REGIONAL COORDINATING UNIT
EAST ASIAN SEAS ACTION PLAN

UNEP UNITED NATIONS ENVIRONMENT PROGRAMME

IMPLICATIONS OF EXPECTED CLIMATE CHANGES IN THE EAST ASIAN SEAS REGION : AN OVERVIEW

Edited by L.M. Chou

RCU/EAS TECHNICAL REPORTS SERIES NO. 2

UNEP
Bangkok, 1994

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PREFACE

In spite of uncertainties surrounding the predicted climate changes, greenhouse gases seem to have accumulated in the atmosphere to such a level that the changes may have started already and their continuation may now be inevitable.

The environmental problems associated with the potential impact of expected climate changes may prove to be among the major environmental problems facing the marine environment and adjacent coastal areas in the near future. Therefore, in line with the Decision of the Fourteenth Session of the UNEP Governing Council on "Global climate change"[1], the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of UNEP launched and supported a number of activities designed to assess the potential impact of climate changes and to assist the Governments in identification and implementation of suitable response measures which may mitigate the negative consequences of the impact.

In 1987, Task Teams on Implications of Climate Change were established for six regions covered by the UNEP Regional Seas Programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South Asian Seas and South-East Pacific). The Task Team for the East Asian Seas region was jointly sponsored by UNEP and the Association of South East Asian Marine Scientists (ASEAMS) with ASEAMS co-ordinating the work of the Task Team.

The initial objective of the Task Teams was to prepare regional overviews and site specific case studies on the possible impact of predicted climate changes on the ecological systems, as well as on the socio-economic structures and activities of their respective regions. The overviews and case studies were expected:

- to examine the possible effects of the sea level changes on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.);

- to examine the possible effects of temperature elevations on the terrestrial and aquatic ecosystems, including the possible effects on economically important species;

- to examine the possible effects of climatic, physiographic and ecological changes on the socio-economic structures and activities; and

- to determine areas or systems which appear to be most vulnerable to the above.

The regional studies were intended to cover the marine environment and adjacent coastal areas influenced by or influencing the marine environment.

The regional studies prepared by the Task Teams were planned to be presented to intergovernmental meetings convened in the framework of the relevant Regional Seas Action Plans, in order to draw the countries' attention to the problems associated with expected climate change and to prompt their involvement in development of policy options and response measures suitable for their region.

The site specific case studies developed by the Task Teams were planned to be presented to national seminars.

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[1]/ Decision UNEP/GC.14/20

Once the initial objective (impact studies) of the Task Teams is achieved, they concentrate on providing assistance to national authorities in defining specific policy options and suitable response measures.

The East Asian Seas Regional Task Team on the Implications of Climate Change comprised scientists from within the region. At its two meetings in May and November of 1989, team members discussed their findings which led to this report. Emphasis was focused on the 5 countries of the region which participate in the Regional Seas Programme (Indonesia, Malaysia, Philippines, Singapore and Thailand) although other countries within the region have been considered in some of the chapters. The team worked to a scenario of a mean global atmospheric temperature rise of 1.5°C and corresponding sea level rise of 20cm by the year 2025. Case studies in this report appear either as individual chapters or are incorporated within chapters.

The publication was prepared by Prof. L.M. Chou on the basis of the work carried out by the UNEP/ASEAMS Task Team on Implications of Climate Change in the East Asian Seas region. The Task Team comprised L.M. Chou (Team Coordinator), J.G. de la Alas, E.C.F. Bird, A.L. Chong, S.C. Lee, S. Panich, J.N. Paw, K.C. Sieh, S. Sudara, H.D. Tjia, H. Uktolseya, P.P. Wong, H.T. Yap.

EXECUTIVE SUMMARY

The five countries in the East Asian Seas Region have an extensive combined coastline of 99,092 km encompassing a combined land area of 295,063,000 hectares. The present population of 312.7 million is projected to increase to 491.5 million by the year 2025. Approximately 75% of the current population live in coastal villages and towns and the rate of coastal development is rapid. Dependence on coastal and marine resources is high, judging from the present rates of habitat destruction and loss.

The region's coastal zone is heavily utilized to support a broad range of socio-economic activities, including industry, transport and commerce, recreation and farming. Coastal aquaculture development is extensive and growing within the region.

Existing records of temperature and rainfall in the coastal areas of peninsular Malaysia since 1930, and East Malaysia (since 1953), show an upward trend in temperature, but no definite trend in rainfall. The data show an average rate of increase per 100 years of 1.7°C in daily mean temperature. The 112-year record of rainfall in Singapore did not reveal any clear trend. However, with the expected further rise in air temperature by 2025, rainfall is also expected to increase.

Statistical tests on apparent increases in wind speed, rainfall and pressure gradients between South China and Southeast Asia showed that the changes were not significant and there is insufficient evidence at present to suggest a change in monsoon and typhoon activity in connection with CO_2 doubling although this is expected to result in an increase in extreme events.

Global warming will cause changes in the physical characteristics of the seas in the region. Present sea surface temperatures of 20°C to 28°C during the colder months at higher latitudes in the East Asian Seas and of 27°C to 29°C for the warmer months in same areas and throughout the year in equatorial areas, are all expected to increase by 1°C. This will be caused by increased long wave energy re-radiated downwards by the atmosphere. However, it can be anticipated that there will be a lag in the response of the surface layers and much longer lag time in the response of the bottom layers. Enhanced evaporation and increased precipitation will affect salinity. Vertical stability of the already stable surface waters of the tropics will increase further, thus inhibiting vertical mixing which has implications for the biological productivity of the marine environment.

The expected increase in atmospheric temperature is predicted to be greater in the high latitudes (4-6°C) than in the tropics (0-2°C). As a result, the warming of the tropical oceans will be less than at higher latitudes resulting in a decrease in the north-south temperature gradient in the oceans, which in turn, will act to diminish the magnitude of the thermohaline circulation. The implications of these changes on the intensity of the Kuroshio current cannot be determined at this stage. Similarly, the impact of such change on other current systems within the East Asian Seas remains uncertain.

Present knowledge of coral reef dynamics indicates that modern day reefs can cope with a sea-level rise of 5mm/yr. Sea-level rise may provide the necessary environmental conditions for reefs to optimize structure and orientation. Many reefs in the region appear to have attained their maximum limits of growth. Reef flats, being relatively shallow, are subject to greater stress factors and thus support less coral growth. A sea-level rise will reduce the frequency of reef flats to aerial exposure and may promote growth on this zone. These assumptions however, have been made without considering erosional factors caused by increased rainfall which will blanket suitable substrata as well as sessile organisms with

sediment. Lowered salinity will also be detrimental to species unable to tolerate large salinity fluctuations. A sudden increase in water temperature may also cause corals to bleach, resulting in mass mortality.

Seagrass and macroalgae can be expected to shift their distribution landward in response to sea-level rise provided that the newly submerged shore areas are suitable for the primary settlement of spores or seedlings. Seagrasses in particular, are frequently exposed at ebb tide and have become adapted to ambient air temperature and rainfall. However, increased air temperature and increased precipitation may exceed their environmental thresholds and result in a reduction of these resources, which would in turn affect certain economically important fish and shrimp species.

Mangroves can theoretically migrate landwards in response to sea-level rise as long as freshwater supply remains adequate. Salinity is of critical importance as the fluctuating regimes of tidal inundation and freshwater dilution influence the characteristic zonation patterns from the seaward to the landward side of these communities. The change in salinity patterns through increased rainfall will affect non-tolerant species and determine the survival or death of affected ecozones. Mangrove species are also expected to be stressed by elevated temperatures.

Direct as well as indirect influences on marine productivity can be expected from climate change. Small-scale temperature increases could result in higher productivity by enhancing the growth of many species. Increased precipitation, if frequent and intense, can however lead to decreased salinity in shallow coastal areas much to the detriment of species inhabiting them. The increased level of nutrients washed out to sea can have a positive effect, encouraging growth of primary producers, as well as a negative effect where enhanced blooms of algae may be detrimental to other marine organisms and mariculture operations. Heavy amounts of sediment washed out to sea will reduce light penetration which is damaging to coastal reefs and marine plants.

Enhanced coastal erosion, through the alteration of coastal topography, may cause large changes in nearshore current patterns. This, coupled with salt water intrusion into the estuarine areas, may have adverse effects on breeding and nursery grounds and the migratory patterns of some economically important species.

Fisheries production would be affected through the change in distribution patterns caused by changes in nearshore currents. Even though the subtidal area would be expanded, allowing more shallow areas for fishery operations, the production would depend on the location. Techniques in mariculture which are now operating along coastlines may change. An example is the greater use of cage or raft culture, due to the unavailability of land since dense human settlements already occupy coastlines. The East Asian Seas is a very productive area. Sea-level rise may bring about some changes in species composition in highly productive areas, affecting economically important species, and thus techniques for fishing would also change.

The effect of climate change on tropical forests will be severe, due to existing situations like the nutrient-poor soils and the alarming rate of deforestation in this region. It has been shown in the past (e.g. the 1982-1983 drought) that tropical forests in this area are not immune to climatic extremes and can be severely affected. CO_2 fertilization has not been proven and may not benefit the forests, as it may alter the balance of the forest ecosystem. The agriculture sector will stand to benefit from climate change through CO_2 fertilization, which may increase the yield by 10-50%, as long as moisture is adequate.

A case study in northern Thailand showed that crop yield (rice) depended on available rainfall in July and August, the "drought periods". The means for conserving water during these months was therefore important, especially because evapotranspiration increased in these months of elevated temperatures. Suggestions for increasing available moisture include bundling and strategic irrigation, both of which would be adequate for the provision of water at the critical period, and allow farmers to enjoy the benefits of CO_2 fertilization. In order to cope with expected increasing drought or "stress periods", new drought tolerant varieties of rice may need to be developed. Switching to other crops may not be feasible because crop types are restricted by market forces, and by domestic and international demands.

The effects of temperature increase are complicated by agricultural practice, increased rainfall and higher evapotranspiration. These can be studied using crop models currently being developed, but preliminary results show a mixture of benefits and losses from climate change. It is noted that certain beneficial measures could result from climatic change, such as use of better irrigation systems to offset the loss of water while taking advantage of the higher CO_2 which increases growth rate. Past records show that agricultural practice in this region is very adaptable to extreme climate events such as droughts and floods, and that it is highly possible to plan for mitigation measures in advance.

It is concluded that impacts on agriculture and forestry from sea-level rise will result mainly from salinity intrusion inland rather than from the actual loss of land.

The impact of sea-level rise is considered to be more direct on coastal geomorphology than elevated temperature. Terrestrial flooding or inundation is the first obvious impact. The extent of flooding is dependent on the coastal gradient and shoreline configuration. Another important aspect is the tidal range, where land affected by a rising sea-level within a small tidal range would be subject to more frequent tidal and wave action than is the case of environments with a wide tidal range.

Coupled with changes in nearshore current patterns, coastal erosion and deposition rates will increase and result in changes to coastal geomorphology. This will be further aggravated by the loss of natural ecosystems which, if unable to tolerate the changed conditions, will lose their coastal protection capability.

Coastal erosion will occur more on soft coasts. Thus, sandy beaches, deltas and cliffs formed from soft materials are more susceptible to erosion from a rise in sea-level. For sandy shores, the resulting retreat from a rising sea-level can be predicted to some extent by the Bruun Rule, although there are limitations and difficulties in the application of this rule. Coral reefs, mangroves and sandy beaches are identified as most vulnerable to sea-level rise. Coastal stretches which require further investigation are classified under five types of coasts: deltas, coral reefs, beach ridges, barriers and spits, lagoons and artificial coastlines.

Coastal dikes and other man-made protection devices will have to be raised or modified to prevent increased wave overtopping, provided geotechnical stability is maintained. However, a sea-level rise of 5 mm/yr may not be considered a serious enough threat to small coastal communities in low lying areas for policy makers to take action.

A 20 cm sea-level rise by 2025 is likely to be insignificant compared with anthropogenic factors operating in the coastal environment. This is indicated by Malaysian case studies and may apply to the other countries in this region. However, it can reasonably be concluded that sea-level rise will aggravate existing erosion rates and initiate new erosion. The role of extreme events, specifically typhoons, in the event of global warming is as yet unclear, though it was suggested that increased occurrences of typhoon activity may result.

Current understanding of the mechanisms of air-land-ocean interactions and muddy coast dynamics remain inadequate but should not preclude adoption of a pro-active posture in parallel with on-going research aimed at improving basic knowledge concerning climate change impacts. It is emphasized that the Bruun Rule, and other techniques such as sediment budget analysis and dynamic equilibrium profile, are strictly applicable only to sandy coasts. There is as yet no analytical technique to compute or even estimate mud coast retreat in the event of sea-level rise.

On the mechanism of mud coast erosion and the role of mangroves, it is suggested that opportunities for prototype observations exist in that seaward erosion, either due to increased storminess or other causes, usually results in a concave-upward shore profile seaward of the mangroves. This is also characteristic of deltaic retreat. On the other hand, mangrove retreat due to physiological stress tends to show up as mangrove dieback adjacent to the coastal bund. The same can be said for mud wave migration.

Just as sand nourishment is perceived as a potential mitigation measure against sea-level rise-induced erosion, mud nourishment also merits similar attention.

A general assessment in the case of Malaysia indicates that the situation may only worsen due to the present trend towards the use of impounding reservoirs since the more easily developed surface water sources have already been tapped. This however, may not reflect the situation in the other countries, such as Thailand. However, it can be concluded that the projected sea-level rise will aggravate the existing problem of saline contamination wherever it happens. Salinity intrusion further inland primarily through rivers, will have implications for low altitude forestry and agriculture. Saltwater intrusion into coastal aquifers will also result and a general raising of water tables can be expected.

Climatic risk factors associated with the greenhouse effect and the consequent sea-level rise have not been considered in national development plans of the East Asia Seas countries. Policy makers in the region are neither fully convinced of the projected climatic change in the next century, nor of the need to incorporate such factors into national development plans, because of the lack of concrete scientific evidence. Although resource managers and private entities appear to be more receptive to including these factors into their plans, it is important to enlighten policy makers on these factors as their policy decisions will have far wider and long-term consequences on the socio-economic well-being of coastal communities.

The coastal areas of Southeast Asia are generally highly populated, due to the perceived higher socio-economic opportunities, especially in the exploitation of common access resources like fisheries, mangroves, coral reefs, etc. Projected climate changes and sea-level rise will probably exacerbate socio-economic problems that already exist in these areas. The incorporation of climatic risk factors in currently formulated coastal zone management plans should enable responses to be taken against the impacts of climatic change and sea-level rise. One recommended measure is the construction of versatile structures along retreating coastlines. The costs involved now could be lower than those incurred for greater protection at a later stage. However, the question of allocation of space and of property rights has to be carefully addressed in broad management and policy plans in the event that zones of people and industries have to be relocated.

It was noted that Indonesia may be the first country in the region to successfully implement an integrated human settlement plan. Environmental regulations in Indonesia incorporate several important aspects, namely the management of the living environment, environmental impact assessment, implementation of environmental quality standards, and spatial planning at various levels.

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L.M. Chou

Department of Zoology
National University of Singapore
10, Kent Ridge Crescent
Singapore 0511

PHYSICAL SETTING AND POPULATION

The East Asian Seas which link the countries of Southeast Asia cover a geographical area stretching from latitudes 20°N to 10°S, and longitudes 95° to 145°E (Figure 1.1). The seas form the interface between the Pacific and the Indian oceans and the countries of the region are recognized as having a high dependence on the coastal and marine environment. Extensive high diversity ecosystems, both terrestrial and marine, characterize the region with a high proportion being heavily exploited. The richness of the natural living resources is supported by the warm tropical climate and abundant precipitation. Coastal and marine life in particular, benefit from the high nutrient load washed down from land to sea.

The five countries within the East Asian Seas region which are participating in UNEP's Regional Seas Action Plan have an extensive combined coastline of 99,092 km (Table 1), encompassing a combined land area of 295,063 thousand hectares. The present population of 312.7 million is projected to increase to 491.5 million by the year 2025.

Table 1.1: Land and population of the East Asian Seas countries (World Resources Institute, 1988).[1]

Country	Land area (thousand hectares)	Coastline length (km)	Population (millions)	
			1989	2025
Indonesia	181,157	54,716	178.5	272.7
Malaysia	32,855	4,675	17.0	26.8
Philippines	29,817	36,289	59.7	102.8
Singapore	57	193	2.7	3.3
Thailand	51,177	3,219	54.8	85.9

[1] Data on land areas, coastline lengths and populations for the countries of the East Asian Seas given in this table differ slightly from figures cited elsewhere in this volume, reflecting the differences in the sources used. In particular, coastline lengths reflect differences in the scale of the maps used for calculation by different authors.

COASTAL DEVELOPMENT

Coastal development is rapid with approximately 75% of the current population living in coastal towns and villages, resulting in extensive coastal habitat destruction and loss.

The region's coastal zone is heavily utilized to support a broad range of socio-economic activities including industry, transport and commerce, recreation, farming. With this development, coastal areas have become rapidly urbanized, placing a great strain on the coastal environment and its living resources. Mariculture and coastal aquaculture development is extensive and growing within the region with ongoing conversion of mangrove forests into aquaculture ponds. Tourism, particularly coastal tourism, plays an important role in the economy of most of these countries and unexploited coastal areas are continually being developed for this purpose.

FISHERIES

The region's dependence on the sea is evident from the average annual marine catch which has been increasing steadily (Table 1.2) although two major fishing areas, the Gulf of Thailand and the Strait of Malacca, have been overfished or polluted by urban discharge. The fishery of these waters is productive and contributes to 11% of the world's total marine catch. Over 2500 species of fish and marine invertebrates make up the fishery. Over five million people are directly dependent on fishing for their livelihood (Samson, 1985).

Table 1.2: Average annual marine catch of the East Asian Seas countries (World Resources Institute, 1988).

	Average annual marine catch	
Country	1983-85 (thousand metric tons)	Percentage change over 1974-76
Indonesia	1732	+ 73
Malaysia	670	+ 33
Philippines	1330	+ 14
Singapore	22	+ 31
Thailand	2012	+ 42

AGRICULTURE AND FORESTRY

Agriculture and forestry are also important in the region with land areas used for agriculture increasing and forestry areas decreasing (Table 1.3). Deforestation has become recognized as an important issue and steps have been taken to reforest logged areas in some countries. The East Asian Seas region is a major supplier of rice, coffee, tea, sugar, spices, rubber and palm oil to the international market.

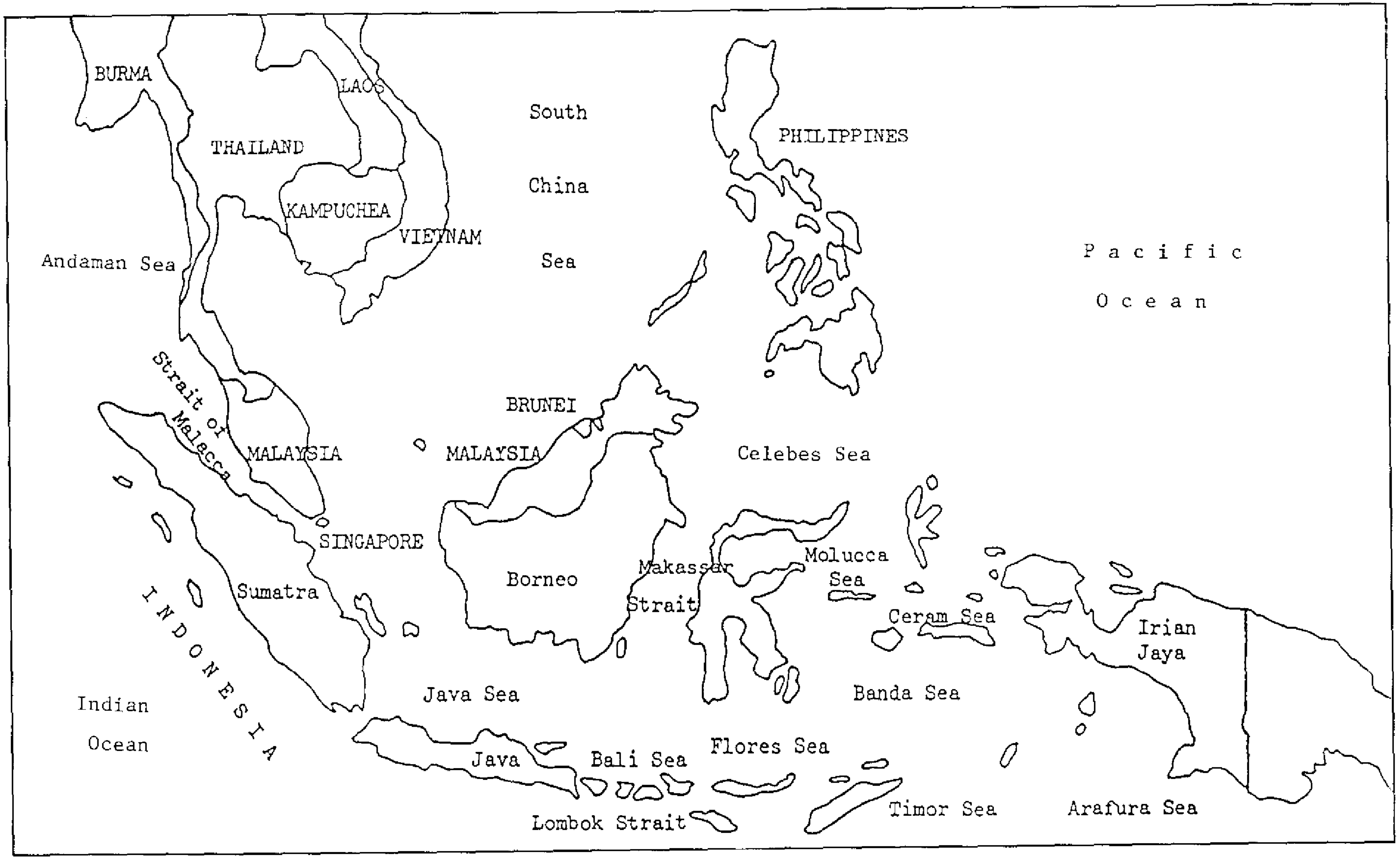

Figure 1.1 The East Asian Seas region

Table 1.3: Extent of agricultural land and forests in the East Asian Seas countries (World Resources Institute, 1988).

	Cropland (thousand hectares)		Permanent pasture (thousand hectares)		Forests (thousand hectares)	
Country	1983-85	% change over 1964-66	1983-85	% change over 1964-66	1983-85	% change over 1964-66
Indonesia	20,680	+ 19.0	11,867	- 5.1	121,698	- 1.5
Malaysia	4,353	+ 17.7	27	+ 12.5	20,677	- 16.8
Philippines	10,150	+ 10.2	1,140	+ 39.4	11,783	- 30.5
Singapore	6	- 56.4	0	0.0	3	- 25.0
Thailand	19,553	+ 55.1	308	0.0	15,267	- 41.4

NATURAL COASTAL AND MARINE ECOSYSTEMS

Natural coastal and marine ecosystems have significant values for the various roles that they perform. The extensive mangrove forests of the region have a combined estimated area of more than 5 million hectares (Aksornkoae, 1986; Chan, 1986; Corlett, 1986; Philippine Natural Mangrove Committee (PNMC), 1986; Soemodihardjo, 1986). They form a valuable resource especially in sustaining other natural resources such as fish, crustacea and shellfish. They also serve as important nursery areas for other commercially important species of fish and shrimps and have been shown to support nearshore fish production (MacNae, 1974; Unar & Naamin, 1984). In Indonesia alone, the value of mangrove forestry products, both for export and domestic use, amounted to an estimated US$26 million in 1978 while mangrove-linked fisheries products amounted to US$194 million (Salm & Halim, 1984).

Mangrove forests are also important in protecting shorelines against erosion and in modifying the effects of typhoons on coastal areas. They trap sediment washed down by rivers and restrict freshwater runoff from land so that the salinity of the coastal area remains stable.

The region's mangroves support a high diversity of over 300 plant species and more than 1000 marine invertebrate and vertebrate species. In addition there are 177 bird and 36 mammal species associated with mangroves.

The estimated extent of coral reefs worldwide is 600,000 km^2 of which 25% to 30% are located in the region (White, 1987). Extensive areas of the coastal near-shore waters of the region are shallow and abound with reefs. Reef life is rich and diverse and the region is considered as the faunistic centre of the whole Indo-Pacific region. The most extensive reefs occur in Indonesia and the Philippines. The diversity of hard corals, reef fish and reef-associated organisms is known to be high. Over 2000 species or 10% of the world's fish are associated with coral reefs and many of them are valuable as a food source.

CONCLUSION

The intense economic development of the region and increasing loss of high diversity natural ecosystems have resulted in the realization that these resource conflicts cannot continue indefinely. Management plans especially for the coastal zone which is the most affected are beginning to be recognized for their importance in contributing towards sustainable development. Many of these plans however have not taken into serious consideration the predicted global temperature increase and sea level rise.

Coastal cities will be most affected by these changes and in some cases, the effect will be aggravated by land subsidence. Saltwater intrusion will bring saline waters further inland through rivers and this has implications for agriculture as well as groundwater resources. Low lying areas will be lost to the sea and adjacent areas subject to severe flooding. Increased erosion will accompany sea level rise.

Ocean circulation patterns will change because the higher latitudes are expected to warm up more than the lower latitudes, and this will result in profound changes to marine productivity and marine living resources of the region.

Climate will change to more extreme conditions i.e. more intense rainfall interspersed by longer drought periods. This will affect agriculture to a large extent.

Marine and coastal ecosystems such as mangroves and coral reefs will be adversely affected by these changes if they are too sudden or rapid.

The region is thus vulnerable to climate change and sea level rise and coastal zone utilization and its effective management must be re-examined to take into account these global changes to the environment.

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2. GLOBAL WARMING AND LONG-TERM SEA LEVEL RISE IN SOUTHEAST ASIA

H.D. Tjia

Department of Geology, Universiti Kebangsaan Malaysia
43600 Bangi, Malaysia[1]

INTRODUCTION

Over the past century, tide gauges indicate that sea level has already risen 10 to 15cm (Fairbridge & Krebs, 1962). The rise has been attributed to increase in carbon dioxide through combustion of fossil fuels since the beginning of the industrial revolution some 200 years ago. The direct consequences of the greenhouse conditions will be global warming of a few degrees Celsius in the 21st century, partial melting of ice, and thermal expansion of seawater resulting in sea level rise. The rise has been estimated to range between 12 cm and 50 cm by 2025 AD, and between 30 cm and 180 cm by 2075 AD (Hoffman et al., 1983; Barnett, 1984). Initially, only thermal expansion of the upper oceanic waters will be responsible for this sea level rise. In the long term, the temperature increase will involve progressively deeper waters contributing to further rises in sea level.

The rise in sea level may also be expected to result in the following changes:

a. drowning of parts of coastal plains and low islands;
b. increasing flood risk in the lower parts of coastal plains;
c. increasing erosion of natural coasts and further threat to man-made structures;
d. raising of water tables;
e. increasing salinity of surface waters and extension of tidal influences over wider areas further upstream;
f. increasing salt water intrusion in aquifers.

For certain coastal segments of the United States such probable changes have been discussed and assessed by Titus (1988, in preparation).

