperatures and this resulted in a rise of mean sea level.

Whereas changes in the volume of land ice seem responsible for the major (first-order) changes of mean sea level which occurred in the past, it is temperature changes which have been largely responsible for the sea-level changes of lower magnitude (second-order changes). A close relationship between temperature and sea level has prevailed for the past few thousand years. In the south-west Pacific islands, temperatures and sea level both began falling about 2000-3000 years ago and have continued to do so in a general sense.

This fall of sea level over the past 2000-3000 years has not been a smooth, unbroken fall. Nature seldom operates with such regularity over long time periods. There have been minor ups and downs imposed on the overall downward trend. For example, between 750-1300 AD, temperatures were higher in most parts of the world and, consequently, mean sea levels rose slightly. Following this period, the earth was plunged into a cooler climate. The period 1300-1800 AD, known as the Little Ice Age, was therefore marked by lower sea levels in most parts of the world.

Since the Little Ice Age ended nearly 200 years ago, world temperatures have increased. In other words, there has been global warming. Most long-term temperature records, including those from Hawaii and from Fiji, exhibit this warming clearly (Nullet and Ekern, 1988; Nunn, 1990c, d, this volume). Temperatures have risen about 0.5-0.7°C in the past 100 years or so. Just as for every other significant temperature change which the earth has experienced in the past few thousand years, mean sea level has also changed since the end of the Little Ice Age. Sea level has been rising in many parts of the world for the past 100 years at least, but probably since the maximum of the Little Ice Age, about 250 years ago in the Pacific (Nunn, 1991a).

Recent sea-level changes in the Pacific

Long-term records of sea-level change in the Pacific are few. The best is that from Honolulu on the stable island of Oahu in Hawaii. It is important that the site of the tide gauge be stable, not rising or subsiding (or doing both) so fast that the record of changes in mean sea level is distorted. The Honolulu tide gauge record shows that mean sea level has been rising there at a rate of 1.5 mm/year since 1900 AD. Analyses of long-term records from New Zealand give similar results.

The 30-year record at Pago Pago in American Samoa is not sufficiently long to allow the long-term trend to be identified with certainty; yet, it suggests that sea level there has been rising at 2.0 mm/year. There are no other tide gauges which have been operating for sufficiently long in the Pacific islands to enable a picture of recent sea-level change to be acquired. In addition, there are few sites which are sufficiently stable to be able satisfactorily to establish even short-term trends. The absence of any trend in the approximately 20 year record from the Suva (Fiji) tide gauge can be best explained by the chronic instability of the site, as testified to by the abundant earthquakes which affect it and the demonstrated compression of the area over recent decades (Berryman, 1981). Rates of sea-level rise in the Pacific are summarised in Table 7.1.

In order to fill the large gap in space between the long-term sea-level records from Hawaii and New Zealand, data were collected from a number of long-established coastal settlements in the south-west Pacific between (and including) Solomon Islands and the Cook Islands. At the 48 stable sites (stable over periods of about 100 years at least), inundation was recorded (Table 7.2). Although inundation does not necessarily equate with sea-level rise, this is regarded as the most plausible explanation for inundation recorded consistently over such a wide area (Nunn, 1990a, c).

Table 7.1: Rates of sea-level rise in the Pacific Basin with comments on specific tectonic conditions over the last 200 years (after Nunn, 1991a).

Site, island group	Rate (mm/year)	Comments
Honolulu, Oahu, Hawaiian Is	+1.5	Island stable
Hilo, Hawaii, Hawaiian Is	+3.8	Island sinking
Kwajalein, Marshall Islands	+0.9	Island stable
Naloto, Fiji	+2.5	Site stable
Pago Pago, Tutuila, American Samoa	+1.4	Island stable
Suva, Fiji	No trend	Site unstable
Chuuk, Federated States of Micronesia	+0.6	Island stable
Wellington, New Zealand	+1.6	Island stable
(Pacific mean)	+1.0	-
(Global mean)	+1.4	-

Table 7.2: Rates of lateral inundation in the Pacific (after Nunn, 1990a).