Global climatic change is only one of the many processes that influence sea level position. Tectonic stability of a particular coastal region also determines what **relative** sea level change will take place. Several researchers believe that the geoid, the shape of the Earth's surface as defined by the sea surface, may change rather rapidly. In short, coastal researchers are now aware that simultaneously occurring sea level changes may vary on different coasts.

SEA LEVEL CHANGE

Long-term sea level change, as opposed to tidal or seasonal changes, may be attributed to four groups of causes:

i. change in the water volume of the oceans;

ii. change in the volume of the ocean basins;

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[1] Present affiliation: Petronas Research and Scientific Services Sdn. Bhd., Lot 1026, PKNS Industrial Estate, Selangor Darul Ehsan, Malaysia

iii change in the shape of the geoid (which alters the water surface in relation to gravity); and

iv. human activities.

Change in the Water Volume

Glacial factor

Water was extracted from the sea and stored in glaciers during the glacial periods. Meltwater from the glaciers returned to the sea during warm interglacial periods. During the Quaternary Era (the last 1.8 million years), alternating glacial and interglacial intervals resulted in lowering and raising of sea level perhaps as low as 130 m below and as high as 30 m above present sea level. During the last Glacial Period which reached its peak 18,000 years ago, sea level in Southeast Asia stood at least 100 m below present datum. At the peak of the last Interglacial some 125,000 years ago, sea level reached 6 m above present levels. It has been estimated that sea temperatures then were perhaps 1°C warmer. During glacial maxima, global temperature may have been 5°C cooler than at present. On East Asian coasts in particular, there is overwhelming evidence that 5000-6000 years ago sea level was again 5 to 6 m higher than it is today.

Thermal factor

Temperature changes affect sea water causing it to expand or to contract in response to warming or cooling. It has been calculated that a global warming of 1°C would cause sea level to rise 65 cm as a result of expansion of **all** ocean waters. At the same time, global warming would also cause glaciers and ice sheets to melt. The West Antarctic ice sheet is mainly resting on the sea and is therefore most susceptible to warming of the ocean waters. During the Last Interglacial this ice sheet probably melted completely and accounted for the 6 metres rise in sea level at 125,000 BP (Before Present; 0 BP = 1950 AD). However, it will take several hundred to a few thousand years to melt the present ice sheet completely.

Juvenile and Connate Waters

Water trapped in the interstices of sediments, or connate water, may be released mainly through compaction and heating. Volcanos produce large volumes of water, most of which consists of recycled surface waters. A small fraction is magmatic or juvenile water. In other words, throughout geologic history volcanic activity has been contributing to the water mass at the surface.

Change in Ocean Basin Volume

Isostasy

Geoscientists accept that beneath a relatively thin (some 150 km) rigid crust, the Earth's upper mantle behaves as a viscous solid with the ability to flow under high pressure and high temperature operating over long periods. Changes of mass distribution in or on the crust are compensated for by flow of heavy mantle material away from areas of heavier loads. This compensation mechanism is called isostasy. Regions that during the Last Glacial were covered by 3 to 4 km thick ice sheets, such as the Baltic region and that of North America from the Great Lakes northward, have risen isostatically more than a hundred metres over the last 10,000 years when the sheets retreated northward and eventually melted completely. Artificial lakes and reservoirs cause loading and result in depressing broad regions containing the new water bodies. From such observations it is estimated that isostatic response to change in surficial mass distribution may begin to take place in about ten years.

Epeirogenesis

Slow vertical movements involving broad regions of the crust, or epeirogenesis, are attributed to phase changes, recrystallization, thermal convection currents, and other still unknown processes in the Earth's mantle. Rates of movement are probably hundredths to thousandths of millimetres annually (Tjia, 1970). Such movements have been documented from geologically stable regions, such as the Thai-Malay Peninsula (Figure 2.1). Epeirogenetic movements probably also take place in geologically mobile regions, such as the Moluccas and the Philippines, where more rapid crustal movements, the so-called orogenetic movements, appear to have masked the effects of epeirogenesis.

Orogenesis

The same causes that result in epeirogenesis probably also result in the rapid vertical as well as lateral crustal movements known as orogenetic movements. Average rates range up to 10 mm yearly. The actual movements, however, are presumably spasmodic. This is suggested by the terrace-like appearance of reef terraces and recurrence intervals of earthquakes. Another difference from epeirogenesis is that orogenetic movements affect elongated zones near continental margins or along fracture zones. According to Plate Tectonic theory, the rigid crust of about 150 km thickness (consisting of the actual Earth's crust of not thicker than 70 km and uppermost mantle), also known as the lithosphere, is composed of six major "plates", each moving as a unit. When two plates move rapidly away from each other, global sea level rises causing widespread transgressions. The stratigraphic record seems to substantiate this. Epeirogenesis and orogenesis cause changes in ocean basin volume.

Sedimentation

Epeirogenesis and especially orogenesis create reliefs that result in increases in the rate of sedimentation. Sediments entering the ocean basin change its volume. High relief also assists mass movements and by this process land-based material may be transferred into the oceans. In certain areas, high topography may change air current systems and regional climate. The climatic changes may contribute to more rapid denudation of the land and thus contribute to ocean basin change more effectively.

Organisms

Adverse changes in the marine environment may result in mass extinctions and contribute to faster sedimentation of organic matter that in turn changes the ocean basin volume. Such changes may also be expected from growth and decay of coral reefs.

Volcanism

Erupting volcanos transfer material from inside the Earth onto its surface. Part of the volcanic products is distributed over large areas and directly or eventually enters the ocean basin contributing to changes in its volume. Coastal and oceanic volcanos change the ocean basin volume directly. Eventually, the topographic elevations created by volcanos will be partly compensated for by subsidence through isostasy.

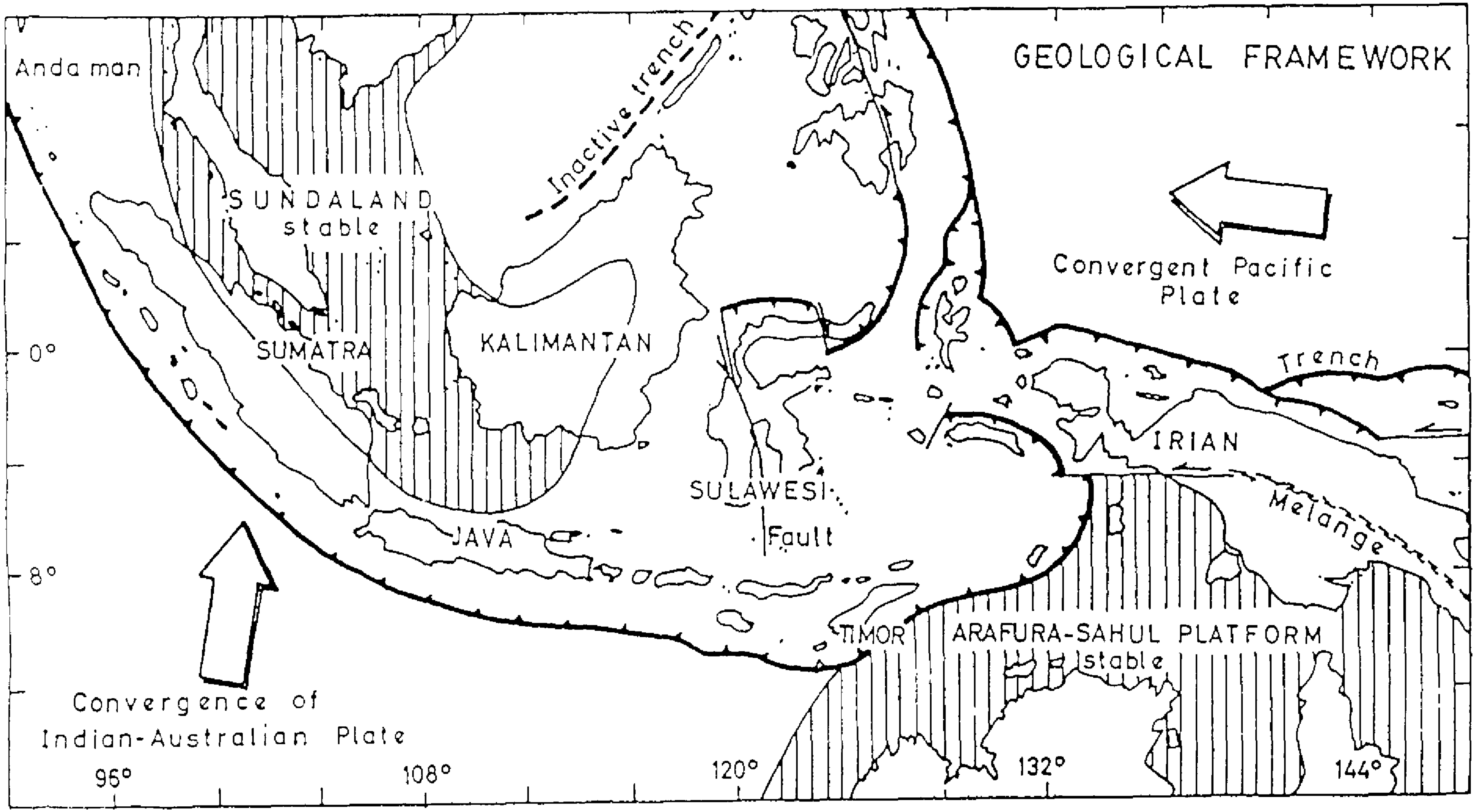


Figure 2.1 Geologically Stable Sundaland and Arafura-Sahul Platform and the geologically mobile region between and around them.

Extraterrestrial Matter

Cosmic dust continuously rains down. Since water constitutes 71% of the Earth's surface, most of the cosmic matter settles on the sea floor. Cosmic dust forms part of the red clay found in deep-sea floors. The rate of red clay sedimentation is a mere millimetre each thousand years. However, cosmic dust and the occasional meteorite also contribute to changing the ocean basin volumes.

Large meteorites may have indirectly caused widespread climatic changes resulting in different precipitation patterns and catastrophic organic and physical changes. For instance, the rather sudden extinction of dinosaurs some 65 million years ago at the end of the Cretaceous has been attributed to a large meteorite (or a meteorite shower) impacting Earth. The collision resulted in fire storms and prolonged dust storms that blocked out sunlight causing most vegetation to expire followed by extinctions of certain herbivores and carnivores. In more than a dozen localities worldwide, sediment representing the Cretaceous-Tertiary time boundary has been found to contain high proportions of iridium, uncommon in Earth material but usual in meteorites.

Geoid

The shape of the Earth as defined by the surface of the seas is the geoid. This surface is everywhere perpendicular to the direction of gravity. In the crust and mantle, material of different densities is distributed unevenly. The different gravity values influence the geoid. The geoid is also influenced by the rotational velocity of the Earth. During a change of angular velocity, one may expect the geoid pattern to change. When the angular velocity becomes less, the geoid relief probably flattens and its pattern shifts eastward (Figure 2.2). If the rotation increases, the geoid relief becomes more accentuated and the geoid pattern shifts westward. One may expect that the rotational speed has changed through changes of mass distributions, probably superimposed with effects of the cyclic changes in the Earth's planetary motions. Three known cyclic changes are: the obliquity of the ecliptic (period of 40,000 years), eccentricity of the orbit (92,000 years), and precession of the equinoxes (21,000 years). Changes in rotational velocity may have occurred every several thousand years to every several hundred thousand years.

Until Morner (1976) pointed out how important the influence of the geoid is for shoreline studies, many researchers were trying to correlate former shorelines in geologically stable regions solely by their elevations. Figure 2.2 shows that currently the geoid highs and lows define maximum relief reaching almost 200m. During a change to lower rotational speed, the geoid pattern may be expected to shift eastward. The newly acquired geoid pattern will be maintained after the change in velocity ceases to operate. In this case, Sumatra and the Thai-Malay Peninsula that lie close to the current zero geoid contour may be expected to experience a drop in sea level, while at the same time the east coast of Argentina experiences sea level rise.

Human Activities

Human activities have certainly influenced the nature and rates of erosion, sedimentation, and isostasy. Direct influences include land reclamation, dredging and mining the sea floor, refuse dumping, and excavation of interoceanic waterways. Since the beginning of the industrial revolution, burning of fossil fuels has added 20% to the concentration of carbon dioxide in the atmosphere (Titus, 1986a). This gas absorbs infrared radiation resulting in global temperature increase. Long-term tidal records indicate that sea level has already risen 10 to 15cm during the past century. In the past 15 years concentrations of nitrous oxide and chlorofluorocarbons have also been increasing. These greenhouse gases are warming the Earth, causing expansion of seawater and melting of glaciers. The actual rise of sea level on a particular coast will be the net result of a combination of factors, that is:

a. global warming;
b. tectonic mobility / stability of the coast;
c. change (?) of the geoid as a consequence of mass redistribution (glaciers to seawater);
d. change (?) in marine conditions (currents, tides);
e. secular change of regional sea level due to unknown causes (see the case for Peninsular Malaysia).

SEA LEVEL CHANGE IN SOUTHEAST ASIA

Southeast Asia *sensu lato* is composed of two geologically stable regions; the Sundaland in the west and the Arafura-Sahul Platform in the east, separated by a broad geologically highly mobile region (Figure 2.1). The mobile region is characterized by high topographic relief, active volcanos, strong and frequent earthquakes, and rates of vertical crustal movements reaching values of 10 mm/yr. In contrast, geologically stable regions have experienced very slow vertical crustal movements at rates 2 to 3 orders of magnitude lower than for the mobile region. Some information is available on the rates of vertical displacements for certain coastal stretches in the mobile region (Figure 2.3) and obviously many more measurements are needed before the orogenetic contribution could be separated from actual sea level changes. Secular sea level changes can be interpreted for Peninsular Malaysia and adjacent areas. This is because the area is part of geologically stable Sundaland and contains many Late Quaternary shorelines dated by the radiocarbon method. A recent review is given by Tjia & Fujii (in press) and its abstract quoted below.

"More than one hundred and fifty radiometrically (radiocarbon method) dated shoreline indicators in tectonically stable Peninsular Malaysia indicate that prior to 5000 BP, sea level rose from its low position (a hundred metres or more below present datum) at rates between 15 mm and 6 mm annually to its maximum Holocene position about 5 m above mean sea level. Subsequently, sea level receded to its present position through a series of fluctuations of progressively lower peaks and depressions. At around 1200 BP, Holocene sea level appears to have dropped one to two metres below current datum. The Late Holocene fluctuations had approximately 2 m amplitudes with periods of 2000 years. If this pattern is repeated, in the near future sea level may be expected to recede at rates between 1.5 mm and 2 mm annually. In the Southeast Asian region, this sea-level drop is expected to lessen the impact of its rise resulting from global warming due to the increase of the so called greenhouse gases in the atmosphere.

Four Early Holocene and two other dates between 26ka and 21ka of shore indicators in northwest Peninsular Malaysia suggest that during these periods geoid highs may have existed, and sea level differences between the northern and southern part of the Malacca Strait reached values of 40m".

Figure 2.2 The geoid according to W.H. Rapp (1974). Contour interval is 20m; dashed contour lines represent 10m interval.

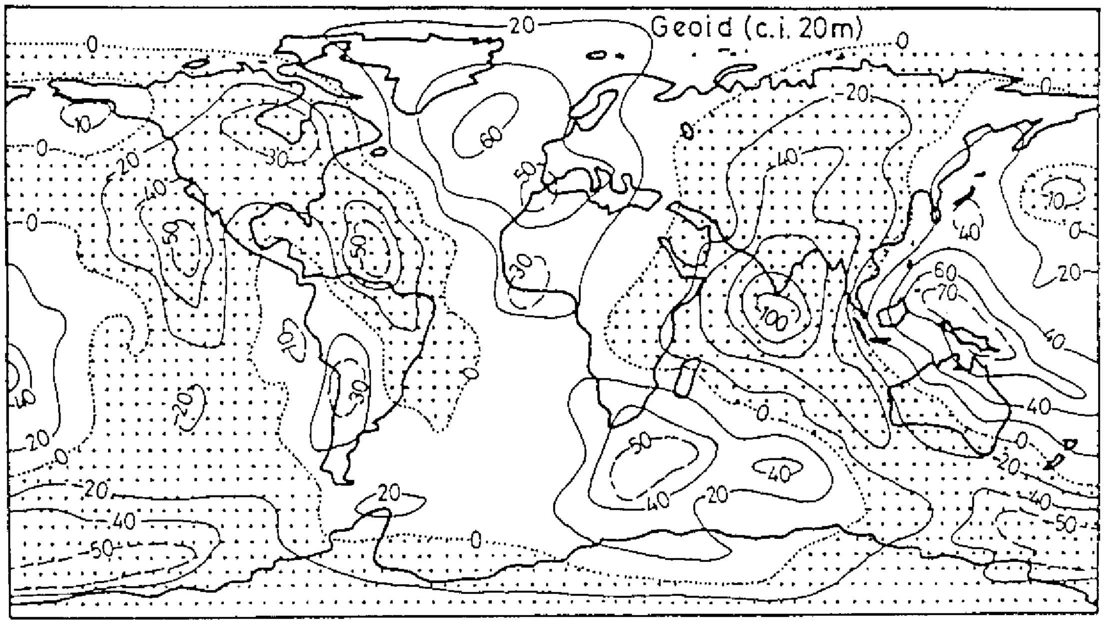
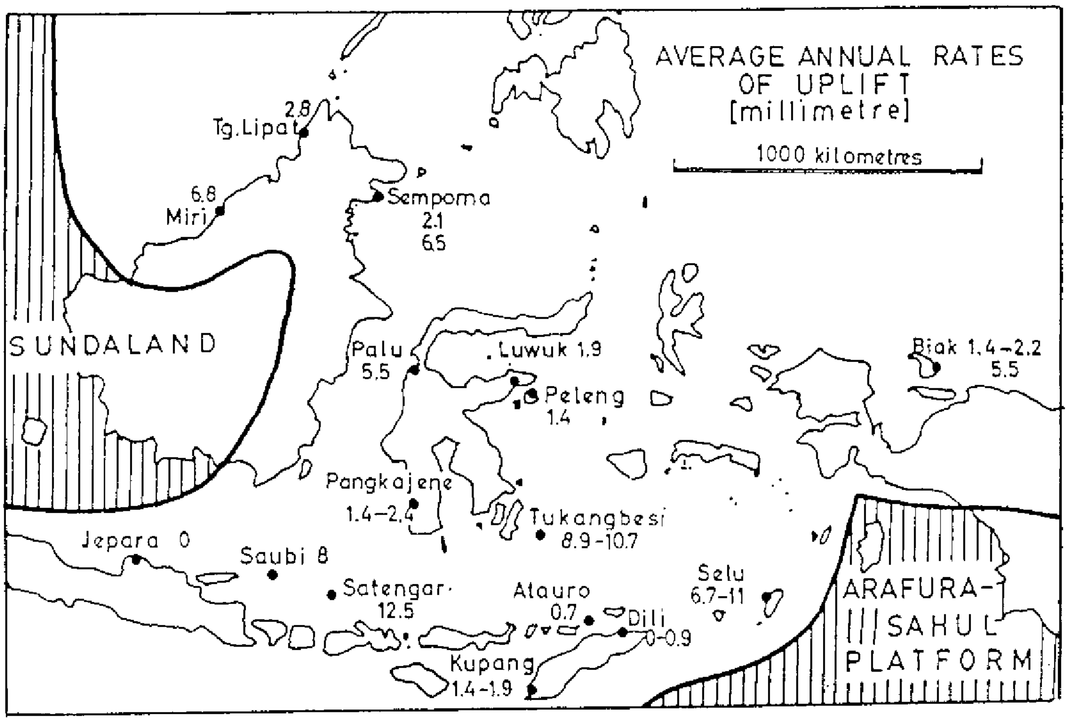


Figure 2.3 Interpreted rates of vertical crustal movement in East Indonesia. Rates were calculated using radiometrically dated shoreline indicators. From H.D. Tjia (in press).



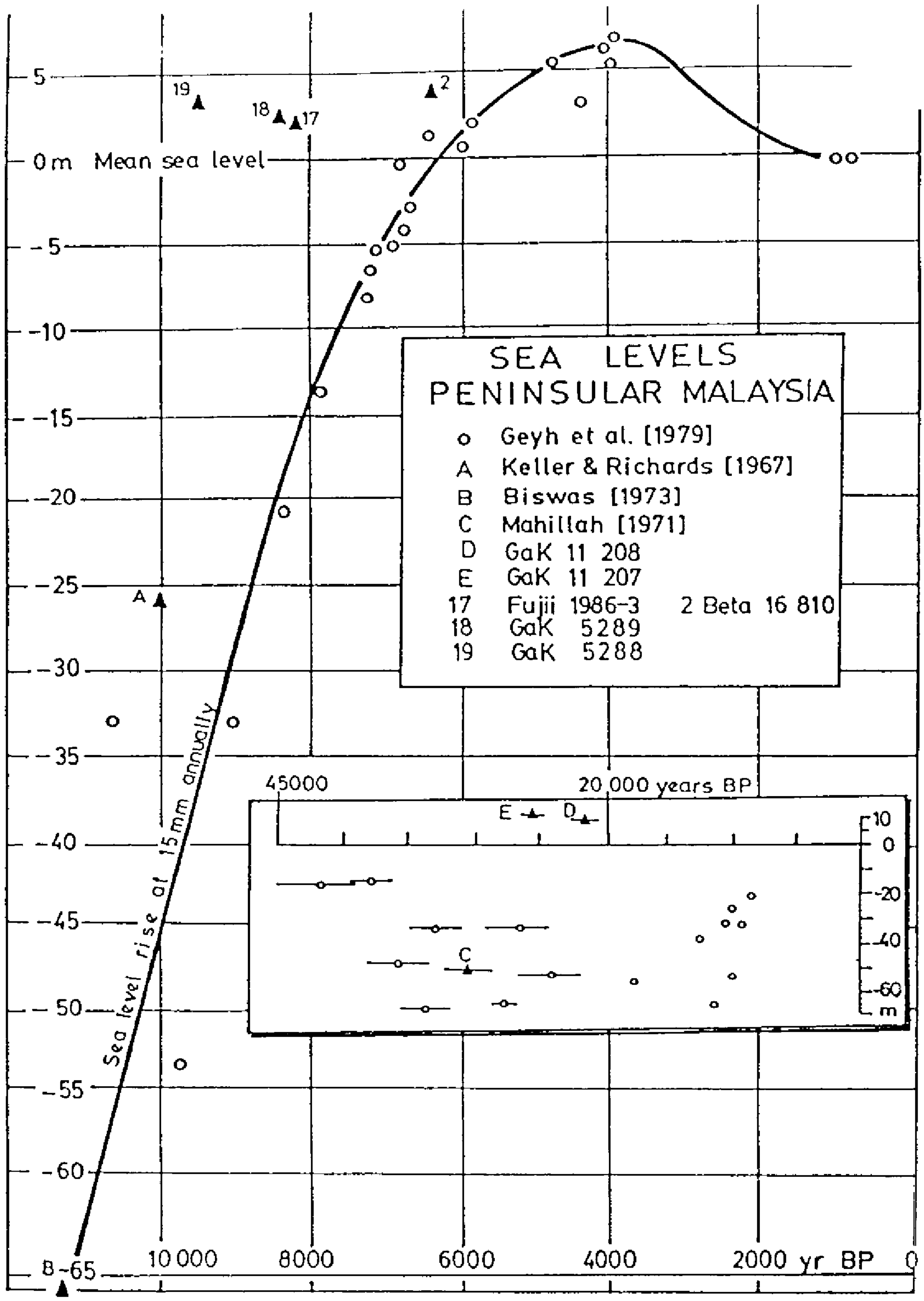
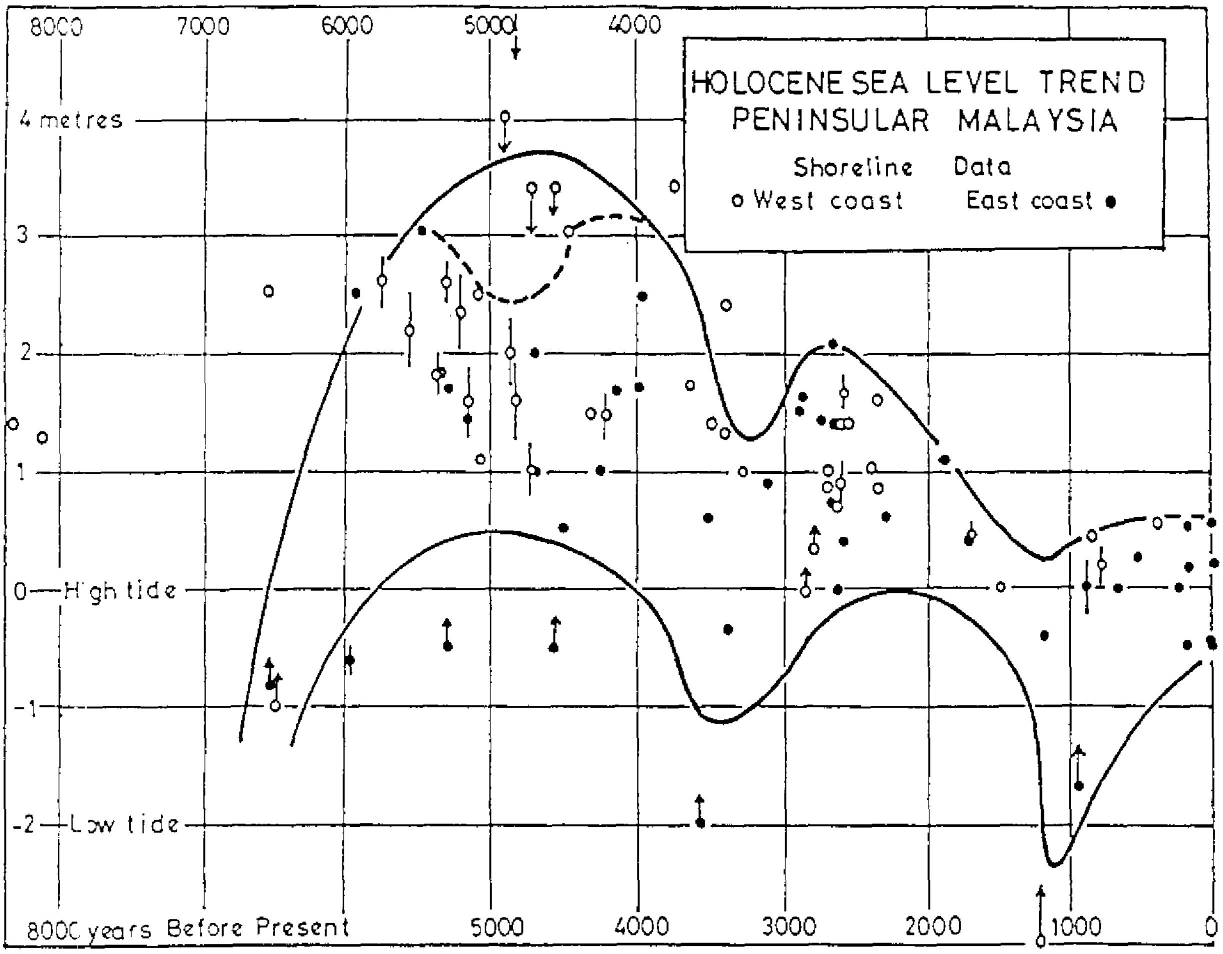


Figure 2.4. Sea level trend in the past 11,000 years in Peninsular Malaysia (From H.D. Tjia, in press)

Figure 2.5. Sea level trend in Peninsular Malaysia since 6,500 BP (from H.D. Tjia & S. Fujii, in press)



Figures 2.4 and 2.5 show the sea level changes in Peninsular Malaysia during the Late Quaternary. Figure 2.5 suggests that current sea level is at the peak of one of the fluctuations and that it will recede in the near future. Upon this regressive tendency will be superimposed the rise of sea level by global warming. For Southeast Asia the net rise of sea level may be 13 to 15cm by 2025 AD. However, the effect of a possible geoid change has not yet been taken into account.