Island group	Number of stable sites	Rate of lateral inundation (cm/yr)
Cook Islands	2	8.4
Fiji	16	15.0
Hawaii	1	125.0
Solomon Islands	20	10.8
Tonga	4	10.0
Tuvalu	1	18.0
Vanuatu	1	7.8
Western Samoa	4	51.4

Recent sea-level rise in Fiji

The data from the 16 stable sites in Fiji are listed in Table 7.3. The highest rate from Lamiti is probably exacerbated by local factors. The next 3 highest rates are probably all amplified by subsidence of the islands in question. Given the inaccuracies of the techniques used to acquire this information, and the variation in shoreline morphology at the different sites, the middle and lower range of rates of lateral inundation (1.25-11.86) are probably the most accurate for particular sites.

The rates of lateral inundation in Table 7.3 cannot be converted into rates of vertical sea-level rise. From investigations along the central east coast of Viti Levu, inundation of around 70 m was associated with a vertical sea-level rise of 10-30 cm (Nunn, 1990d).

Table 7.3: Rates of lateral inundation in Fiji.

Site, island	Rate of lateral inundation (cm/yr)	Minimum time (yrs)
Lamiti, Gau	88.24	68
Qalikarua, Matuku	31.88	69
Malawai, Gau	29.17	72
Tovu, Totoya	21.00	63
Soliaga, Beqa	11.86	59
Nawaisomo, Beqa	11.36	44
Dakuibeqa, Beqa	9.26	82
Viseisei, Viti Levu	7.35	51
Rukua, Beqa	6.33	79
Namoli, Viti Levu	5.61	49
Natunuku, Viti Levu	4.17	48
Navutu, Viti Levu	4.09	55
Culanuku, Viti Levu	3.13	64
Galoa, Viti Levu	3.13	64
Nasaqalau, Lakeba	1.49	67
Vakano, Lakeba	1.25	60

Conclusions

The evidence for sea-level rise over at least the past 100 years in the Pacific islands is irrefutable. At present the data from the region are not sufficiently precise to allow us to state with certainty whether the trend of rising sea level is that associated only with the warming since the Little Ice Age *or* whether this trend has been overprinted within the past few decades with that resulting from the human-enhanced greenhouse effect. What seems certain is that, if the mainstream predictions about future sea-level rise resulting from the human-enhanced greenhouse effect become reality, then the *rate* of vertical sea-level which the region has experienced for the past 100 years will *increase* by perhaps a factor of 2 or 3 in the next 40-80 years at least.

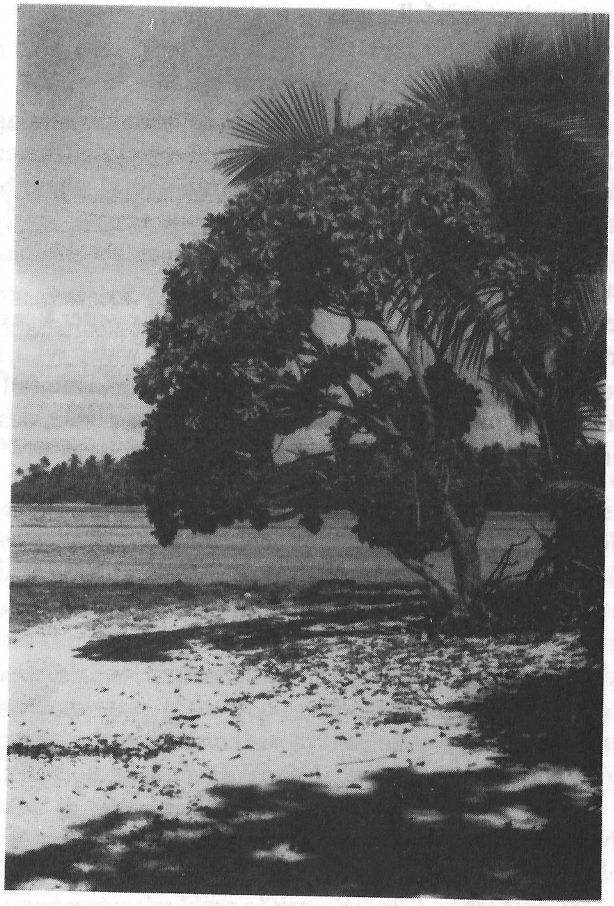

Plate 12. Planting of vegetation along vulnerable coastlines can play an important part in their conservation. Here in the Marshall Islands, *Tournefortia argentea* (syn. *Messerschmidia argentea*) is common but increasingly being removed for firewood, thus increasing the vulnerability of these coasts to erosion.

9

Strategic planning for climate change: Some concluding thoughts

Eric Waddell

The portrait that emerges from the preceding pages is an extremely complex one. There is no doubt about the fact that we are presently experiencing climate change and sea-level rise on a planetary scale. Further, the trajectory is clear for the decades to come - a progressive warming of the earth's atmosphere and an expansion of its water mass.