The interpreted sea-level fluctuations for Peninsular Malaysia are probably representative for Thailand and other areas of Sundaland. Similar Holocene sea level curves have been published for those regions (Sinsakul et al., 1985; Tjia et al., 1983 / 1984).

Predictions of relative sea level change for the coasts in geologically mobile regions would be very speculative at this stage. General interpretations about subsiding, rising, and stable shorelines in that region can be carried out using available geomorphological, geological and seismic indications. In order to arrive at semi-quantitative predictions, more details about former shorelines are needed. The vastness of the mobile region places practical constraints and detailed investigations could probably be carried out only for areas that have been earmarked for immediate development.

The relative sea level rise as a result of global warming for the geologically stable Arafura-Sahul Platform will probably be different from that for Sundaland. This assumption is based on the geoid pattern (Figure 2.2) that suggests a current difference of 50m to 60m between the two regions.

It is probable that by partial melting of current ice masses and redistribution of the meltwater in the world's oceans, the geoid will also change. Titus (1988) suggested that by melting of ice in Greenland and Antarctica, the centre of Earth's gravity may shift to a new position and predicted that sea level would actually drop at Cape Horn and along the coast of Iceland. Titus' prediction implies that the geoid pattern would have shifted eastward. If this were to happen, for most of Southeast Asia a geoidal sea level lowering will be superimposed upon the rise predicted to result from the greenhouse effect. It is probable that the net result would be a regional lowering of sea level.

Global warming and resulting sea level rise may also be expected to alter wind patterns, ocean current systems, atmospheric pressures and precipitation. The global warming of about 1.5°C and a 20cm rise of sea level by 2025 AD would raise the sea surface to cover low parts of the coastal plains. This will change their microclimates. Among other things, precipitation will probably increase. Elsewhere in the tropical zone, where temperatures do not change much throughout the year, changes in rainfall and shifts in precipitation patterns will probably be insignificant, except for critical areas. Eastern Nusatenggara is such an area, and more rain would ameliorate agricultural conditions. Titus (1986b) states that warmer temperatures would intensify the hydrologic cycle, increasing rainfall. However, "the most severe changes of rainfall from the greenhouse effect are still decades in the future" according to a U.S. Environmental Protection Agency draft report (1988). At present, strong winds and typhoons only occur at latitudes higher than 8°. Warmer temperatures might widen the typhoon-free equatorial zone. Changes in atmospheric circulation may also alter the length of seasons/monsoons and change ocean current patterns.

ACKNOWLEDGEMENT

James G. Titus of the U.S. Environmental Protection Agency has written extensively on sea level rise and the greenhouse effect. I deeply appreciate his positive and generous response to a request for information on the subject by sending many articles, some still in draft.

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3. IMPLICATIONS OF CLIMATE CHANGE ON OCEANOGRAPHIC CONDITIONS IN THE EAST ASIAN SEAS

J.G. de las Alas

Department of Meteorology and Oceanography
College of Science, University of the Philippines
Diliman, Quezon City 1101

INTRODUCTION

The ocean is a very important component of the earth's climate system. It provides heat to the atmosphere through the latent heat released by the water vapor it injects into the air. Because of water's relatively large heat capacity, the ocean acts to moderate temperature contrasts over the surface of the earth. Through the major currents, the ocean also helps in transferring heat from the tropics to higher latitudes.

There is general agreement that changes in climate would inevitably cause changes in some of the ocean's physical characteristics. Projections of the ocean's responses to climatic perturbations are very difficult to describe, much more to quantify, due to the availability of very limited data bases. The task of postulating the changes in oceanographic conditions of regional seas due to climatic shifts is even more challenging.

The coupling of the atmosphere and ocean is realized through the various components of the atmosphere-ocean feedback processes shown in Figure 3.1. These physical processes include the transfer of momentum and temperature between the atmosphere and ocean by large-scale motion and small-scale turbulent motion, the selective emission and absorption of radiation, and the evaporation and condensation processes that account for the transfer of latent heat between the two media.

A climatic scenario will now be considered where there will be an average 1.5°C increase in atmospheric temperature which might be realized when the carbon dioxide content of the atmosphere doubles from its late 19th century value. The increase in atmospheric temperature can now be detected from observations in some Philippine stations. The time series of mean temperatures for Manila and Aparri stations are shown in Figs. 3.2 and 3.3, respectively, to show the trend in surface air temperature for a highly urbanized station represented by Manila and for a typical rural setting represented by Aparri. Figure 3.2 shows that the long-term mean temperature in Manila increased by about 1°C over a period of approximately 100 years while the temperature of Aparri showed the same increase in about 70 years. The exact increase in temperature may not be accurately established but one thing seems definite: that there is an increase in surface air temperature.

Concurrent with this increase in atmospheric temperature is the predicted rise in sea-level by approximately 20 cm. Changes in some of the oceanographic properties of East Asian Seas (Figure 3.4) are inevitable under these influences.

EFFECTS ON SELECTED OCEANOGRAPHIC PARAMETERS

Water temperature

The oceans act as a vast energy reservoir that stores heat during summer and releases energy in winter. They provide the thermal inertia that moderates temperature differences over the earth's surface.

An increase in the temperature of the atmosphere will also warm the ocean surface due to the increase in the long-wave energy re-radiated downwards by the atmosphere and the clouds. Because of its large thermal inertia, the surface layer of the ocean will require around 10 years to complete its response to an imposed thermal perturbation in the atmosphere. The ocean's bottom layer will take a few hundred years to adjust to a new thermal equilibrium level when subjected to the same perturbation.

While there are no available data to verify the long-term changes in sea surface temperature in the East Asian Seas region, it may help to present here the sea surface temperature time series for the Central Pacific (Figure 3.5) and the Eastern Pacific (Figure 3.6) areas. These figures indicate an increasing trend in the sea surface temperature for both areas.

Surface temperatures in the East Asian Seas range from about 20° to 28°C in winter and from about 27° to 29°C in summer. The anticipated changes in sea surface temperature in the region may be considered similar to that expected for the Central and Eastern Pacific regions which is in the order of 1°C.

Salinity

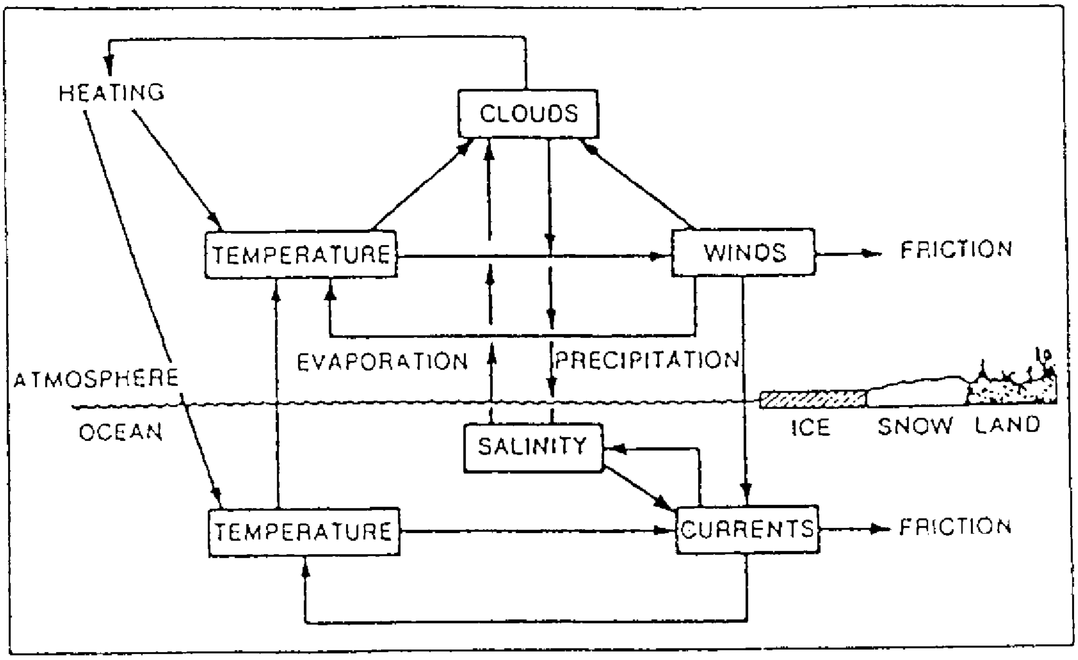
Salinity is one of the major factors that determines ocean water density. Differences in density create currents that help drive the general circulation of the oceans.

Changes in salinity can be brought about by changes in the hydrologic cycle, particularly, evaporation and precipitation. Upward adjustment of air temperature and hence sea surface temperature would tend to increase the evaporation rate at the ocean surface since it will also tend to increase the water holding capacity of the air. This enhanced evaporation would tend to increase the salinity of the ocean's surface layer. On the other hand, increasing the amount of water vapor in the atmosphere would tend to increase the amount of precipitation and fresh water runoff which would in turn decrease the surface salinity of the oceans, particularly in the nearshore areas. A global temperature increase would also mean the melting of high latitude ice which would tend to lower the salinity of the oceans.

Currently available estimates of the change in global precipitation patterns are provided by mathematical models used to simulate global climate. Tentative results showed increases in the mean precipitation and evaporation rates. The geographical distribution of changes in precipitation rates was not consistent between the various existing models.

In view of this, it may not be possible at this point to determine, even qualitatively, the change in salinity of the surface waters in the East Asian Seas that may result from warming of the atmosphere.

Figure 3.1 Major components of atmosphere-ocean feedback processes (Source : Gates 1979).



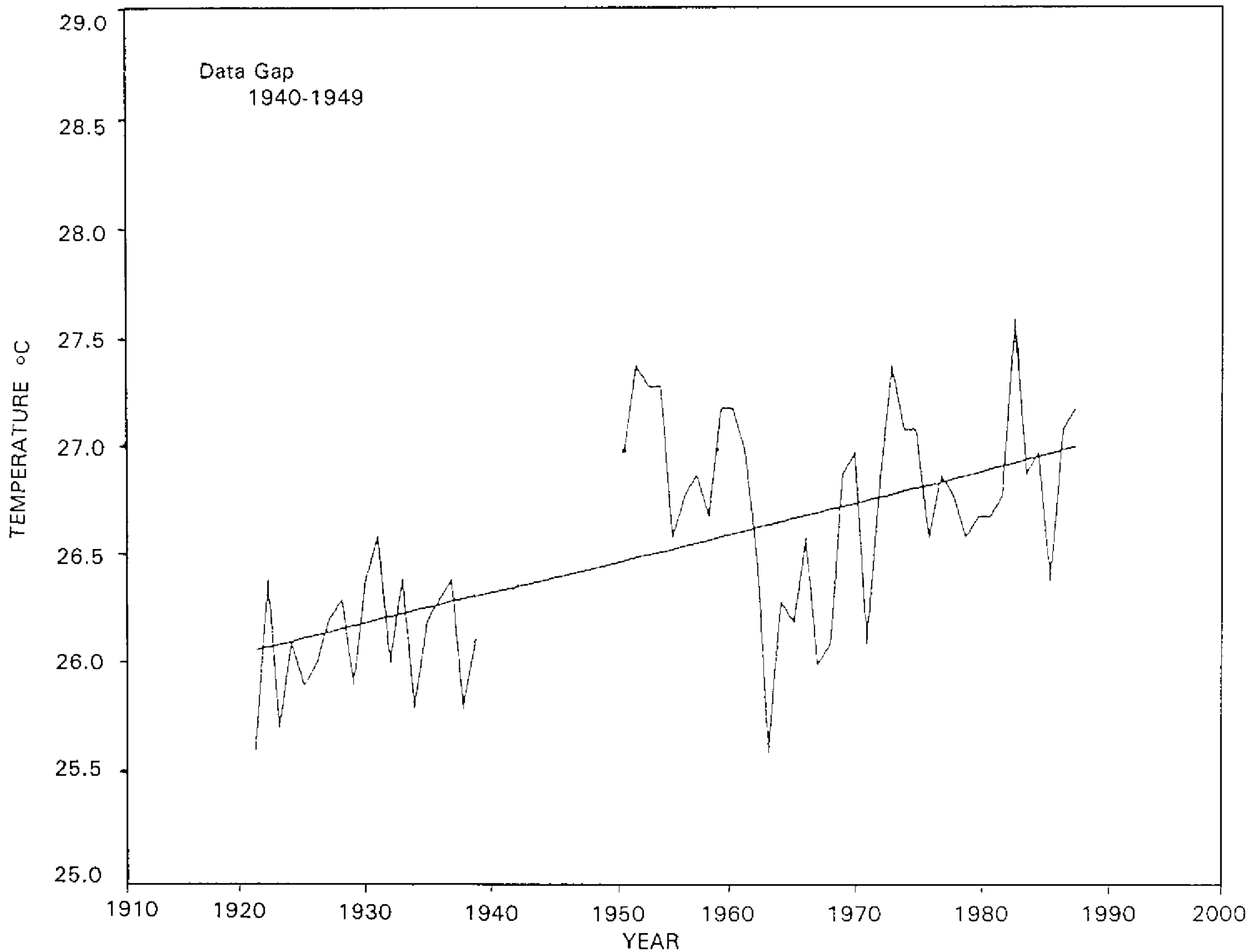
Vertical stability

Due to global warming of the atmosphere and the attendant increase in the temperature of the ocean's surface layer, there will be a tendency to increase the vertical stability of the already stable surface waters in the tropics. Vertical stability tends to reduce vertical mixing which has profound effects on the biological productivity of the region.

Horizontal currents

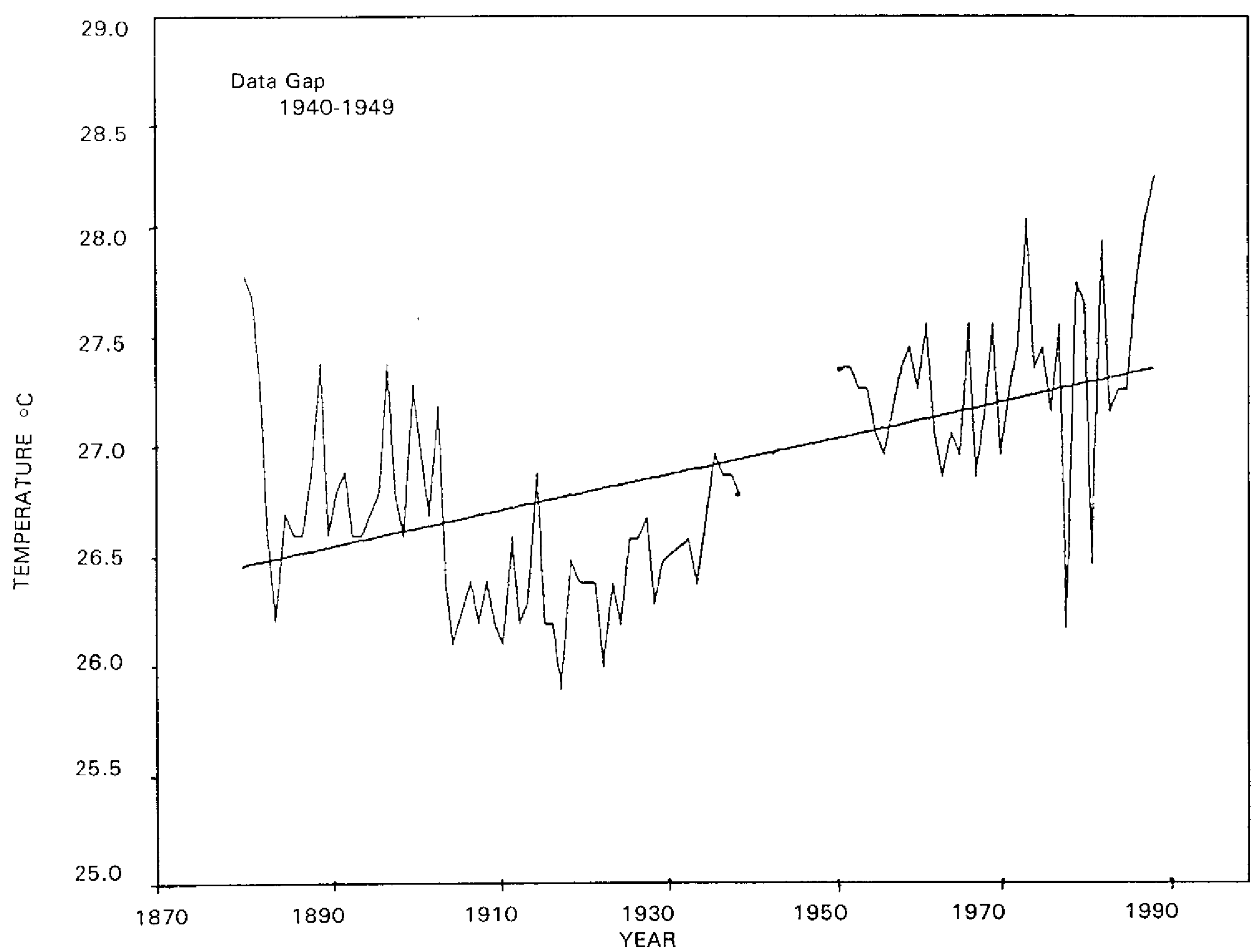
Horizontal surface currents result from the combined action of surface wind stress, the horizontal distribution of pressure resulting from lateral temperature and salinity distribution, and the geometry of individual basins. The change in freshwater discharges from continental runoff can generate density currents that will alter nearshore current systems. Although the current system may be modified by local changes in temperature and salinity distribution, the major potential changes would result from changes in the surface wind patterns. Additionally, there may be changes or shifts in areas of sea surface convergence and divergence which may result in the shifting of downwelling and upwelling areas.

Quantification of the climatic impacts on current systems in the East Asian Seas region is only possible after determination of the implications of global warming for the wind and temperature patterns in the East Asian Seas region.



Source : Philippine Atmospheric Geophysical and Astronomical Services Administration

Figure 3.2 Time series of mean temperature - Manila



Source : Philippine Atmospheric Geophysical and Astronomical Services Administration

Figure 3.3 Time series of mean temperature - Aparri

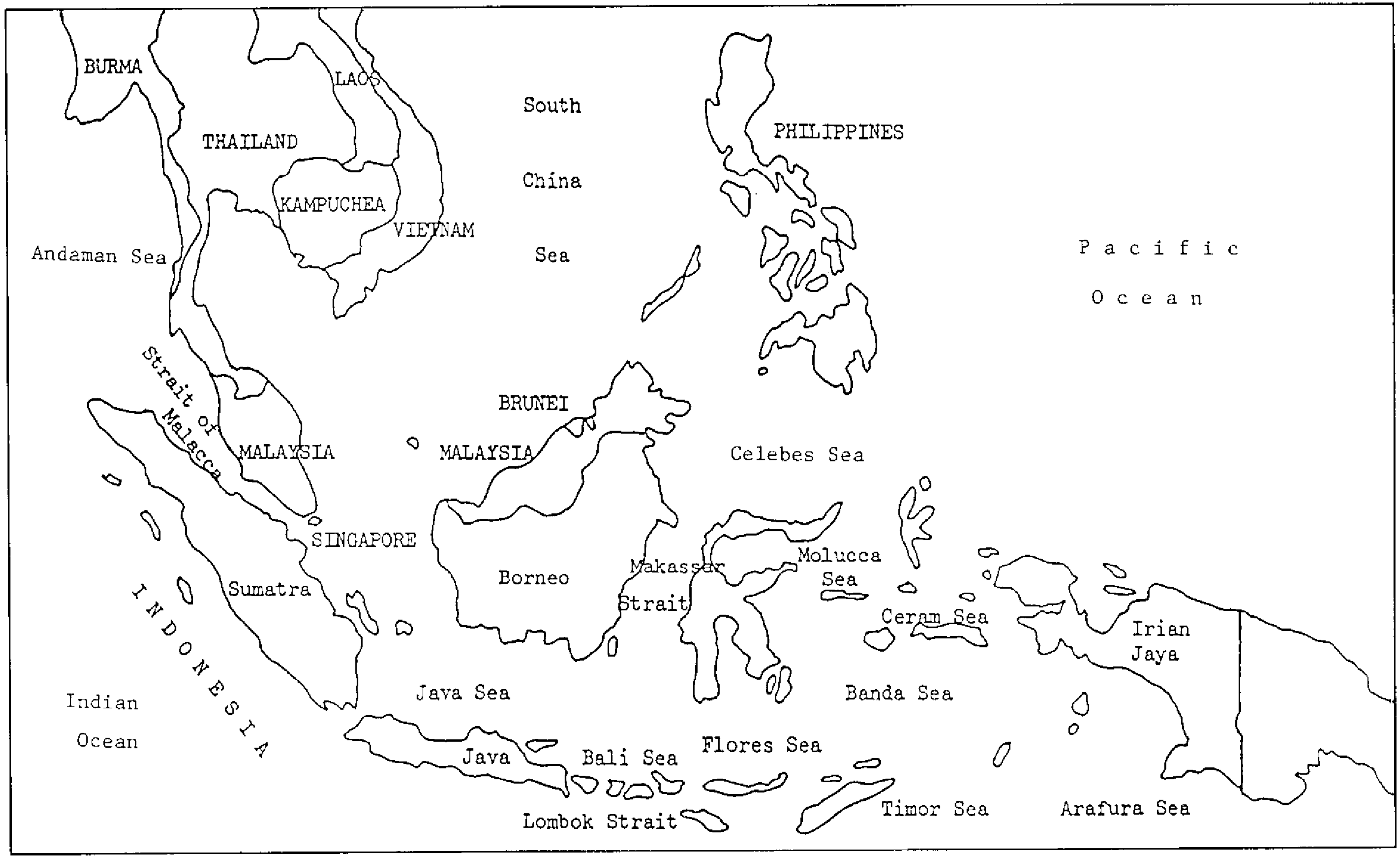
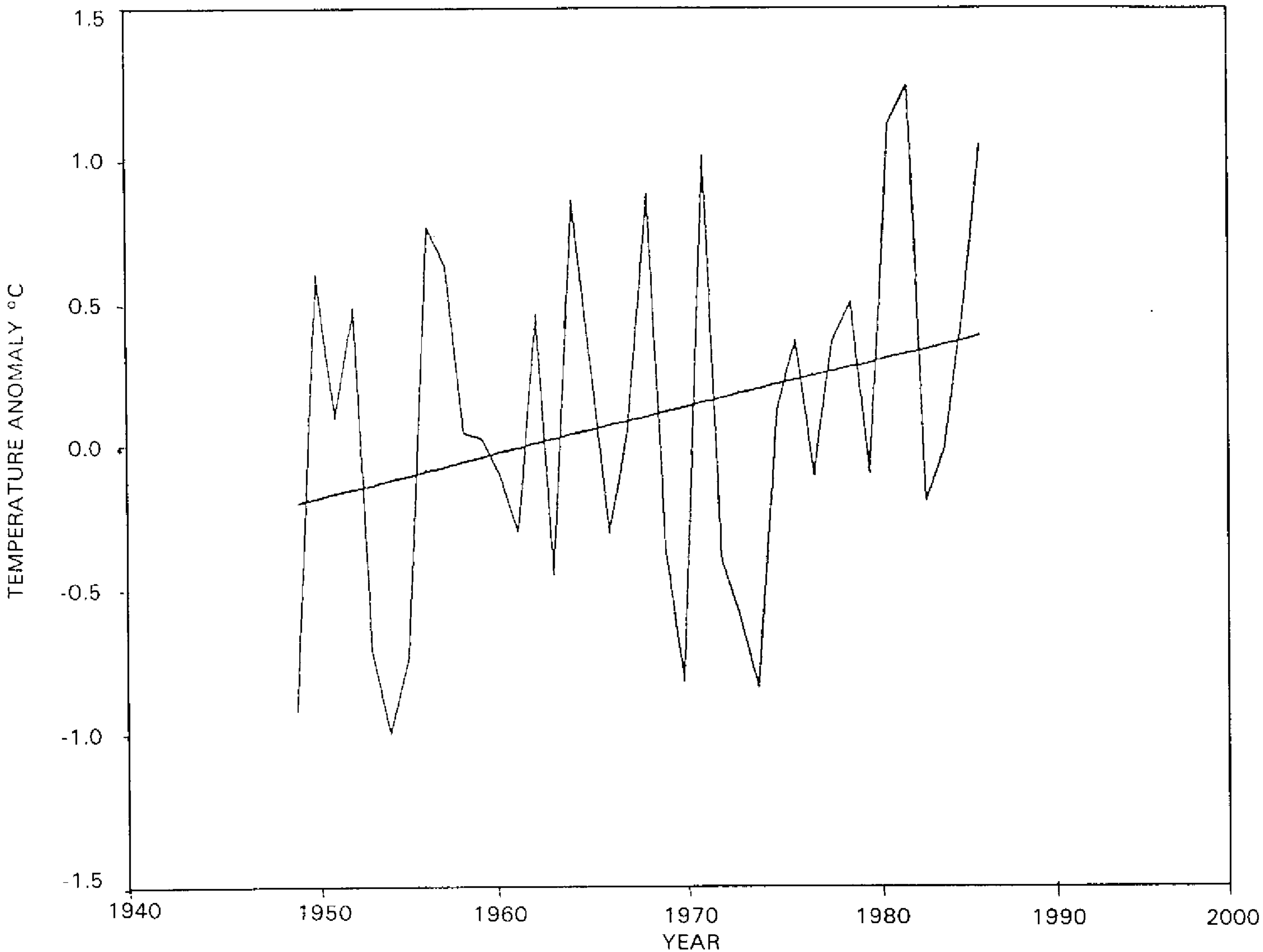
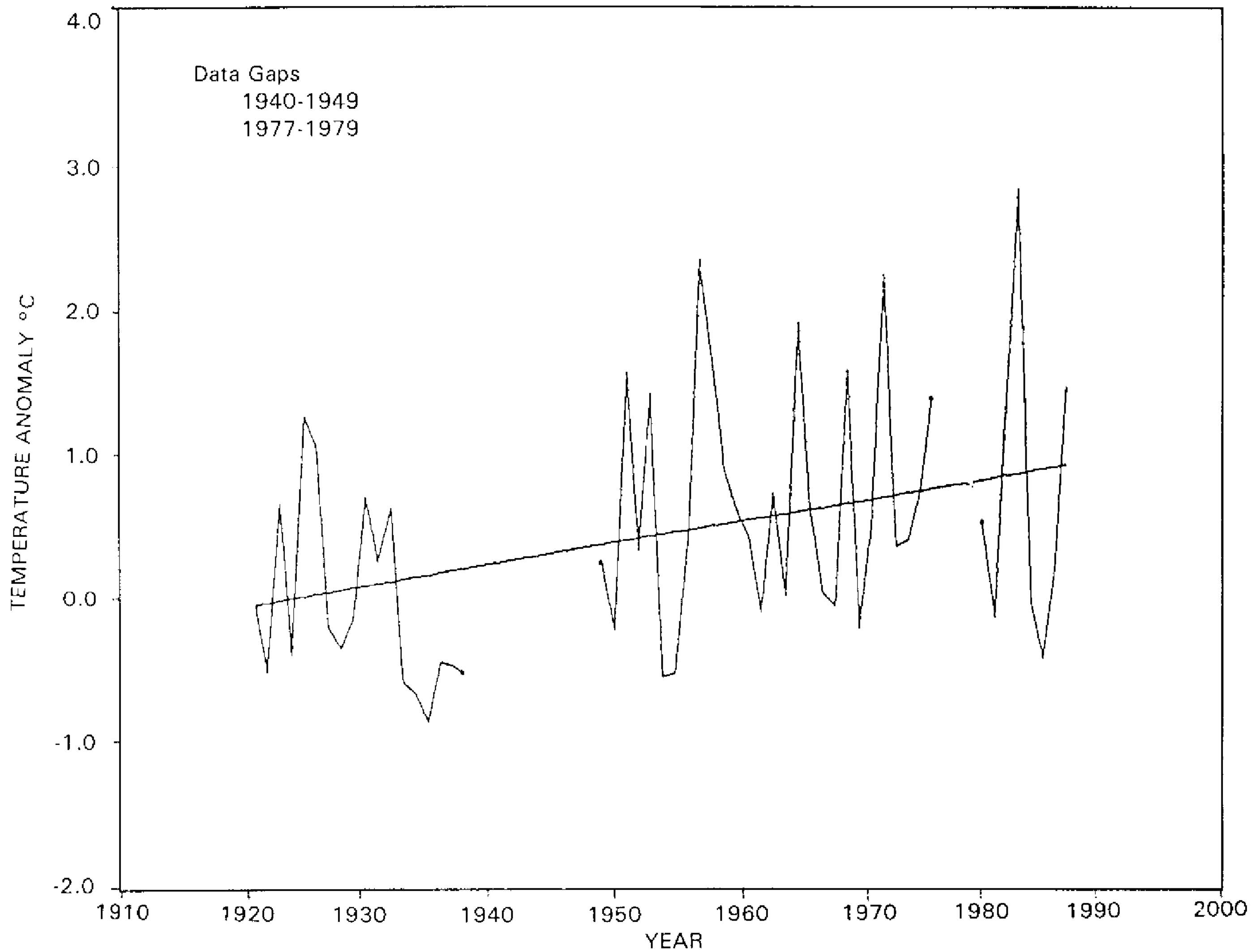


Figure 3.4 The East Asian Seas region



Source : Climatic Diagnostic Bulletin, NOAA

Figure 3.5 Central Pacific sea surface temperature time series



Source : Rasmusson & Carpenter, 1983
Climatic Diagnostic Bulletin, NOAA

Figure 3.6 Eastern Pacific sea surface temperature time series

CONCLUSIONS

The anticipated global warming due to increased carbon dioxide content of the atmosphere will definitely affect the oceanographic characteristics of the East Asian Seas. Limited observational data prevented the detection of any long-term changes in oceanographic parameters in the area. Oceanic response to global warming is indicated by mathematical models of the general circulation patterns but extension of their results to regional areas must be regarded with caution. More regional research is required in order to determine qualitatively the degree of changes that global warming will bring about in the East Asian Seas region.