However, the configuration and the intensity of the trajectory is uncertain as, indeed, are some of the causes and the consequences of these changes. So, Dr Nunn draws our attention to *natural* as distinct from *human* explanations for sea-level rise in the Pacific, while Professor Willatt raises the question as to whether the climate will become *wetter* or *drier* in the future. It is hardly surprising, in the circumstances, that a number of contributors to this collection are obliged to write of several possible *scenarios* for the future.

As a geographer I am, by profession, constantly called upon to synthesise and interpret complex and often disparate sets of information. My task is, if you wish, to understand the dynamic - to make sense of it all. Prior to my reading the preceding chapters and, in fact, participating in the conference where the papers themselves were first presented, I had no preconceived ideas on the greenhouse issue.

As I first listened to, and subsequently read, the papers which comprise this volume, a *strategy* for dealing with the complex, potentially dangerous and unpredictable world that future generations will live in became clear in my own mind. In the weeks which preceded the conference we were all subject to a barrage of information in the media about the Gulf War. Ironically, my proposed strategy is influenced by these events as it exploits a *military analogy* which seems particularly appropriate to small Pacific islands nations.

We are all small, remote and relatively powerless in the face of global change and the greenhouse effect. As Fiji's Permanent Secretary for Foreign Affairs, Robin Yarrow, pointed out in his opening speech: "...as a small, non-industrial developing nation, these threats are none of our doing". True. But this does not mean that we cannot or should not do anything.

What, then, can a Pacific islands nation reasonably do? I would suggest three things, which can be conceived in the following manner, which constitute a hierarchy of strategies:

1. *Monitoring* - a good research capacity, which is in the hands of qualified scientists;
2. *Preparing* - a good system of defence to counter events as they occur, to be developed by professionals; and
3. *Attacking* - the capacity to take initiatives internationally, this being the responsibility of politicians and public servants.

In other words, we should have a first-class *intelligence system,* a capacity to *react defensively* in the face of aggression (or win individual battles), and the means to *take the initiative* (and win the war), thereby modifying the course of history.

By *monitoring,* I mean we need to understand better what is actually happening in a whole range of areas from sea levels, to ground water supply, to temperature and rainfall patterns, to frequency and intensity of cyclones and storm surges. This information will help determine the degree of vulnerability of our islands, their populations and economies. The information generated in the Pacific is limited. Worse, most of it is analysed outside the region and the results are not always shared with island governments.

Improved *monitoring* is important not only for the Pacific, but for the world as a whole. If we take into consideration their Exclusive Economic Zones, the South Pacific Forum countries cover perhaps one sixth of the Earth's surface. Perhaps even more important, the South Pacific is far removed from the great urban-industrial heat islands of the northern hemisphere. Hence, the quality of data gathered - or, if you wish, intelligence - is, according to Dr Nunn, superior to that obtained in many other parts of the world. There is much less "diversionary noise" and, as such, the Pacific can provide a more accurate portrait of global trends.

The Pacific Islands have no choice but to be well *prepared* for global change. Our very survival, in the short run, depends on our degree of preparedness. Several states are constituted exclusively of low islands, with no land over 5 m above sea level. Their vulnerability to storm waves, sea-level rise and the destruction of freshwater lenses is extreme. Even on the high islands most of the population and economic activities are located in the coastal zone. In the circumstances, we have no choice but to defend ourselves adequately. Not to be well prepared would be suicidal.

Given their extreme vulnerability to global change, Pacific islands nations must take the *initiative* in the world arena. There is no reason to be defeatist, saying "we are only 6.5 million people and mere specks of land on the surface of the earth". The Pacific islands constitute a substantial body of independent nations and, in the family of nations, the vote of Nauru is equivalent to the vote of the United States of America, at least in principle. Through sound regional collaboration the Pacific islands countries can effectively influence global environmental policy.

To hark back to our military analogy, *attack* is the best form of defence. It is the best form of defence for ourselves and for the world of which we are an integral part. It is a way of acting responsibly. It is a way which requires close collaboration between scientists, public servants and politicians. This conference, created through the joint initiative of the Fiji Institute of Agricultural Science and the Climate Change Researchers' Group at the University of the South Pacific, is a good example of what can be done. I sincerely hope such collaboration will continue, intensify and expand to include other Pacific islands countries in the future.