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4. CLIMATE CHANGE IN THE EAST ASIAN SEAS REGION

A.L. Chong & A.K. Chan

Malaysian Meteorological Service
Jln. Sultan, Petaling Jaya
46667 Selangor, Malaysia

INTRODUCTION

Climate affects humans and their activities in a countless number of ways. Humans take advantage of favourable climate, but are also vulnerable to changes and variations of climate and to the occurrence of extreme climatic conditions such as droughts and floods. Even variations and modest changes relative to the normal climate have a significant influence upon human activities.

Global climate has varied in the past and will continue to vary in the future on account of natural causes. However, since the last century, human activities have significantly influenced the climate locally, regionally and even globally. The generation of heat, release of pollutants, carbon dioxide (CO_2) and other greenhouse gases into the atmosphere have contributed towards the warming of the earth. Scientists predict that the accelerating increase in concentrations of CO_2 and other greenhouse gases in the atmosphere, if left unchecked, will result in a probable warming of the earth's surface by 1.5°C to 4.5°C before the middle of the next century, and a sea level rise of 20cm to 140cm.

In order to determine the changes in weather patterns in the East Asian Seas region, this paper examines the temperature and rainfall records of the Malaysian coastal regions and the climate scenarios generated by a general climate model of the Goddard Institute of Space Science (GISS) of U.S.A. It also discusses some of the plausible effects of these changes.

APPROACH

The global climate system processes are so large and complex that it is impossible to reproduce them physically under laboratory conditions. However, with the advent of high speed super computers, mathematical equations that describe the physical principles governing the system can be formulated and run in the computer. Based on these equations the computer can then simulate how the climate will evolve and predict what it will be like in the future. Unfortunately present-day mathematical climate models have limitations and they cannot describe the full complexities of reality. They only reveal logical consequences of plausible assumptions about the climate.

Another way of projecting the future climate is to examine time series of weather records and detect trends in these series.

The following sections examine the time series of temperature records in Malaysia and report the work on trends in Malaysian rainfall data by Todorov & David (1982). A relatively longer record of rainfall at Singapore is also studied. The results generated by the GISS general climate model are also described.

CLIMATE TRENDS IN MALAYSIA AND SINGAPORE

Temperature in Malaysia

The temperature records of 11 principal meteorological stations which are near the coast are analysed. The stations are grouped into 4 regions: west Peninsula, east Peninsula, Sarawak and Sabah. The average values of each region are calculated for the following parameters: annual mean maximum, annual mean minimum and annual 24-hour mean temperature. Details on the names, locations and periods of data used at the stations are given in Table 4.1.

Table 4.1 Stations and periods of weather records used in the analysis.

(A) Temperature (Annual Mean, Maximum and Minimum)

Region	Station	Period of Records	
West Peninsula	Penang	1930-40, 1948-87	(51 years)
	Sitiawan	1930-40, 1948-87	(51 years)
	Malacca	1930-40, 1948-87	(51 years)
East Peninsula	Kota Bharu	1930-40, 1948-87	(51 years)
	Kuala Trengganu	1930-40, 1948-87	(51 years)
	Mersing	1930-40, 1948-87	(51 years)
Sarawak	Kuching	1953-87	(35 years)
	Bintulu	1953-87	(35 years)
	Miri	1953-87	(35 years)
Sabah	Kota Kinabalu	1954-87	(34 years)
	Sandakan	1954-87	(34 years)

(B) Rainfall (Annual Total)

Station	Period of Record	
Singapore	1975-1986	(112 years)

Figs. 4.1 - 4.12 show the time series of the chosen temperature parameters as 5-year running means for each parameter and the fitted regression lines. The slopes of the regression lines provide estimates of the rates of change of the temperature parameters, while t-tests of the difference in slope from zero provide an objective assessment of whether the temperatures possess any trend.

Except for the annual minimum temperature at the west Peninsular region, all the temperature series indicated increasing trends which are statistically significant. However, the values of the trends vary spatially and temporally. Generally, at each region the annual mean maximum temperatures (occurring in the afternoons) have the largest trends following by the annual 24-hour mean temperatures. The annual mean minimum temperatures (occurring in the predawns) have the smallest trends. The average rates of increase of the mean maximum; 24-hour mean; and minimum temperatures are about 2.1°C, 1.7°C and 0.8°C per 100 years respectively.

It is necessary to point out that urban development also warms the climate within urban areas because of the "heat island" effect. Unfortunately, the effect of urban development on the temperatures of the locations used in this analysis has not been quantified. Hence it is not possible to ascertain whether the increasing trends observed in this analysis are caused by urban "heat island" effects or by the greenhouse effect or both.

Figure 4.1 West Peninsular Malaysia mean temperature - Five years running mean and regression line.

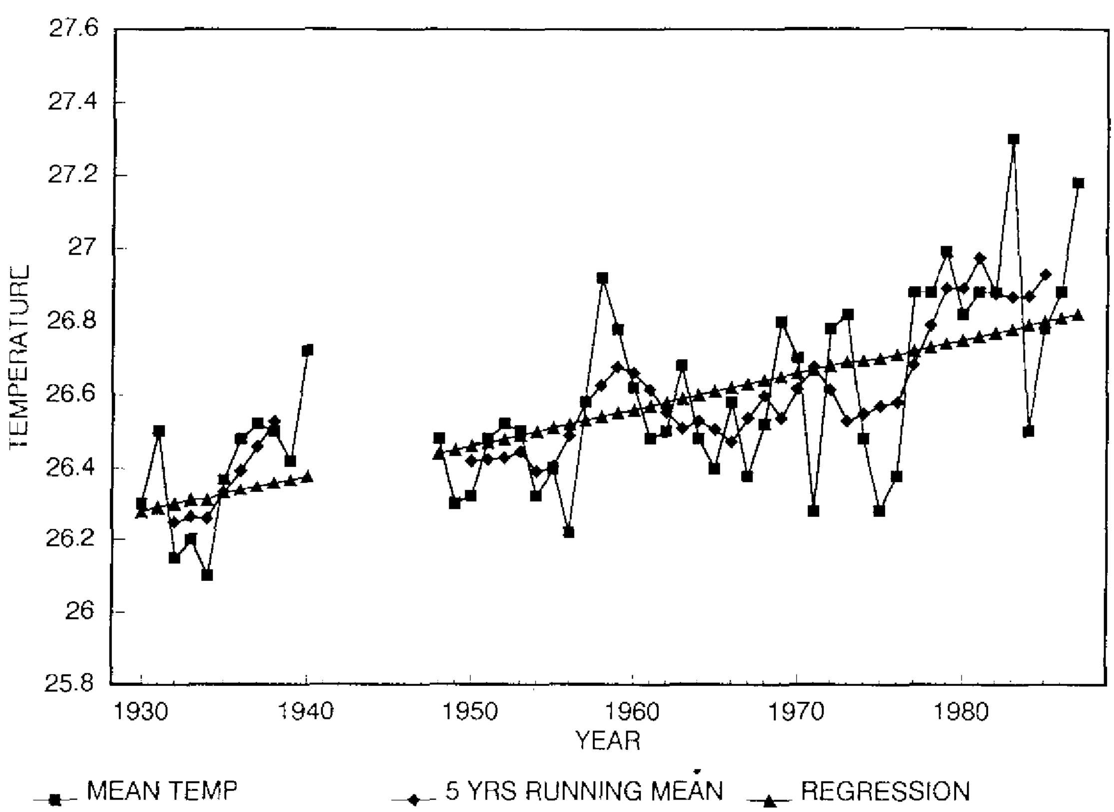


Figure 4.2 West Peninsular Malaysia minimum temperature - Five years running mean and regression line.

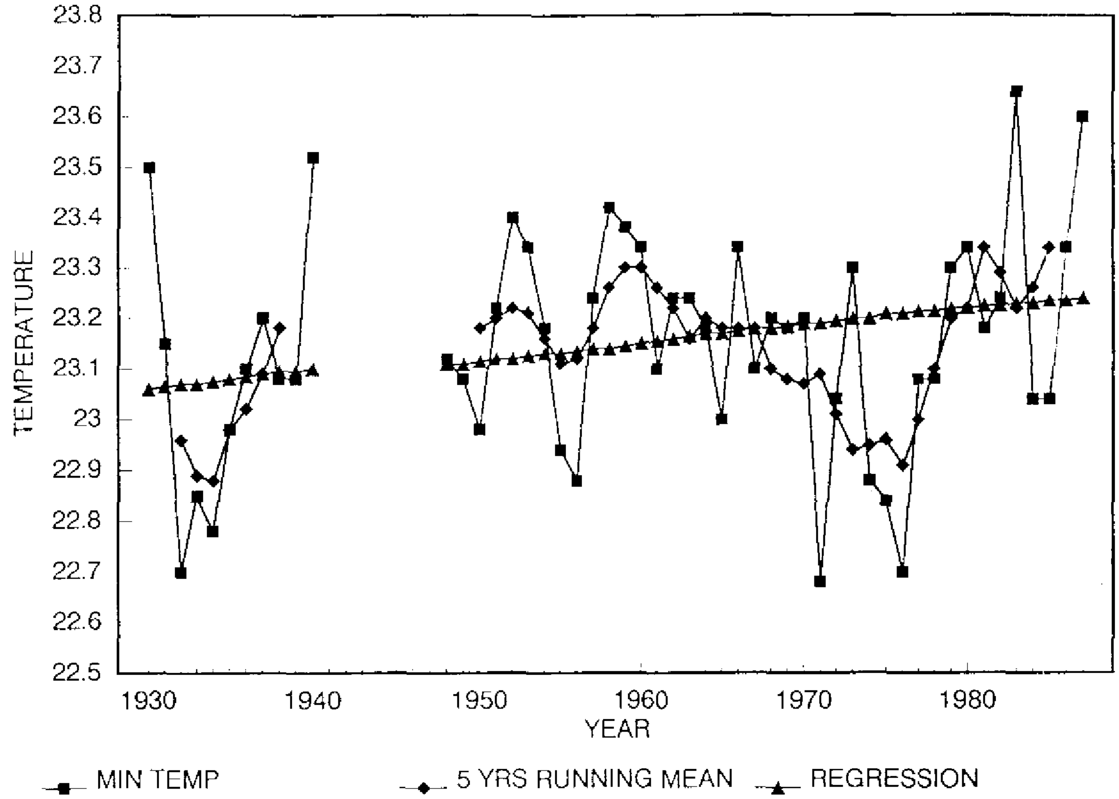


Figure 4.3 West Peninsular Malaysia maximum temperature - Five years running mean and regression line.

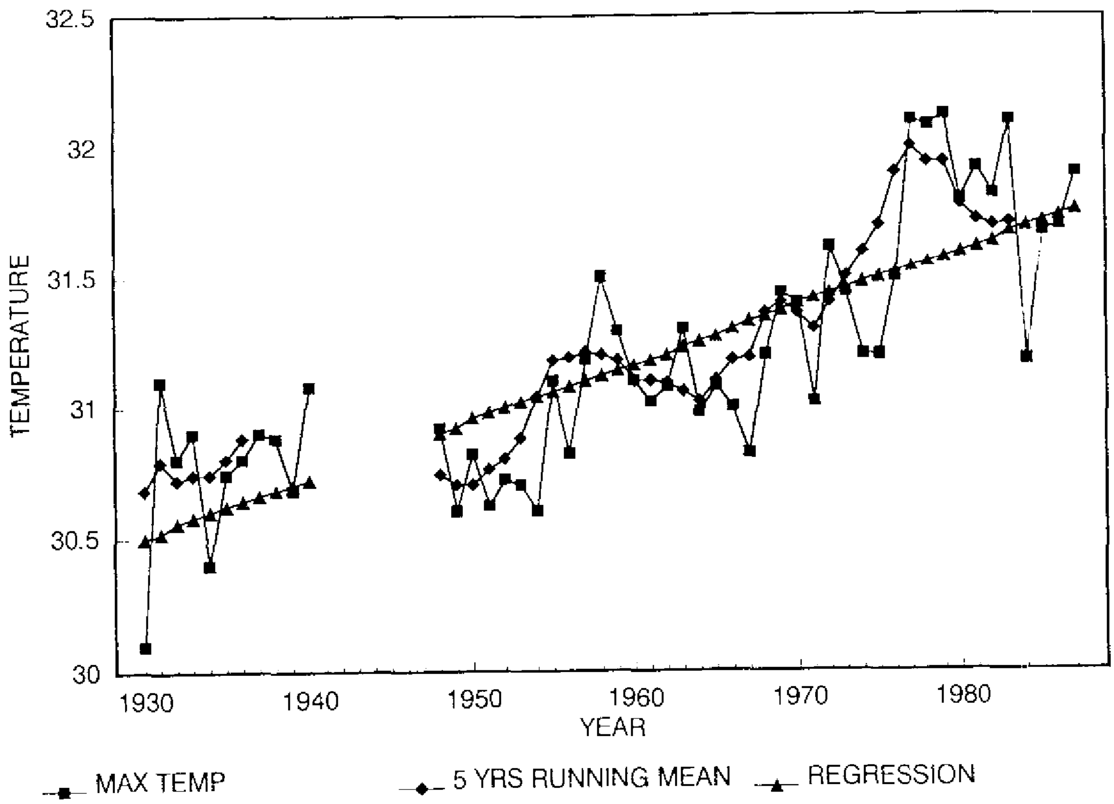


Figure 4.4 East Peninsular Malaysia mean temperature - Five years running mean and regression line.

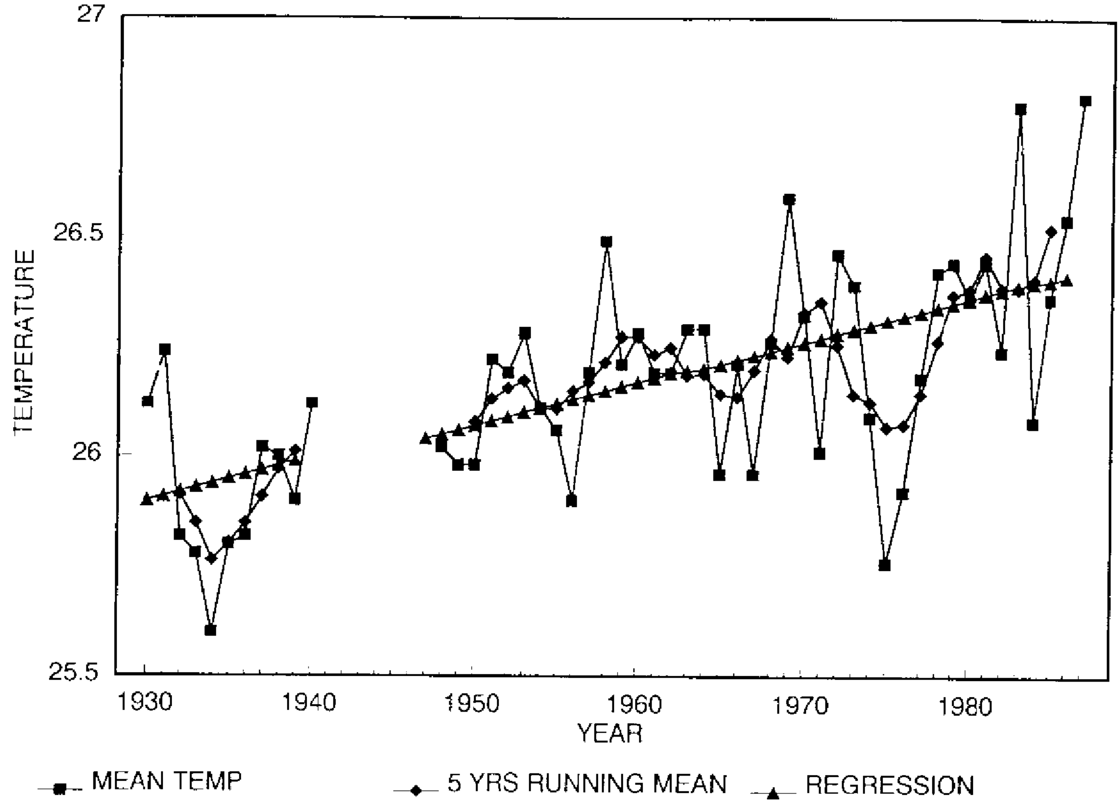


Figure 4.5 East Peninsular Malaysia minimum temperature - Five years running mean and regression line.

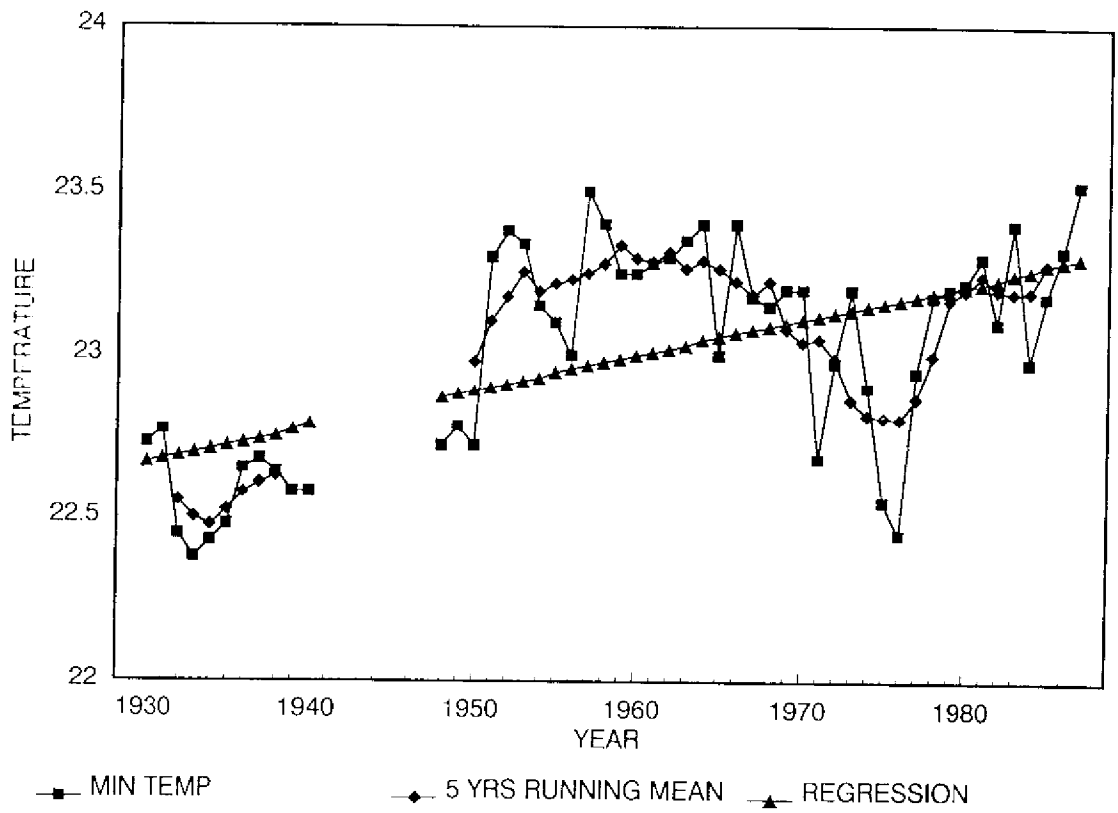


Figure 4.6 East Peninsular Malaysia maximum temperature - Five years running mean and regression line.

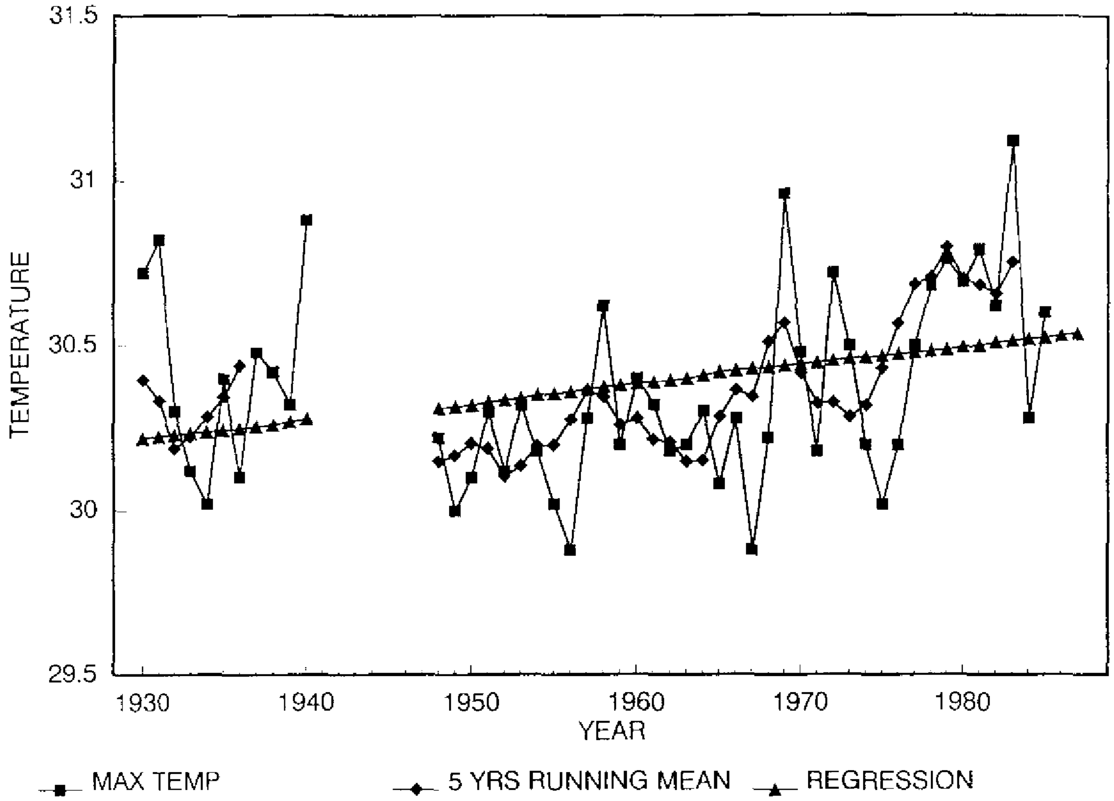


Figure 4.7 Sarawak mean temperature - Five years running mean and regression line.

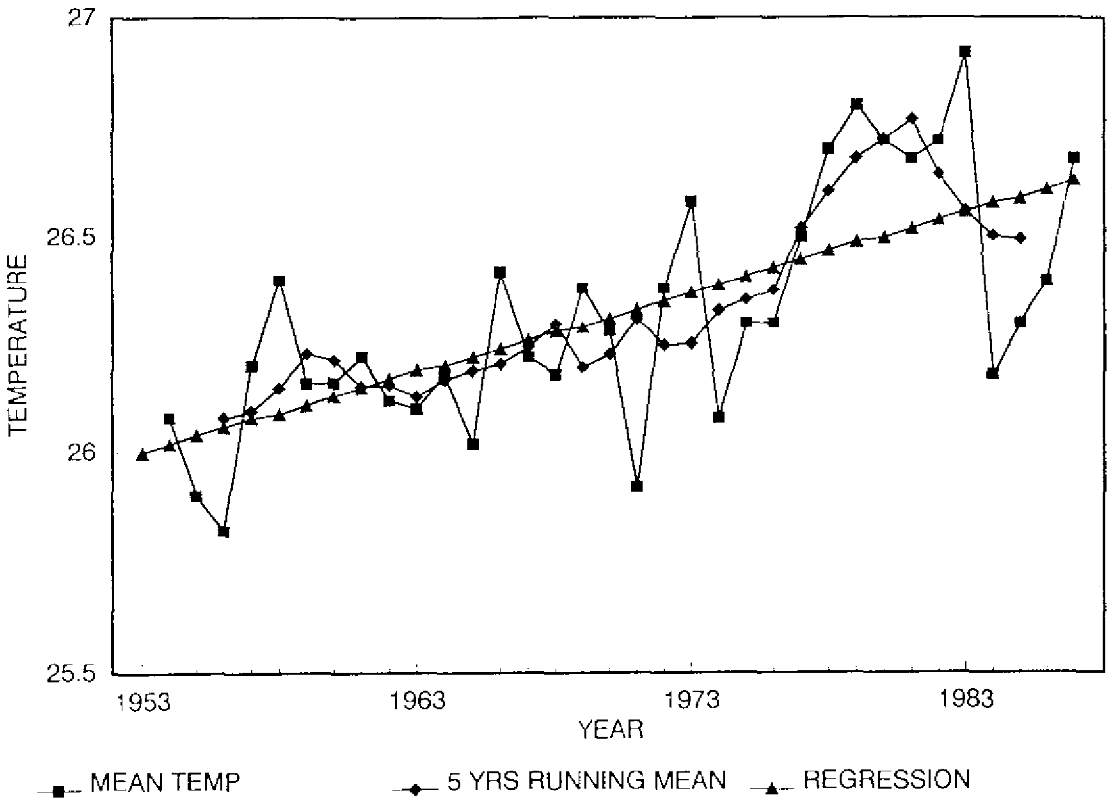


Figure 4.8 Sarawak minimum temperature - Five years running mean and regression line.

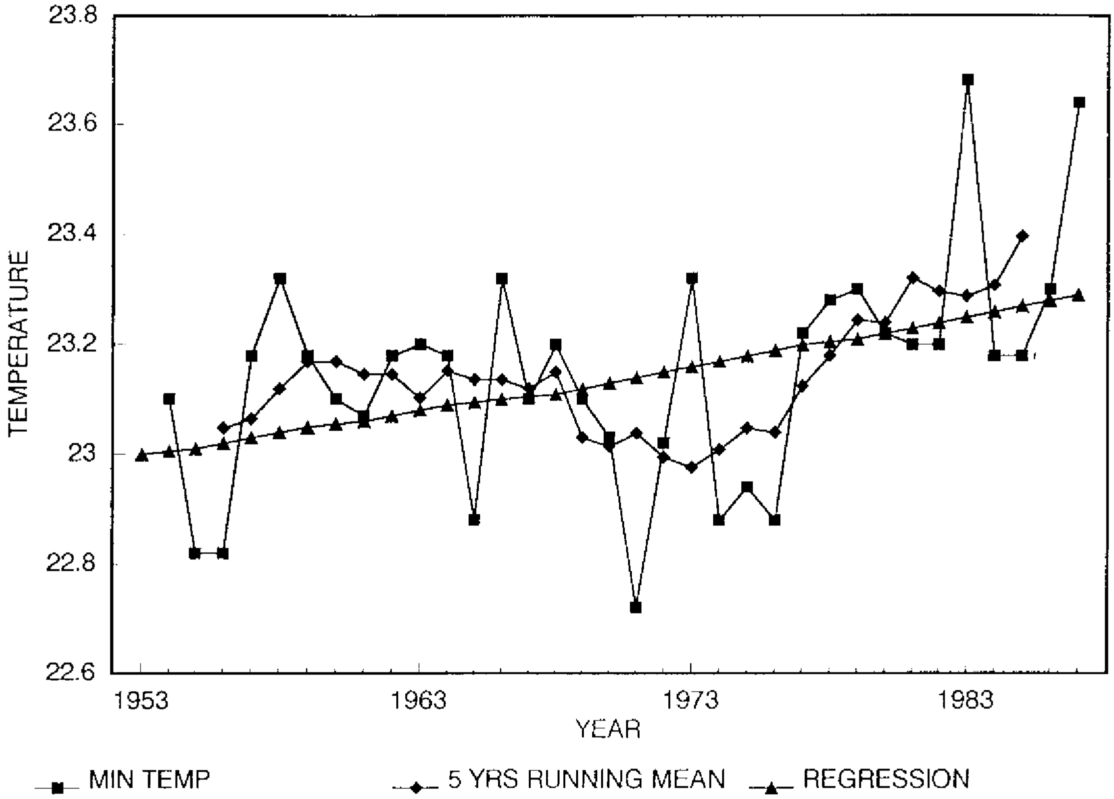


Figure 4.9 Sarawak maximum temperature - Five years running mean and regression line.

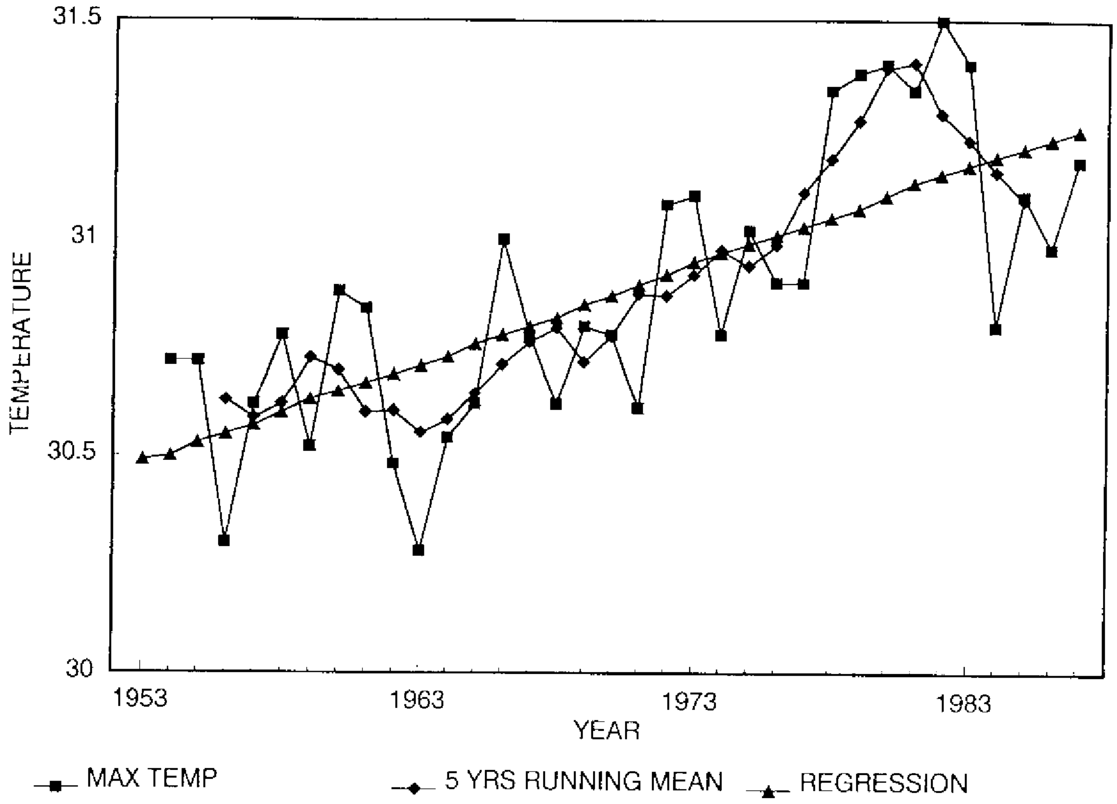


Figure 4.10 Sabah mean temperature - Five years running mean and regression line.

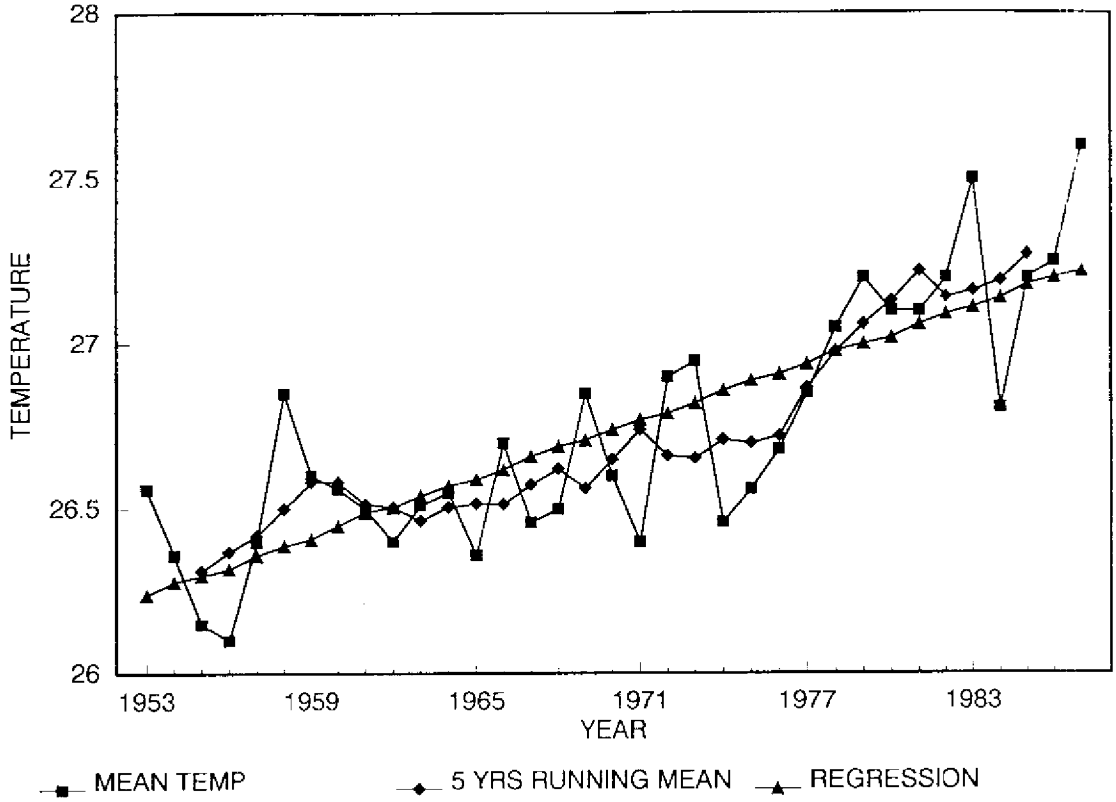


Figure 4.11 Sabah minimum temperature - Five years running mean and regression line.

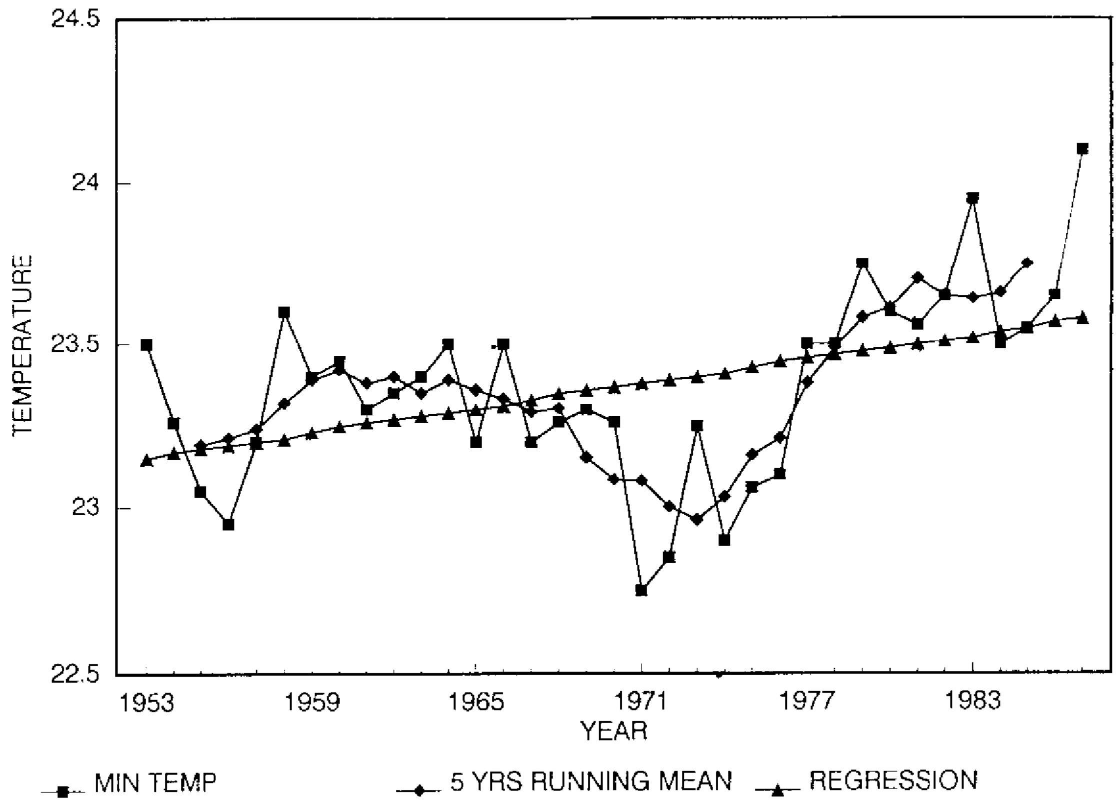
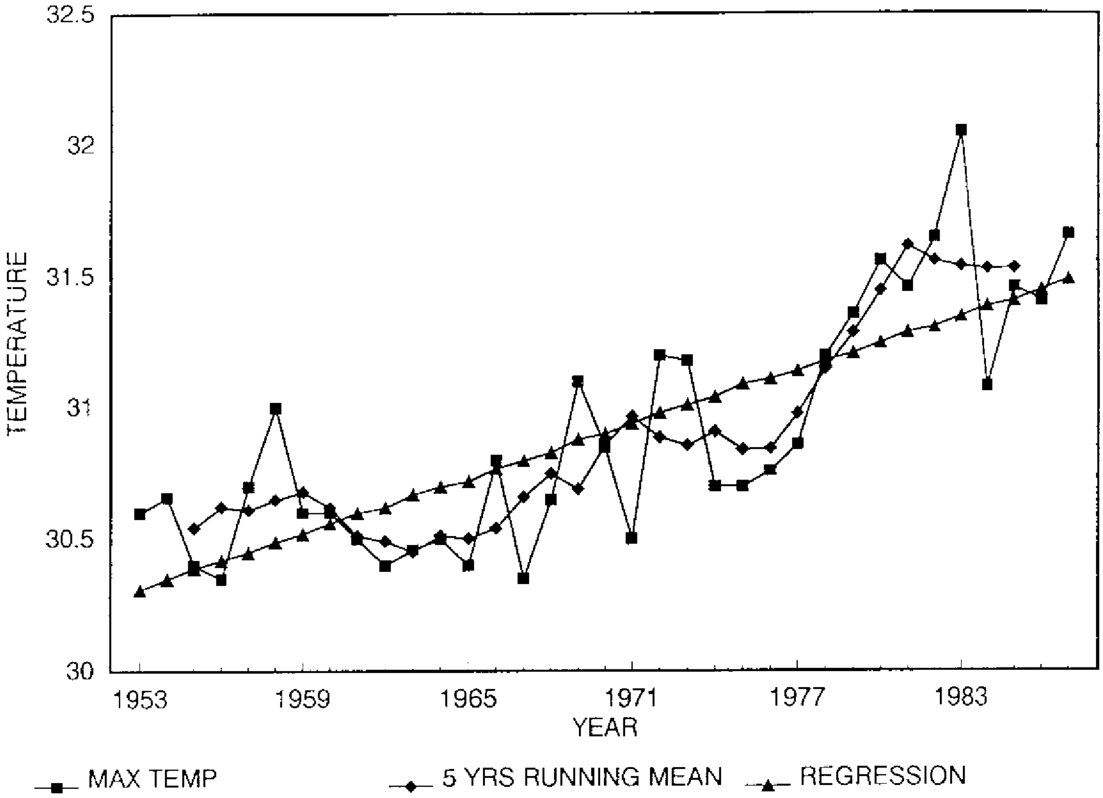


Figure 4.12 Sabah maximum temperature - Five years running mean and regression line.



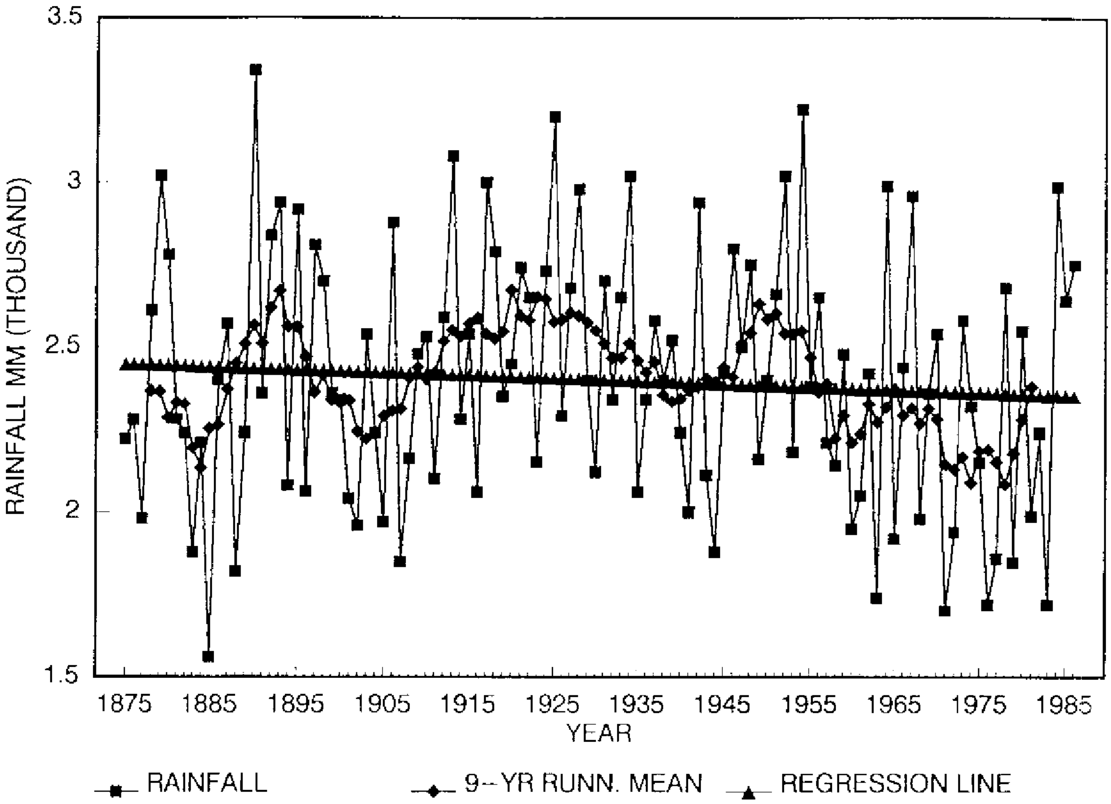
Rainfall

Todorov & David (1982) analysed rainfall records for 13 stations in Malaysia to detect temperal trends. The lengths of the records analysed by them varied from 48 to 95 years. Based on visual examination of the time series of rainfall data and some derived parameters, they could not find any consistent trends in the data for most of the stations. Though they observed downward trends in the last 5 to 10 years in the data from 3 stations, they also saw similar downward trends in the earlier parts of the same data sets. Hence they concluded that short period trends in the time series were part and parcel of climate variability in Malaysia.

A slightly longer rainfall record from Singapore (112 years) is also examined here for time trends. The data are plotted together with the 9-years running means in Fig. 4.13 and do not appear to show any definite upward or downward trend. Though the regression line fitted to the rainfall data has a small negative slope, this is not significant. This confirms the observations of Todorov & David (1982) that there is no evidence of increasing or decreasing trends in the rainfall record.

Therefore, the rainfall recorded in Malaysia and Singapore does not indicate any consistent or significant trends.

Figure 4.13 Singapore annual rainfall - regression line and nine years running mean.



GISS Model Results

This section describes and analyses the data generated by the GISS climate model. (The model is described in detail in Monthly Weather Review, April 1983, p. 609). Two main data sets are compared. One is from a control run where the model simulates the present climate ($1xCO_2$). The other is from a run where the model atmosphere is brought to a steady state for an atmosphere with double the present amount of CO_2 ($2xCO_2$).

Like other general circulation models, GISS model is limited in the amount of spatial detail it can resolve. No computer is fast enough to calculate climate variables everywhere on the earth's surface and in the atmosphere in a reasonable length of time. Instead the calculations are executed at widely spaced points that form a 3-dimensional grid at and above the surface. The horizontal spacing between grid points in the GISS model is 7.83° of latitude and 10° of longitude.

For this study, the positions of the grid points at which data are extracted for any analysis are those in the East Asian Seas region and are shown in Fig. 4.14. Data used in the analysis are long period (25 year) mean values of selected weather variables.

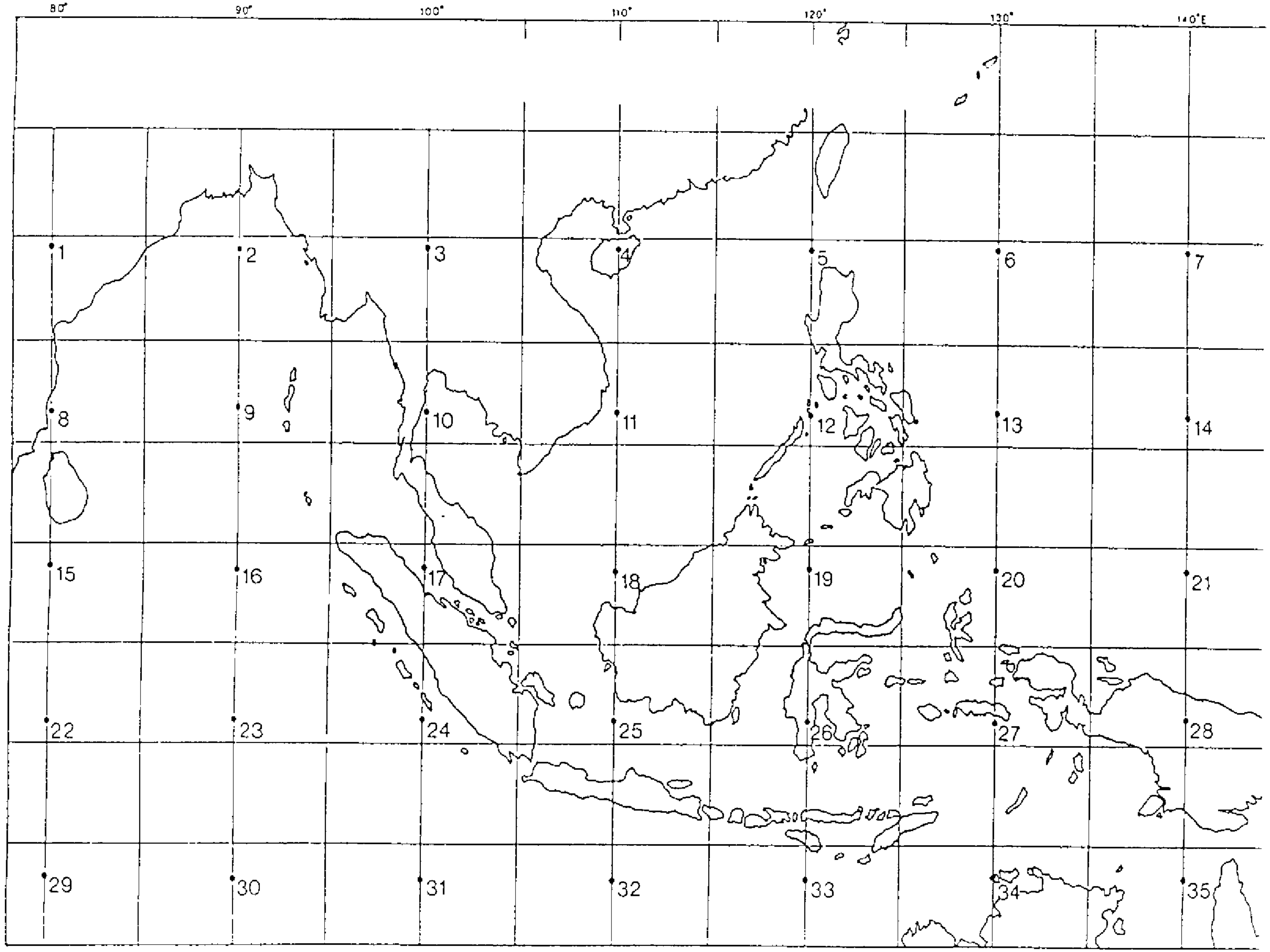


Figure 4.14 Positions of the selected grid points for analysis of greenhouse warming

GISS Temperature

Table 4.2 shows the difference between the surface mean annual temperatures generated by the GISS model at the selected grid points for the two climate scenarios ($1xCO_2$ and at $2xCO_2$ atmospheres). As it can be clearly seen, there is a consistent and quite uniform increase of between 3-4°C over the whole region.

GISS Rainfall

As the world weather changes, so will one of its most vital aspects rainfall, which is the single most important factor affecting human activities. Most models indicate that the hydrological cycle of evaporation and precipitation runs faster overall under increased CO_2. However, the increased precipitation would not necessarily be uniformly distributed over the hemispheres and the geographical regions.

The change in precipitation pattern over the East Asian Seas region is studied by analysing the percentage change in the annual rainfall amounts as generated by the GISS model for the two different scenarios. These percentages are plotted in Figure 4.15 which indicates that the changes are not uniform in the region. Some other observations from the figure are as follows:

The Philippines and its coastal areas appear to have slightly less annual rainfall under increased CO_2.

Thailand seems to have very little change in rainfall. However, for the atmosphere with more CO_2, the rainfall in its coastal areas increases slightly (by about 5%) whereas the inland areas of central and north Thailand have about 5% less annual rainfall.

After the greenhouse warming, Malaysia and Singapore have more annual rainfall. The percentage increases are from 10% to 15% in Peninsular Malaysia and Singapore, and, 5% to 10% in East Malaysia.

Indonesia has the largest increase in annual rainfall as the weather changes. The increase is about 15% in the islands at the extreme west and east of the country, and rises rapidly to almost 50% in the south central islands.

By interpolating the percentage changes in monthly rainfall at the grid points, the values of the changes at selected towns in the ASEAN region are calculated. Using these values and the rainfall records at these selected locations, the monthly rainfall histograms of each place are plotted for the two climate scenarios in Fig. 4.16 and 4.17. Observing carefully these histograms, one can see that though there are changes in rainfall amounts, there is no significant shift in rainfall pattern in each place. In other words, the "peaks and troughs" occur essentially during the same time of the year at each location for the two scenarios.

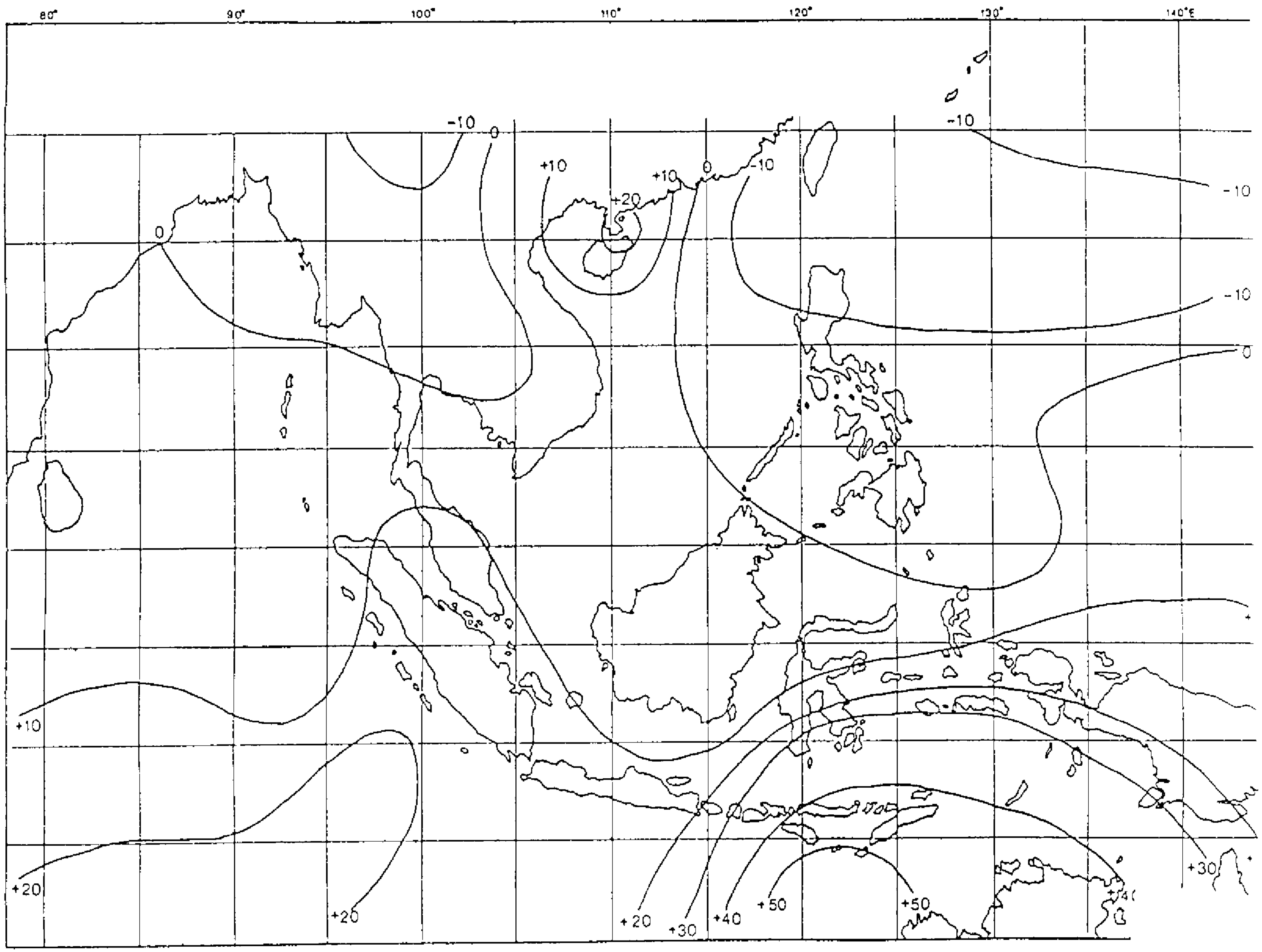


Figure 4.15 Percentage changes in annual rainfall over the East Asian Seas region after greenhouse warming.

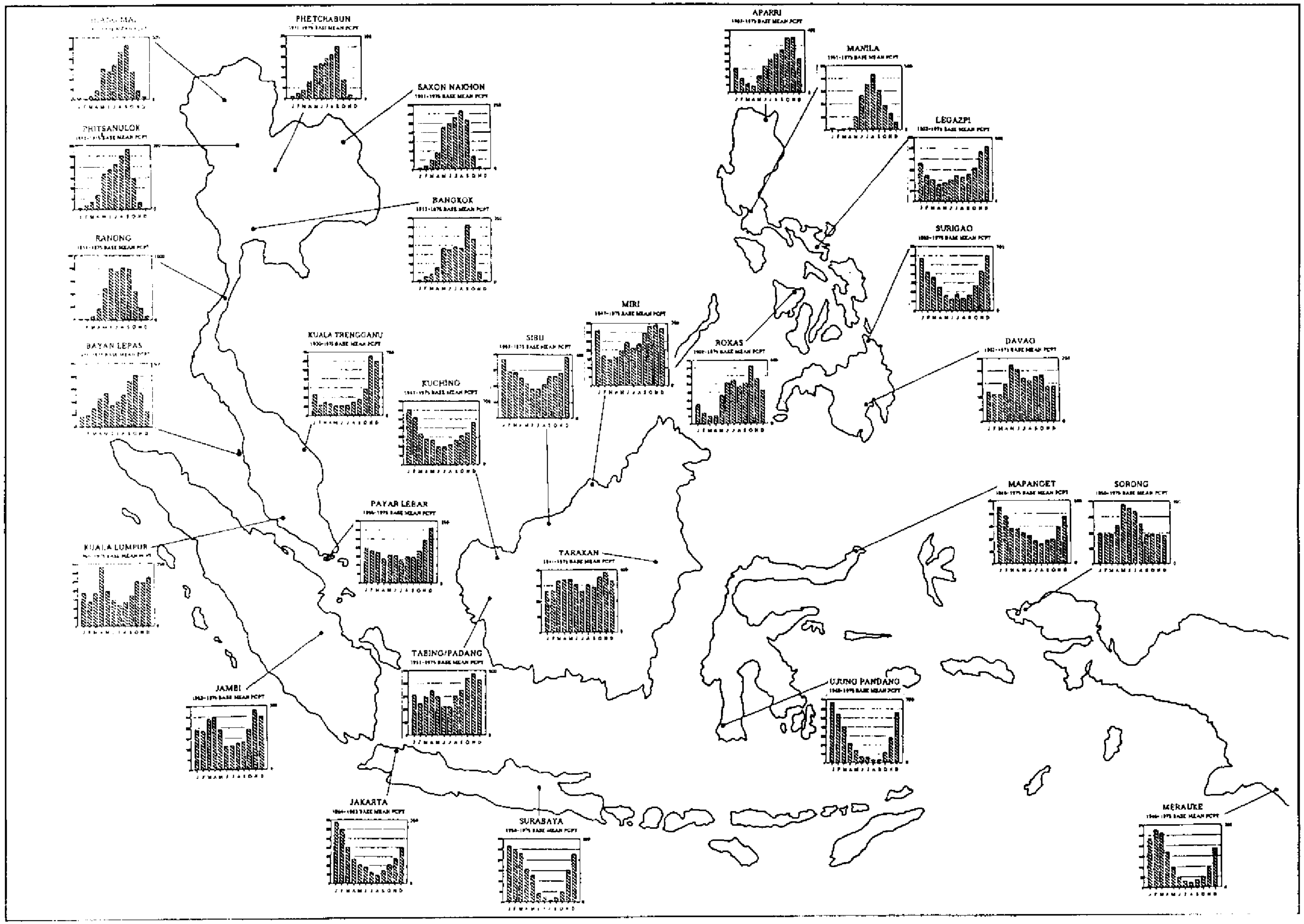


Figure 4.16 Present rainfall distribution

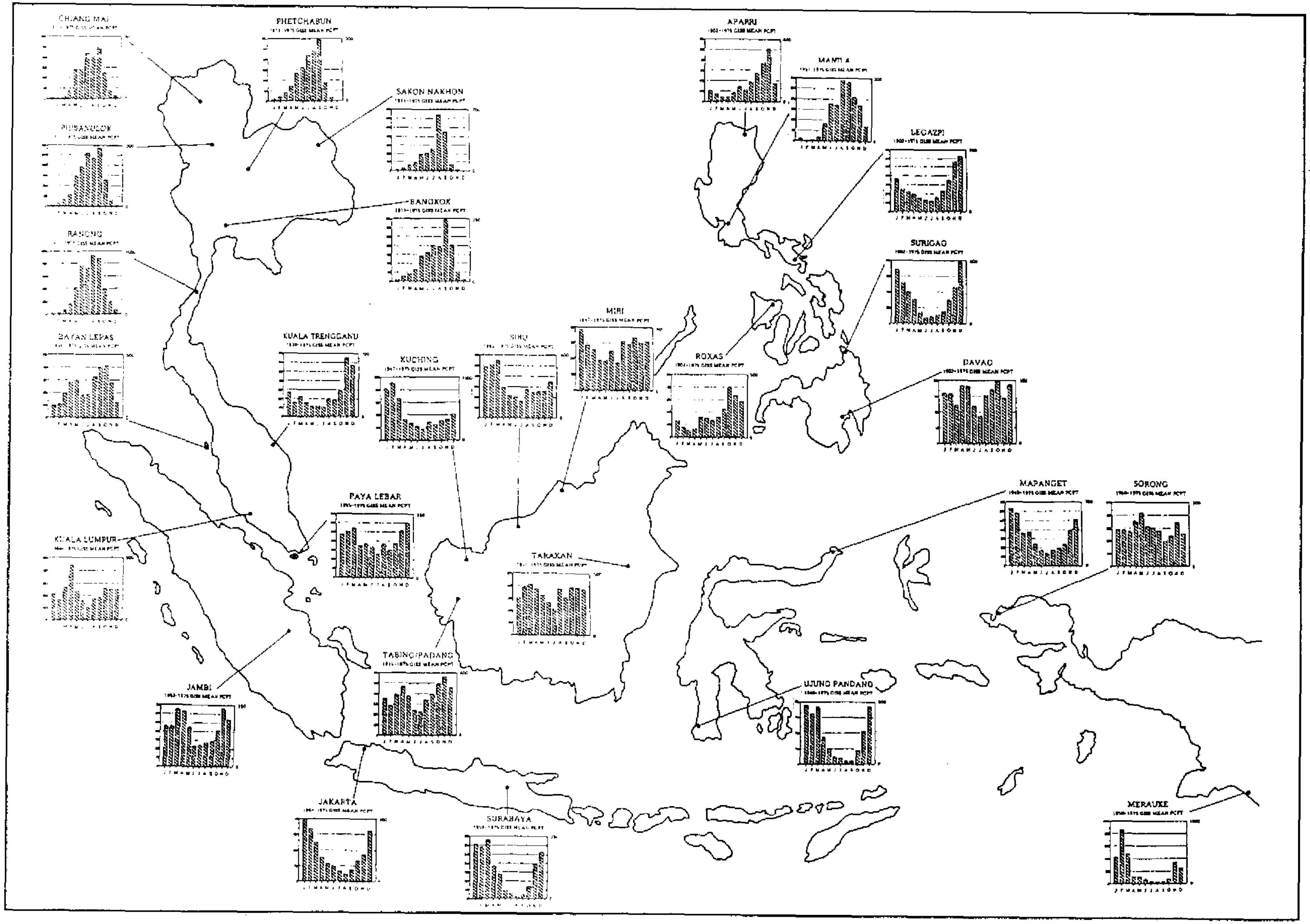


Figure 4.17 Rainfall distribution after greenhouse warming (GISS model output)

GISS Humidity

Like temperature, there is a consistent and quite uniform increase in humidity in the whole region. This can be seen in Table 4.7 which shows the percentage changes in humidity at all the selected grid points. This observation is reasonable as the increase in air temperature will lead to a higher rate of evaporation. However, unlike specific or absolute humidity, the relative humidity of the air may not change significantly because its temperature has increased. The brief calculation below shows that the relative humidity is about the same:

	Present ($1xCO_2$)	Future ($2xCO_2$)
Mean air temp.	25°C	(25 + 4)°C = 29°C
Mean vapor pressure	26mb	(1.25x26) = 32.5mb
Saturated vap. pressure	32mb (at 25°C)	40mb (at 29°C)
Mean relative humidity	26/32 = 0.81	32.5/40 = 0.81

Table 4.2 Difference between surface mean temperatures of $2xCO_2$ and $1xCO_2$ scenarios as generated by the GISS model.

GP	T	GP	T	GP	T	GP	T	GP	T	GP	T	GP	T
1	3.7	2	3.8	3	3.7	4	3.7	5	3.6	6	4.0	7	3.7
8	3.8	9	3.9	10	4.0	11	3.8	12	3.6	13	3.5	14	3.7
15	3.9	16	3.6	17	3.7	18	3.5	19	3.6	20	3.2	21	3.3
22	3.6	23	3.7	24	3.6	25	3.5	26	3.4	27	3.2	28	3.2
29	3.6	30	4.0	31	4.4	32	3.3	33	2.9	34	2.8	35	3.0

GP - Grid points position (see Figure 4.14)

T = (Temp. of $2xCO_2$ atmosphere) - (Temp. of $1xCO_2$ atmosphere)

Table 4.3 Difference (%) between humidities of the $2xCO_2$ and $1xCO_2$ climate scenarios as generated by the GISS model.

GP	H	GP	H	GP	H	GP	H	GP	H	GP	H	GP	H
1	25	2	27	3	27	4	22	5	20	6	17	7	19
8	25	9	23	10	22	11	23	12	24	13	24	14	24
15	24	16	24	17	28	18	26	19	27	20	27	21	24
22	24	23	24	24	27	25	26	26	25	27	23	28	27
29	24	30	25	31	24	32	23	33	24	34	30	35	24

GP - Grid points position (see Figure 4.14)

$$H = \frac{(\text{Humidity for } 2xCO_2) - (\text{Humidity for } 1xCO_2)}{(\text{Humidity for } 1xCO_2)} \times 100$$

EFFECTS OF GREENHOUSE WARMING ON IMPORTANT WEATHER SYSTEMS

Winter Monsoon

During the northern hemisphere winter monsoon months, large parts of Malaysia and Indonesia experience heavy rain and strong winds. The wet and windy weather is not continuous throughout the monsoon months, occurring in periods of 4/5 days interspaced by periods of drier and calmer weather. The wet and windy periods are associated with the development of high pressure cells in mainland China. As the high pressure cell develops and moves slowly across China, the pressure gradient between South China and Southeast Asia increases, thus strengthening the north easterly wind-flow over the region. As the air moves over the South China Sea, it "picks up" considerable amounts of moisture which it subsequently deposits as continuous heavy rain in the unstable equatorial trough lying over the Malaysian and Indonesian region. Therefore the intensity of the monsoon will depend on the pressure gradient between these two regions.

An interesting question which warrants attention is whether the greenhouse warming effect would intensify or weaken the winter monsoon wind flow over this region.

In general, scientists have predicted that the temperature increase due to the greenhouse warming will be higher near the poles and less near the equator. This scenario would imply that the cold high pressure cell in Central Asia will be less intense with the greater rise in temperature there. Consequently, the pressure gradient between China and Southeast Asia will be reduced, resulting in a milder monsoon with less rainfall and weaker winds over the Malaysian and Indonesian region.

A preliminary analysis of the monthly rainfall and wind speeds generated by GISS model at 6 selected grid points in the Malaysian and Indonesian regions (Fig. 4.18) during the monsoon months of November, December and January, and a comparison of the pressure gradients between 4 selected grid points in South China and the 6 grid points in the Malaysian and Indonesian regions are provided in Tables 4.8 - 4.10. For the $2xCO_2$ atmosphere, though there are consistent increases in rainfall, wind speed and pressure gradient between South China and Southeast Asia. The changes are, however, not statistically significant. These results are indicated by the non-significant t-values for the comparison tests performed on the data.

Based on the above preliminary comparisons, there is insufficient evidence to suggest that the winter monsoon wind flow over Southeast Asia will be stronger or weaker if the atmosphere has double its amount of CO_2.

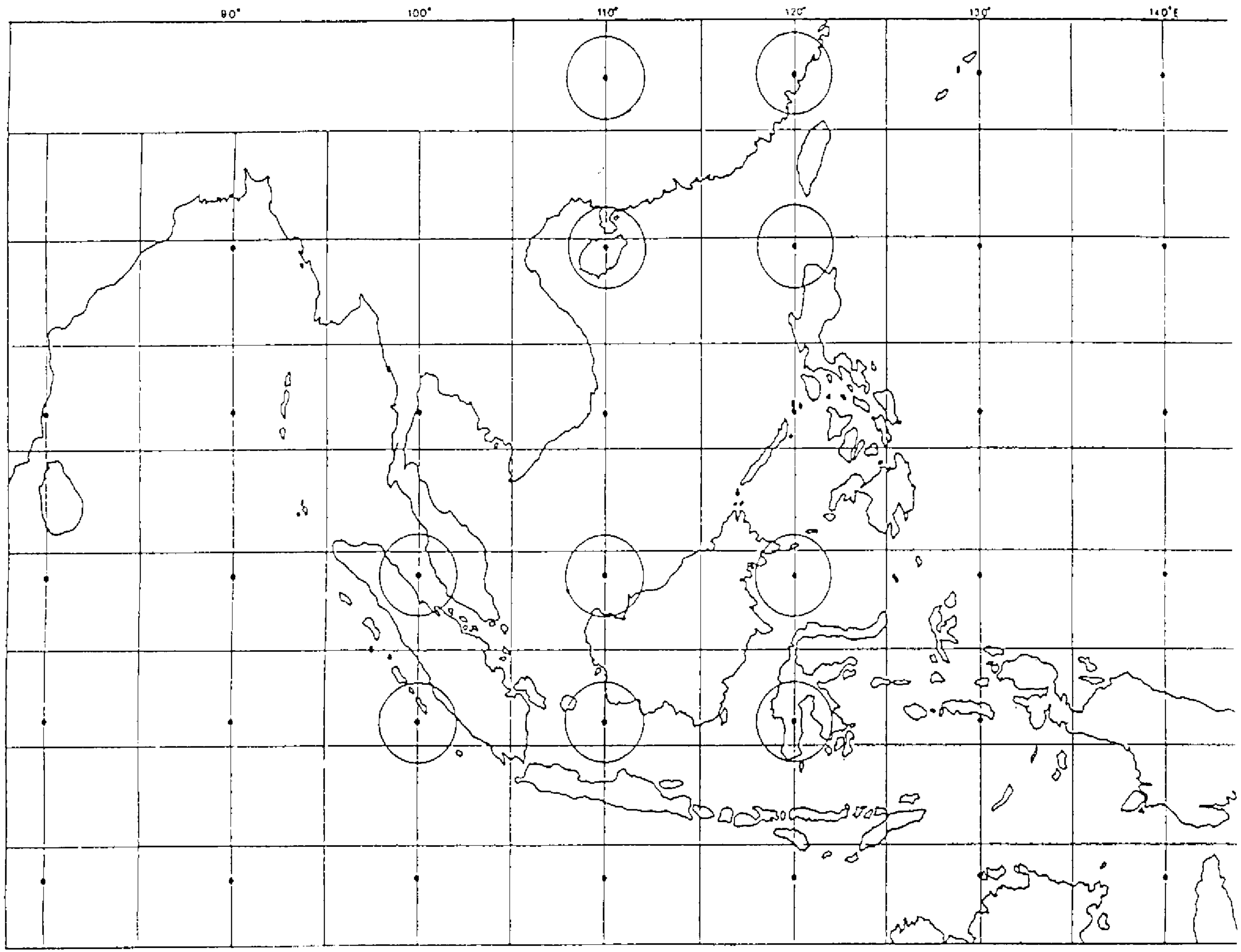


Figure 4.18 Positions of the 6 selected grid-points at the Southeast Asia region and the 4 points at South China for winter monsoon analysis.

Table 4.4 Comparison of rainfall (mm/day) at the 6 selected grid points over the Malaysian and Indonesian regions for the 2 climate scenarios.

	November		December		January	
	$1xCO_2$	$2xCO_2$	$1xCO_2$	$2xCO_2$	$1xCO_2$	$2xCO_2$
	7.96	10.16	8.50	10.13	8.65	9.93
	8.26	8.79	8.47	7.75	8.27	7.88
	5.20	6.80	6.23	7.47	5.96	6.15
	3.81	2.86	3.13	2.32	2.48	9.27
	3.34	5.08	3.99	5.22	5.55	3.41
	5.13	5.39	3.68	4.53	4.23	4.59
Monthly Mean	5.62	6.51	5.67	6.24	5.86	6.87
$(2xCO_2) - (1xCO_2)$	0.89		0.57		1.01	
Mean % increase	15.8%		10.1%		17.2%	
t-value	1.88 (ns)		1.31 (ns)		2.45 (ns)	

ns - not significant

Table 4.5 Comparison of surface winds (m/s) at the 6 selected grid points over the Malaysian and Indonesian regions for the 2 climate scenarios.

	November		December		January	
	$1xCO_2$	$2xCO_2$	$1xCO_2$	$2xCO_2$	$1xCO_2$	$2xCO_2$
	0.56	0.54	0.59	0.51	0.88	1.09
	1.13	1.23	0.87	1.04	0.82	1.30
	0.69	0.63	0.69	0.42	1.23	0.86
	1.00	1.10	0.82	0.76	0.94	0.94
	0.91	0.84	0.76	1.09	1.01	0.95
	0.94	0.91	0.81	1.03	0.80	0.90
Monthly Mean	0.872	0.875	0.757	0.808	0.947	1.007
$(2xCO_2) - (1xCO_2)$	0.003		0.051		0.060	
Mean % increase	0.3%		6.7%		6.3%	
t-value	0.11 (ns)		0.56 (ns)		0.52 (ns)	

ns - not significant

Table 4.6 Comparison of surface pressures (mb) of South China and Southeast Asia for the 2 climate scenarios.

		November		December		January	
		$1xCO_2$	$2xCO_2$	$1xCO_2$	$2xCO_2$	$1xCO_2$	$2xCO_2$
South China Grid Points	1	1011.0	1010.6	1013.5	1014.9	1014.2	1016.5
	2	1024.2	1020.6	1029.5	1028.3	1030.0	1025.9
	3	1006.4	1006.7	1007.2	1009.9	1009.7	1011.6
	4	1016.0	1019.2	1021.9	1023.4	1024.2	1026.0
Mean		1014.4	1014.3	1018.0	1019.1	1019.5	1020.0
Southeast Asia Grid Points	1	1005.0	1004.5	1005.2	1005.4	1003.8	1003.6
	2	1004.7	1004.4	1004.3	1004.5	1003.8	1003.9
	3	1005.0	1004.5	1005.1	1005.1	1003.6	1003.7
	4	1004.8	1004.2	1004.3	1004.6	1003.6	1003.6
	5	1004.6	1004.3	1004.4	1004.4	1003.4	1003.4
	6	1004.7	1004.3	1003.9	1004.4	1003.3	1003.6
Mean		1004.8	1004.4	1004.5	1004.7	1003.6	1003.6
(South China) - (Southeast Asia)		9.6	9.9	13.5	14.4	15.9	16.4
$(2xCO_2)$ - $(1xCO_2)$		0.3		0.9		0.5	
Mean % increase		3.1 %		6.7 %		3.1 %	
t-value		0.10 (ns)		0.24 (ns)		0.15 (ns)	
Effective degree of freedom		4		4		4	

ns - not significant
See Figure 4.18 for grid point positions

Typhoon Activity

It is important to consider possible changes in the behaviour of severe weather systems such as typhoon in response to the increased greenhouse gases. In the ASEAN region, Philippines is often affected by typhoons or tropical storms which cause considerable damage to property and crops.

The number of typhoons and their structural characteristics are influenced by the sea surface temperature, the atmospheric humidity, the degree of vertical sheer through the troposphere, the ability of the atmosphere to support clouds and the available cyclonic vorticity that can be concentrated into an intense storm. Sea-temperature is expected to rise as the air temperature rises though the warming of the sea would be much slower than that of the air. Future sea-temperature distribution patterns are difficult to predict accurately as they are influenced by ocean currents and mixing. The previous section has shown that the atmospheric humidity increases quite uniformly over the region. Unfortunately the other variables affecting typhoon intensity are not easily available from GISS model outputs. Hence this paper examines the changes in surface pressure and wind speed over the West Pacific region to detect the effect of greenhouse warming on typhoon activity. It is reasoned that if typhoon activity increases or decreases, there would be changes in the distribution pattern of surface pressure and wind speed. Even if the model does not generate typhoon weather systems because of the large distances between grid points, the increased typhoon activity should manifest as deeper pressure troughs and stronger winds in the region.

Figs. 4.19 - 4.21 show the analyses of the percentage changes in wind speeds over the Philippine region for the 2 climate scenarios. The periods chosen for the analyses are the quarters of March-May, June-August and September-November. Figs. 4.22 - 4.27 show the isobaric analyses of the same periods for the 2 climate scenarios. Though the wind speed has strengthened over large areas near Philippines during the March-May and September-November periods, the surface pressure pattern does not seem to show corresponding significant changes. Therefore there is not enough evidence to conclude that the typhoon activity increases or decreases in the region after the greenhouse warming.

CONCLUDING REMARKS

The time series for temperature have shown increasing trends. Though the increase in the temperature may be due to urban effects as all the stations selected are located near urban areas, the warming due to the increase in concentrations of greenhouse gases cannot be discounted. Unlike temperature in the region, rainfall has a very high degree of variability which makes it difficult to detect trends using records of rather short periods. Longer rainfall records are therefore required to determine the trends with a greater degree of confidence.

Most of the climate changes discussed are based on the results generated by the GISS model. Like other general climate models, it has limitations. The results of these climate models agree in the global or large regional scales. However, they differ at finer scales. Observations in this paper especially on the climate changes at each country must only be viewed as initial findings which need to be verified by more studies.

This paper examines the effect of the greenhouse warming on the climate of the East Asian Seas region by analysing the changes in the average values of selected weather elements. It should be noted that a shift in the normal climate may give rise to changes in the frequencies of extreme events causing more floods, droughts and storms. It should also be noted that the sea-temperature will lag behind the land-temperature in the warming process. It may take 10-20 years for the sea-temperature to equilibrate with the rise in air temperature, making unstable and unknown weather more likely.

Far reaching impacts may be caused by global warming and sea level rise, which are becoming increasingly evident as a result of the continued increase in the atmospheric concentrations of CO_2 and other greenhouse gases. The world has been subjected to climate changes and variabilities in the past. Human beings have adapted to these changes. However, what is critical and unprecedented in human history is the rate and possible extent of the present greenhouse gases induced change. According to the statement issued at the International Confereance on the Changing Atmosphere at Toronto, Canada in 1988, the ultimate consequences could be second only to a global nuclear war. If rapid action is not taken now by countries of the world, the problems caused by the greenhouse warming may become pregressively more serious, more difficult to reverse and more costly to address.

REFERENCE

Todorov, A.V. and A. David, 1982. "Recent rainfall trends in Malaysia". MARDI Report No. 79. MARDI, Malaysia

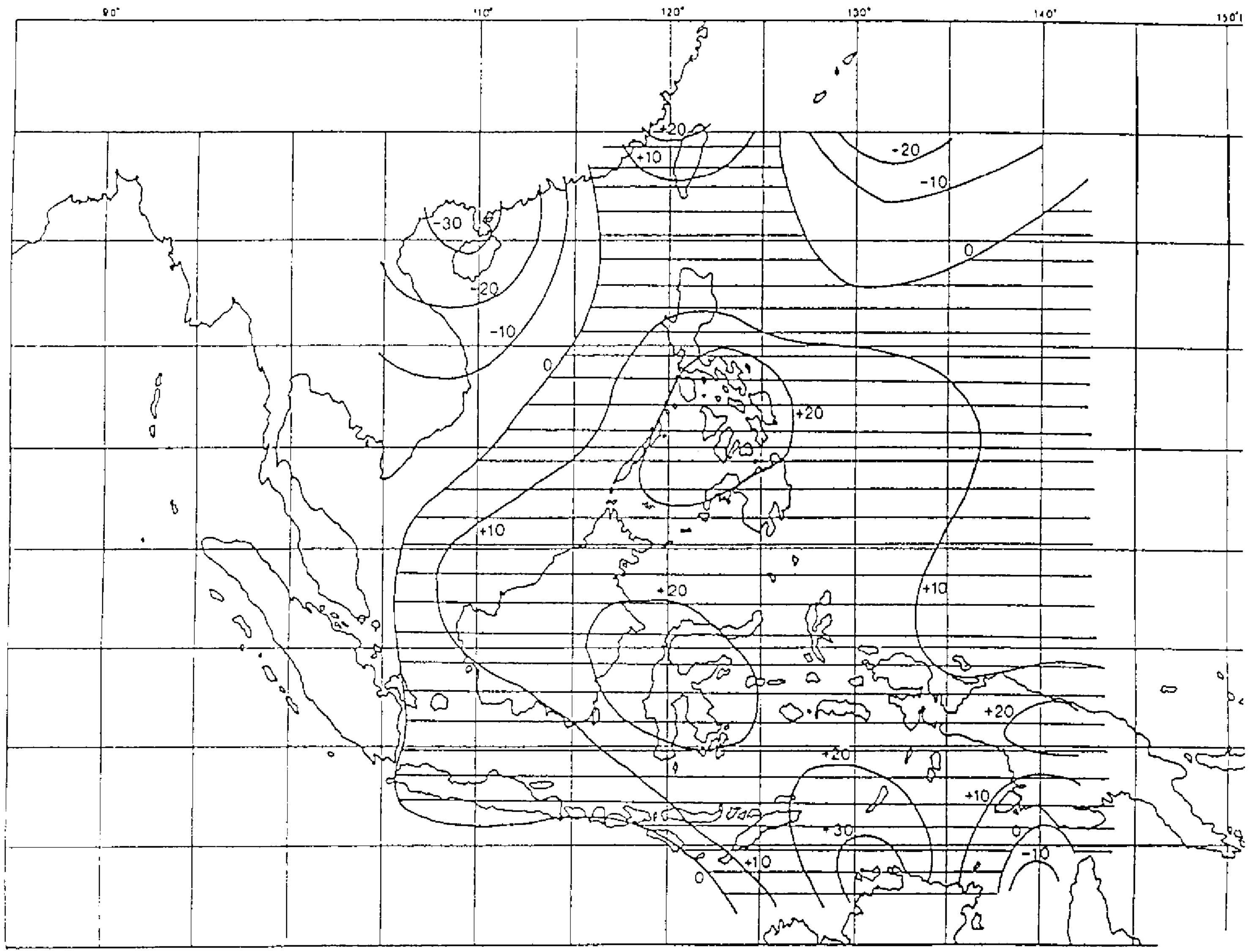


Figure 4.19 Percentage changes in wind-speed after greenhouse warming over West Pacific region from March to May(shaded areas indicated increase).

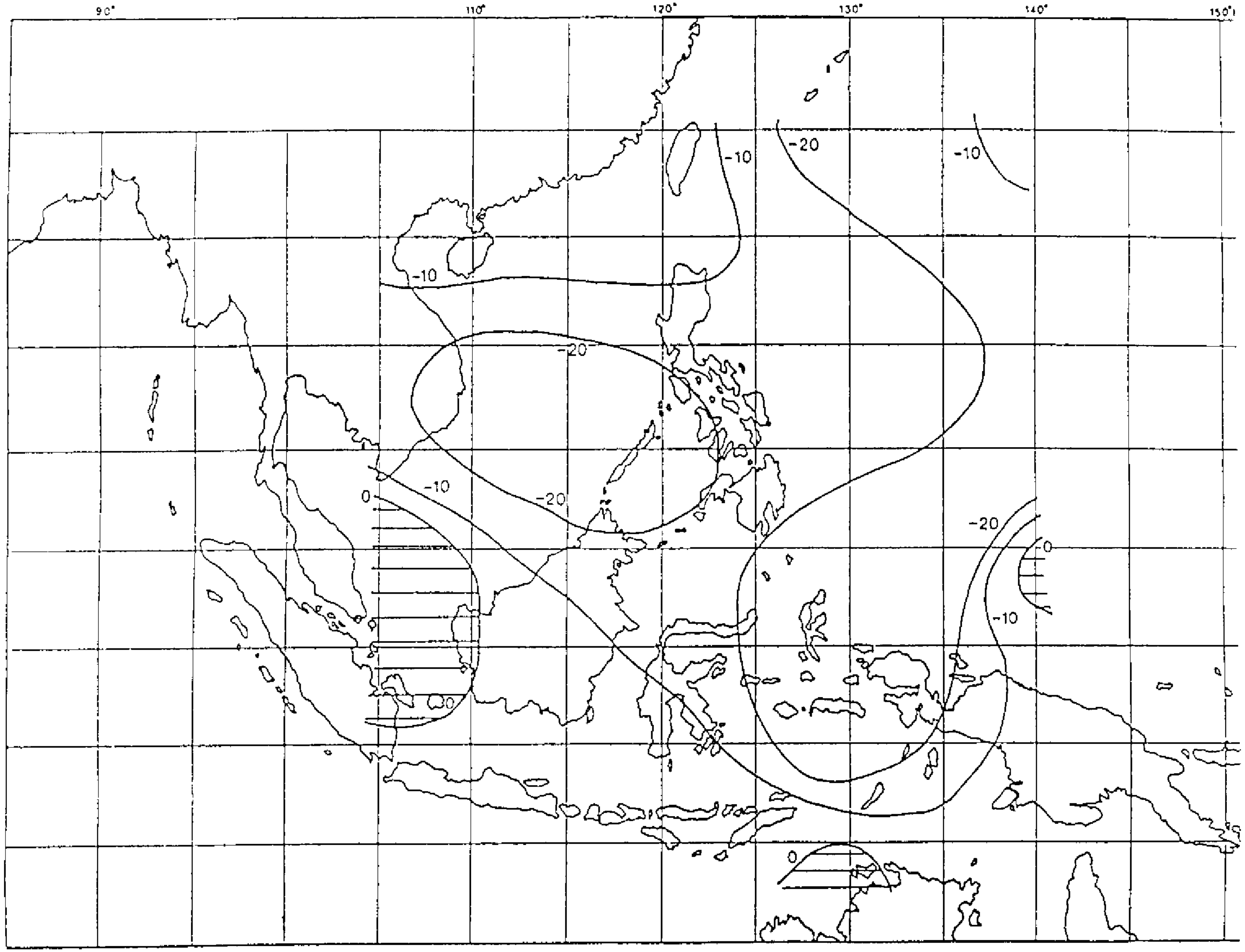


Figure 4.20 Percentage changes in wind-speed after greenhouse warming over West Pacific region from June to August (shaded areas indicated increase).

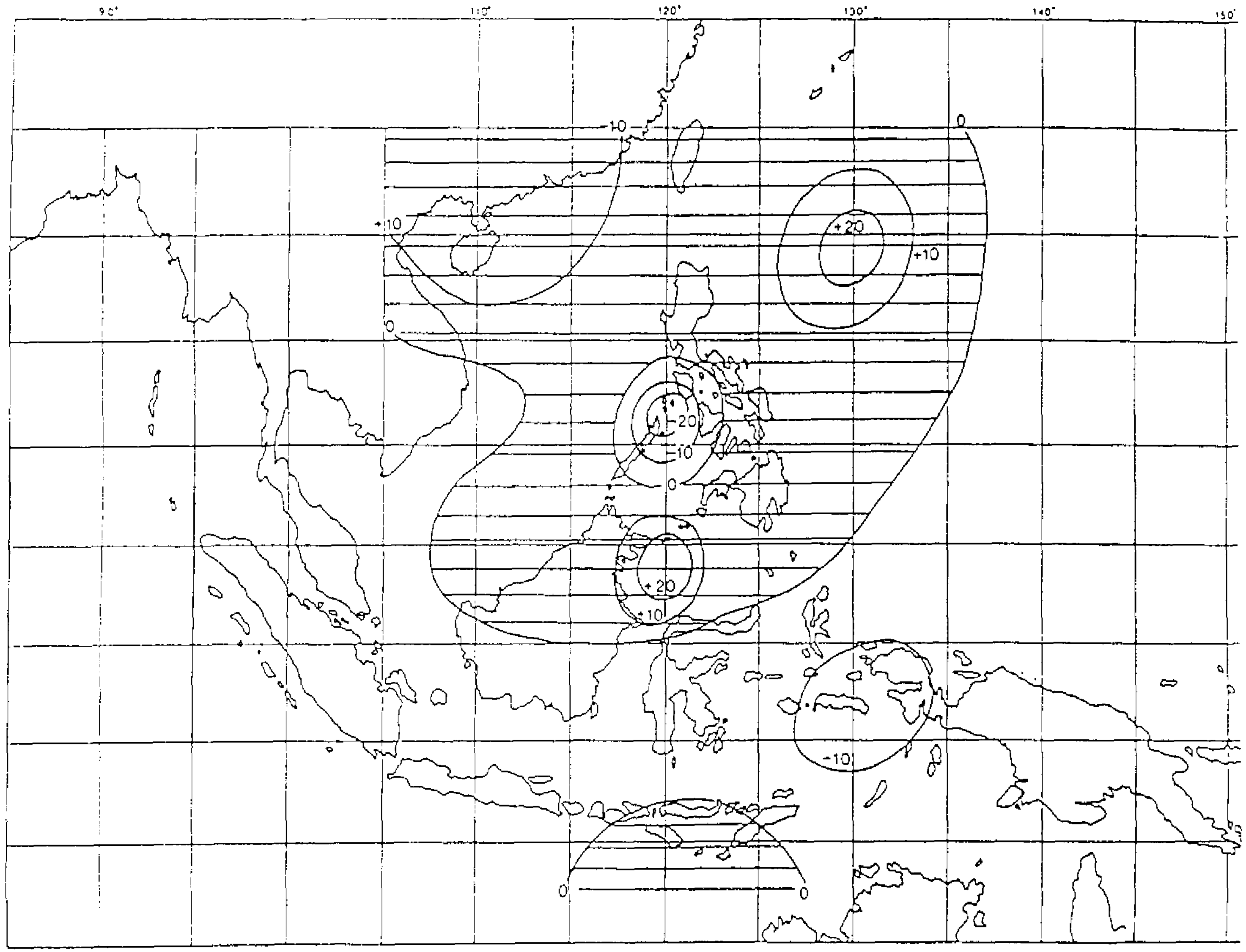


Figure 4.21 Percentage changes in wind-speed after greenhouse warming over West Pacific region from September to November (shaded areas indicated increase).

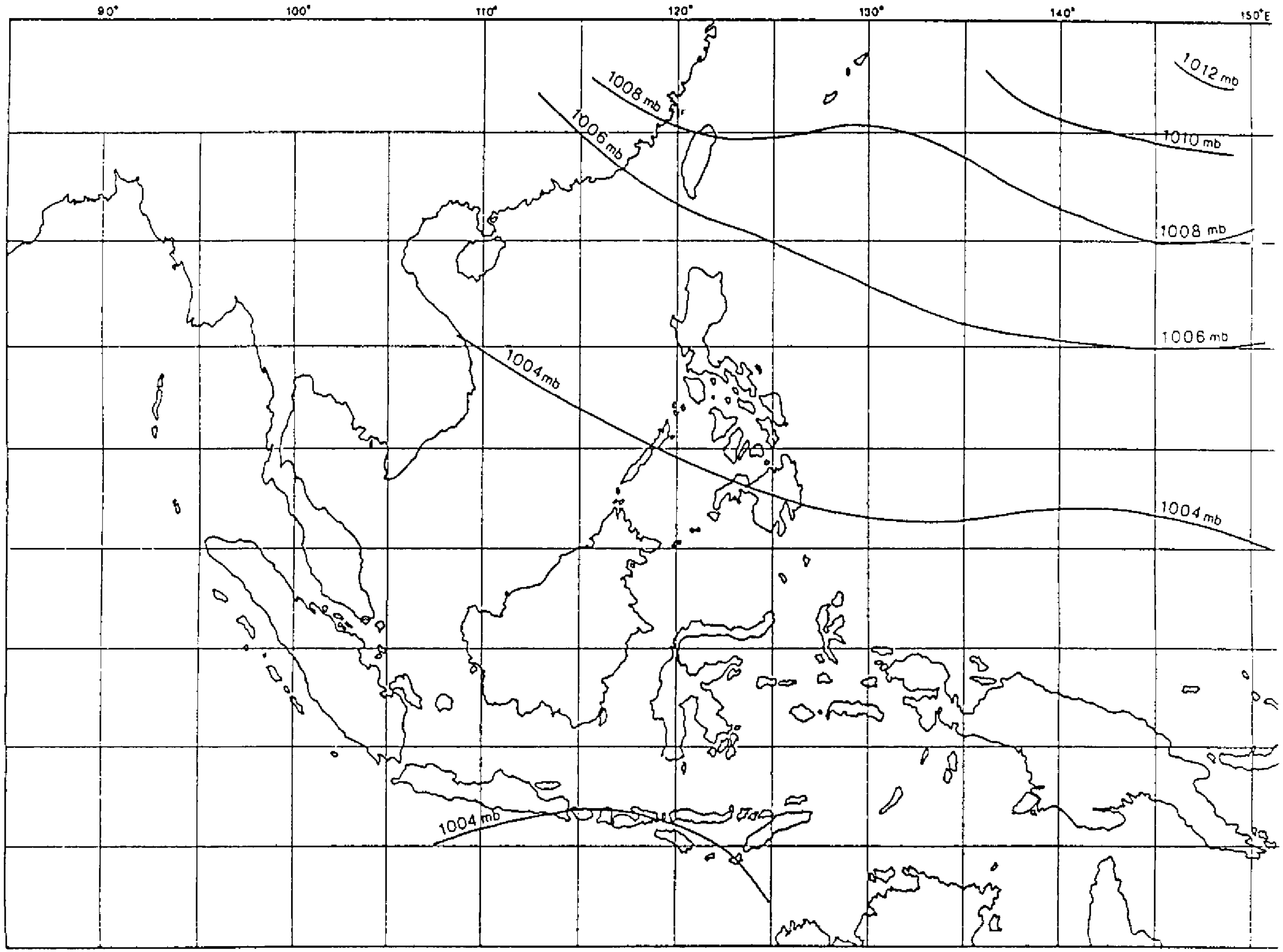


Figure 4.22 Sea level pressure under present atmosphere over West Pacific region from March to May.

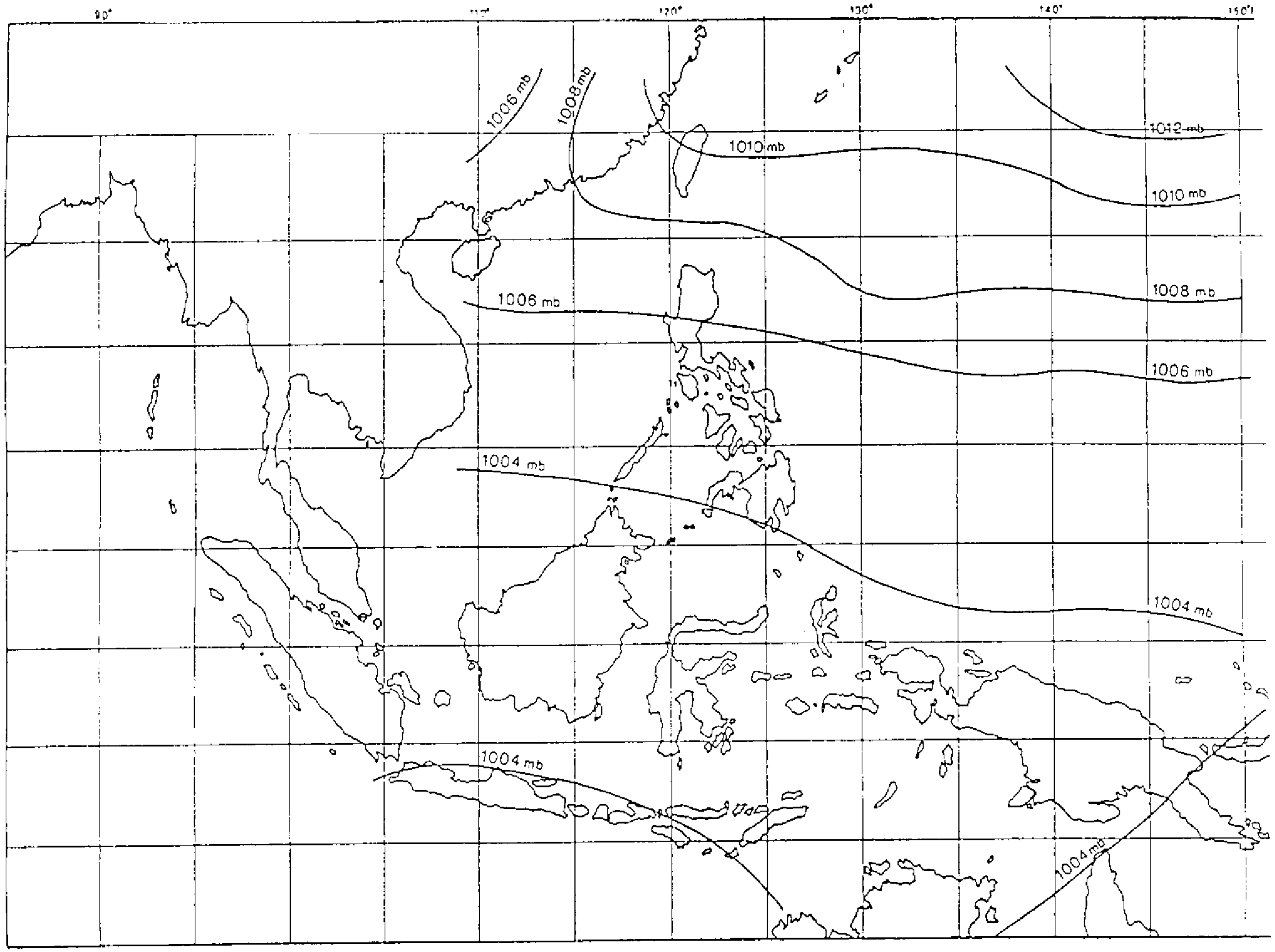


Figure 4.23 Sea level pressure under 2xCO_2 atmosphere over West Pacific region from March to May.

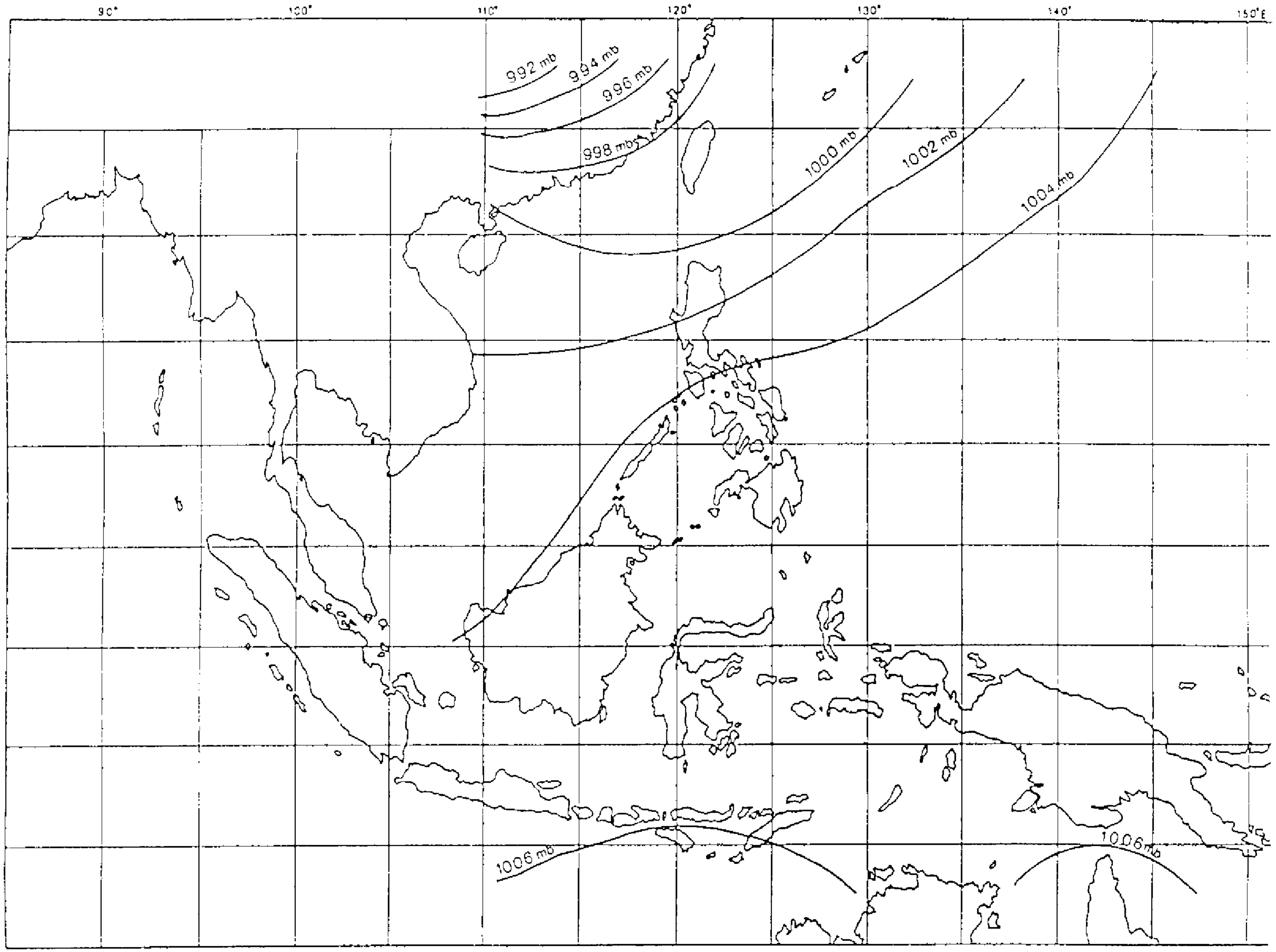


Figure 4.24 Sea level pressure under present atmosphere over West Pacific region from June to August.

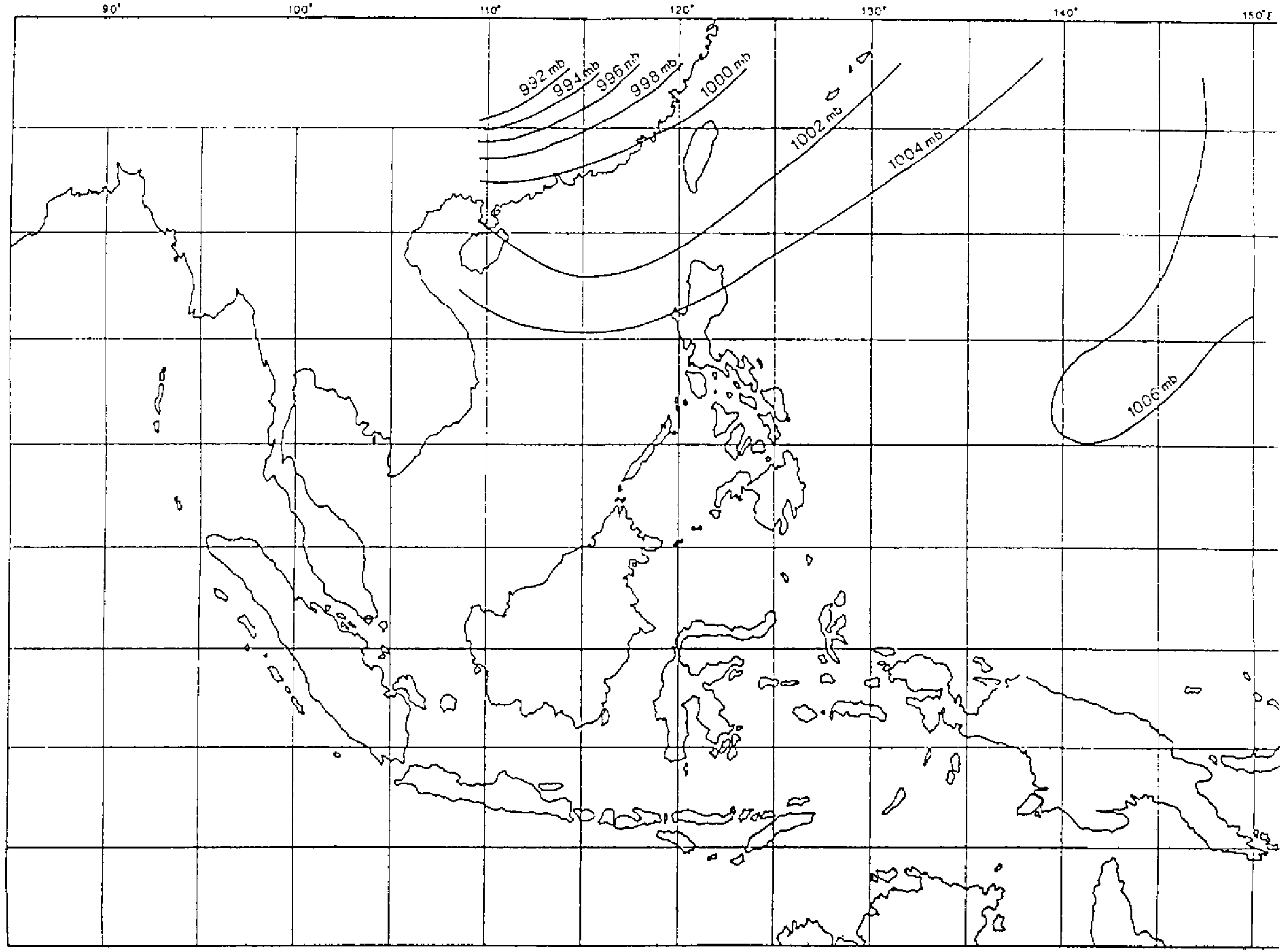


Figure 4.25 Sea level pressure under $2xCO_2$ atmosphere over West Pacific region from June to August.

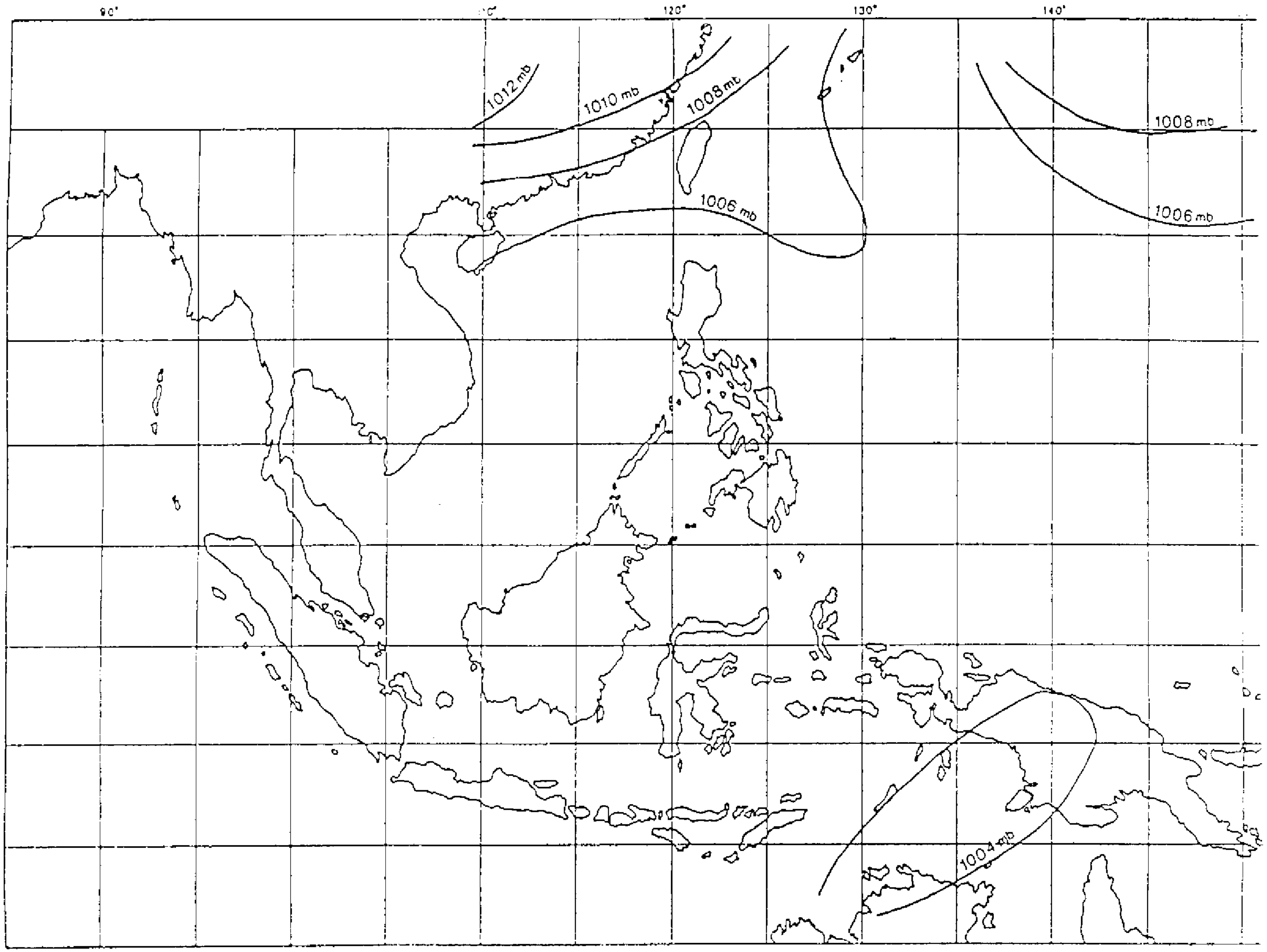


Figure 4.26 Sea level pressure under present atmosphere over West Pacific region from September to November.

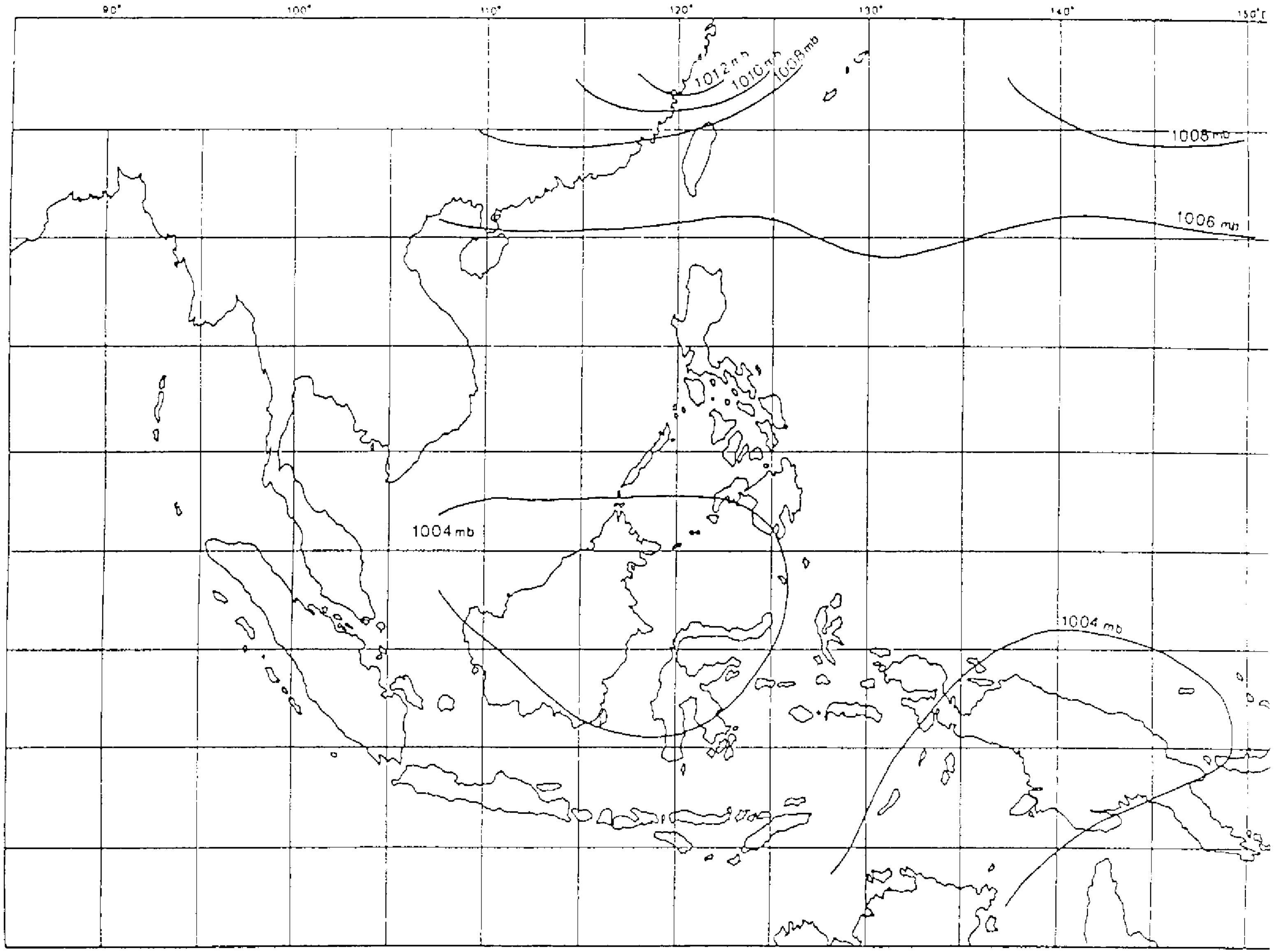


Figure 4.27 Sea level pressure under $2xCO_2$ atmosphere over West Pacific region from September to November.

5. IMPLICATIONS OF SEA LEVEL RISE ON THE COASTAL GEOMORPHOLOGY OF THE EAST ASIAN SEAS REGION

P.P. Wong

Department of Geography
National University of Singapore
Kent Ridge, Singapore 0511

INTRODUCTION

It is widely accepted that the increase in carbon dioxide and other gases generated by human activities on Earth will lead to warming of atmospheric temperatures, the "greenhouse effect" and consequently to an increase in global sea level. Most scientists are in general agreement that the global warming of 1 - 4.5°C would lead to an increase of 0.2 - 1.4m in sea level (Devoy, 1987). Various authorities have published different scenarios of the rise in atmospheric temperature and sea level. The UNEP has adopted the scenario of a temperature rise of 1.5°C and a corresponding rise of 20cm in sea level by the year 2025 for its project to evaluate the possible ecological and societal implications for all the regional seas. It should be noted that this scenario is rather conservative as it is between Hoffman's (1984) conservative and low scenarios in sea level rise, which are 13.0cm and 26.2cm respectively by 2025. Regionally, the scenario does not take into account the possibility of a compensation fall in sea level at the rate of 1.5 - 2mm per year due to vertical crustal uplift and a change in the geoid (Tjia, 1989).

The impact of a 1.5°C temperature rise on the coastal geomorphology of the East Asian Seas region would be mainly indirect through changes in rainfall, runoff and sediment yield to the coast. On the other hand, the impact of a 20cm rise in sea level on the region's coastal geomorphology would be more direct and its implications will be considered in this preliminary report. The basic responses of the coast will be considered first; this is followed by an evaluation of the extent of impacts in the region.

COASTAL MORPHOLOGICAL RESPONSES TO A RISING SEA LEVEL

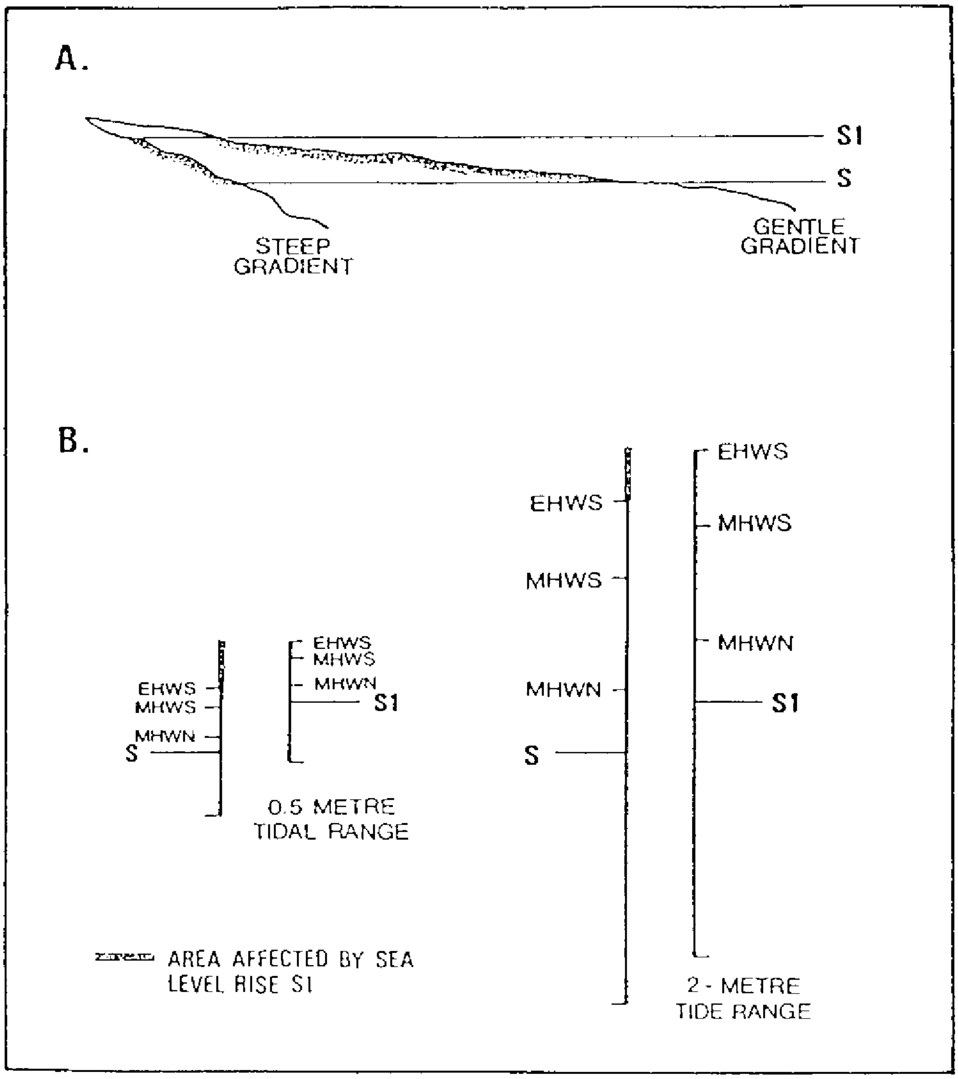
The coastal morphological responses to a rising sea level are not only determined by the coastal character but also by the rates of erosion and deposition which are influenced by many processes including a rise in sea level itself. The extent of the impact of a sea level rise depends on the degree to which the rise can alter the coastal character and the processes of coastal erosion and deposition.

Several basic morphological responses of coasts to a rising sea level can be identified.

1. **Terrestrial flooding or inundation i.e. submergence of the otherwise unaltered shore**

The extent of inundation is largely dependent on the coastal gradient and shoreline configuration. Considerably larger areas of gentle-gradient coasts (i.e. tidal flats, mangroves, sandy beaches) would be affected by rising sea level when compared to steep gradient or near vertical coasts (i.e. cliffs) (Fig. 5.1A). Also, a relatively larger area of gentle-gradient embayments would be inundated than straight coasts of a similar gradient.

Figure 5.1 Impact of a sea level rise on different coastal gradients (A) and in different tidal ranges (B).



The tidal range can influence the character and extent of inundation. Land affected by a rising sea level in a small tidal range environment would be subject to more frequent tidal and wave action than in the case of a large tidal range environment. Thus, for a sea level rise of 0.2m, which would account for 40% of a 0.5m tidal range, both the new MHWS and the new MHWN could affect hitherto dry land, whereas for a 2m tidal range, the newly affected land could only be reached by the new EHWS (Fig. 5.1B). The impact of sea level rise in small tidal range environments would be further accentuated in funnel shaped bays and especially during storm surges.

2. Coastal erosion, i.e. the physical removal of material from the coast

Increased coastal erosion is expected as a result of deeper water and consequently increased wave energy arriving at the shore. Coasts composed of erodable material (e.g. sandy beaches, deltas, cliffs of soft materials) are expected to be more vulnerable than hard coasts (e.g. cliffs of crystalline rocks). Erosion would be accelerated on eroding coastlines and possibly initiated on coastlines not previously eroded. Erosion is also likely to accelerate along present low lying shores subject to storms and along semi-enclosed channels where tidal amplification occurs. The relationship between sea level rise and coastal erosion is causal, based on evidence from the U.S. shoreline and worldwide erosion reported from coasts not altered by man or influenced by increased storminess (Bird, 1985c).

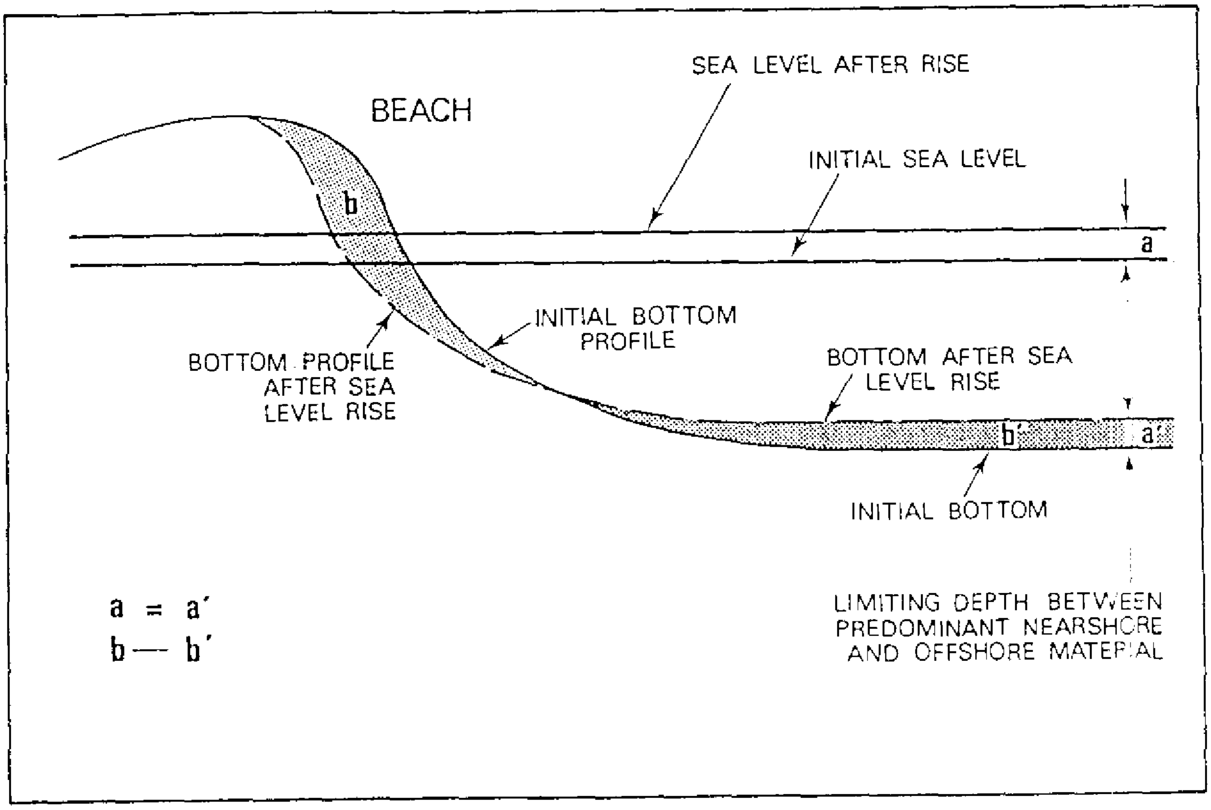
3. Other processes, such as overwashing and lagoon filling

With increasing wave energy, beaches and barriers may be breached by overwashes which transfer water and sediment across them to form extensive lenticular, sheet-like washovers. These constitute an important mechanism in the landward transfer of material, e.g. washovers infill lagoons which leads to the landward migration of the barrier. Shallow lagoons will also expand rapidly in response to a rise in sea level because of their gentle gradient and the loss of lagoon vegetation.

The rate of sea level rise deserves a closer examination in relation to the various processes of coastal erosion and deposition. The UNEP scenario of sea level rise would be equivalent to a rise of 5mm/yr. To what extent can the upward growth of corals in the East Asian Seas region keep pace with this rate? Also, to what extent can the seaward extension, of mangroves and deltas in this region keep pace with coastal erosion? Under natural conditions, the reefs of the East Asian Seas regions are likely to maintain their upward growth but this would not be so in reefs affected by human activities (Yap, this volume).

For coastal engineering purposes, the extent of change to a coast from a rising sea level can be predicted by the Bruun Rule. Basically, given a discrete sea level rise, the rule provides for a new equilibrium profile in which the material removed during shoreline retreat is transferred and equal to that on the nearshore bottom, and that the rise of the nearshore bottom level equals the sea level rise (Schwartz, 1967) (Fig. 5.2). Studies have shown that a centimetre rise in sea level would result in the shoreline retreating 0.5 - 10m (Titus, 1987). Although the rule is appealing there are certain limitations and difficulties. Longshore sediment transport is not considered; neither are certain lateral movements of sediments, onshore movement of sediments during storms; and sediment removal to depositional sinks. There are also difficulties in obtaining precise bathymetric data and integrating these with nearshore profiles over long periods of time.

Figure 5.2 Bruun Rule (after Schwartz, 1967).



EXTENT OF IMPACT IN THE EAST ASIAN SEAS REGION

The length of coastline varies enormously for the countries in the East Asian Seas region (Table 5.1). A variety of coastal types can be identified in this region (Eisma, 1982). More details are given by various authors in the volume edited by Bird & Schwartz (1985).

Table 5.1. Length of coastline

Country	Length (km)
Brunei	161
Burma	3,060
Indonesia	54,716
Kampuchea	443
Malaysia	4,675
Philippines	36,289
Singapore	193
Thailand	3,219
Vietnam	3,444

Source: Kent & Valencia, 1985

Of the various types of coasts in the East Asian Seas region, coral reefs, mangrove swamps and sandy beaches are the most vulnerable to a sea level rise of 0.2m. Fig. 5.3 summarizes the distribution of these three coastal tides and tidal range environments of less than 1.5m in the East Asian Seas region.

It should be noted that the factor of local coastal diversity can be important in this region. For example, the islands around Singapore have coastal forms which are very different from those supposed to characterize such coasts in the humid tropics (Swan, 1971). This is a reflection of chemical weathering and differences in rock type and exposure. As such, the assessment of the impact of a sea level rise on a coastal sector should be as site-specific as possible.

In general, several factors have to be considered in assessing the vulnerability of a particular coastal stretch to a given sea level rise: the nature of sediments, coastal topography, and the degree of existing erosion (National Research Council, 1987). A tentative list of the coastal stretches, which consist of five major coastal types, in the East Asian Seas region requiring further investigation is given below.

Deltas

There are several major deltas in the East Asian Seas region. Except where the sediment supply has been reduced, the deltas have continued to grow. The progradation rates are comparatively higher for deltas on the Sunda Shelf than for those outside the Shelf. The deltas are colonized by mangroves, which dominate protected coasts such as the east coast of Sumatra, Kalimantan. An important question is whether the deltas are likely to receive a sediment supply that can keep pace with the predicted sea level rise. This involves not only physical factors, including the projected rise of the atmospheric temperature, but human factors in reducing the supply of sediments to the coast.

1. Irrawaddy delta

This delta occupies 30,000km^2 of which one-sixth is intertidal and extensive flooding occurs during the wet season. Its progradation rate is up to 60m/yr or a land gain of 10km^2/yr. High natural levees continue to be built up by silt deposition alongside river channels (Bird, 1985a). Although the sediments are rapidly colonized by mangrove swamps, some sediments are transported eastward and offshore during the wet monsoon period (MacIntosh, 1982). The supply of sediments will be an increasingly crucial factor in maintaining the delta's growth during a sea level rise.

2. Inner Gulf of Thailand

Here, the deltaic coastline progrades at a rate of 5m annually. Waves have constructed a sand bar about 1.5km offshore to form a sheltered environment for silts and clays to settle (Bird, 1985c). The extensive tidal mudflats are expected to be reworked with an increasing sea level. The sea level rise is expected to aggravate the existing flood problem in Bangkok which is suffering from subsidence as a result of groundwater extraction.

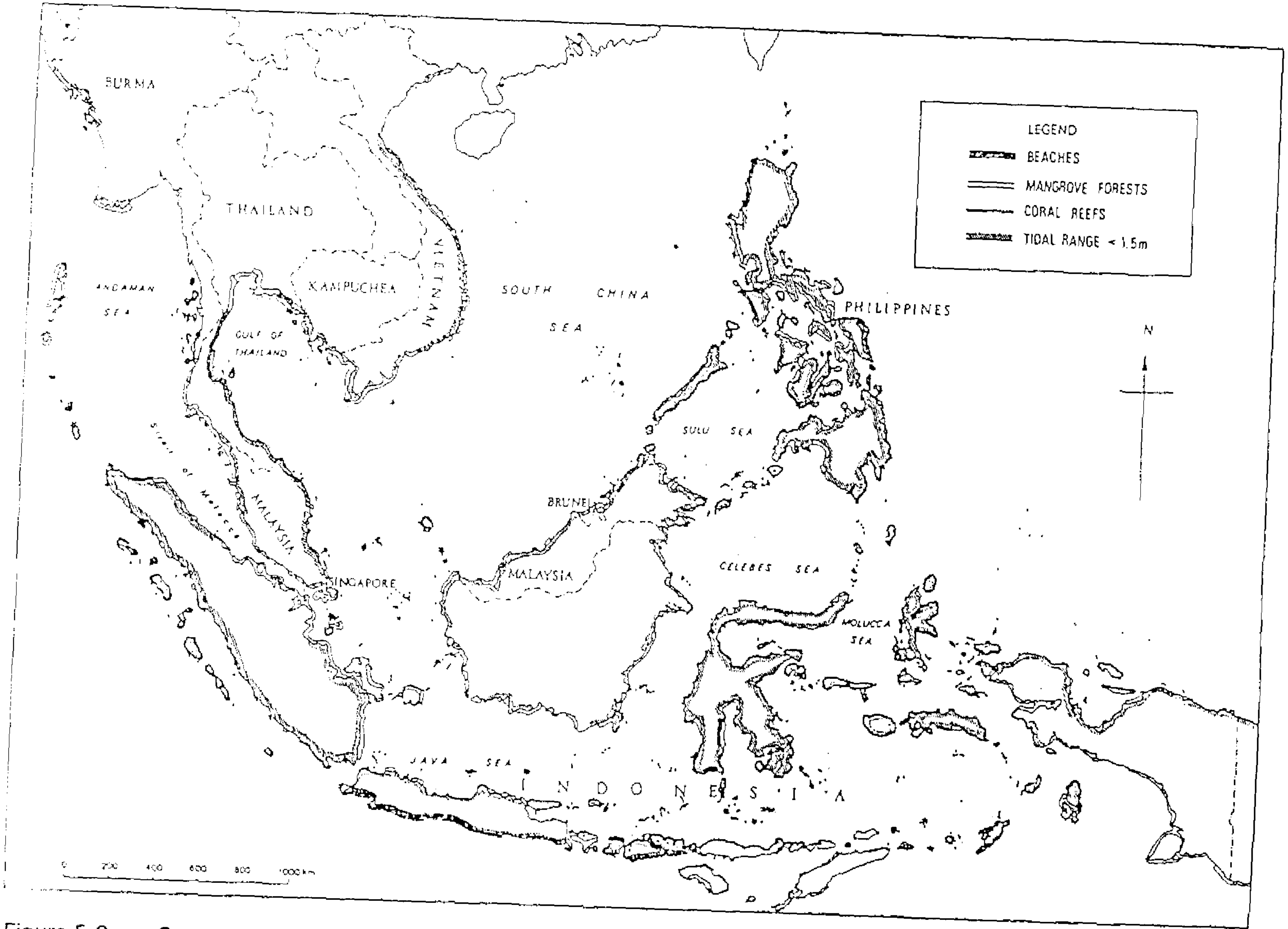


Figure 5.3 Coastal types most vulnerable to a sea level rise in the East Asian Seas region (compiled from Morgan and Valencia, 1983)

3. Red River delta

The delta progrades at about 100m/yr. At present the metre-high beach ridges with low dunes offer sufficient protection against the tides. These ridges are separated by wide depressions which are flooded during very high tides. Dikes had been constructed since the eleventh century to protect the delta against flooding (Eisma, 1985). With a rise in the sea level the Red River delta would become more vulnerable to increased flooding.

4. Mekong delta

Mud flats and mangroves are limited to the seaward fringe. The sediments move southward under the influence of the northeast monsoon into the Gulf of Thailand (Eisma, 1985).

5. Northern coast, Java

During the past century the rivers and canals on the northern coast of Java received sediments resulting from the clearance of forest and farming activities upstream. As a result, the coastal sectors around them have prograded. Sectors not receiving sediments are new subject to coastal erosion, for example the Citarum River delta eroding, due to completion of a dam upstream in 1970 (Bird & Ongkosongo, 1980). With a rise in sea level, erosion of such sediment-starved deltas would be accelerated particularly where they are unprotected by a mangrove fringe.

6. Other deltaic coasts in Indonesia

These are well colonized by mangrove swamps. The extensive mangrove swamps on the east coast of Sumatra continue to prograde rapidly. Palembang which was near the coast in the fifteenth century is now 50km inland. The Jambi delta prograded up to 7.5km between 1851 and 1922 (Verstappen cited in Bird & Ongkosongo, 1980). On Kalimantan the swampy plains prograde at the mouths, of the Mahakam, Pawan and Kapuas rivers. In Irian Jaya the swampy shoreline is at Cape Valsch is advancing and it is possible that the wide belt of mangrove swamps in these coasts would slow down or even prevent any significant erosion related to a rise in sea level.

7. West coast of Peninsular Malaysia

This coast has actively prograding mangroves which are best developed around the estuaries. The impact of a rising sea level is likely to be increased by various current activities leading to the clearance of the mangroves.

8. Andaman coast, Thailand

Around the river mouths are well developed mangroves with a clearly defined ecological zonation related to the frequency and depth of flooding. There are extensive mud flats with gradients less than 1% (Pitman, 1985). The ecological zonation would change with a rise in the sea level.

Coral reefs

In contrast to the pattern of mangrove swamps, coral reefs are poorly developed in the Sunda Shelf at the marginal areas. Fringing reefs occur along the Indian Ocean coasts of Sumatra, Java and the Mergui Archipelago. Coral reefs also abound in the archipelagoes east from the Makassar Strait. The strength and direction of monsoons are important in influencing reef shape, and because of the seasonal reversal in water circulation the reefs in the East Asian Seas do not show the characteristic windward and leeward reef forms of the Pacific trade wind zone (McIntosh, 1982). From Balikpapan to Sumbawa Island a Pleistocene fringing reef had grown upward with the gradual rise in sea level to reach the sea surface as separate coral islands (Eisma, 1982).

Coral reefs in the East Asian Seas region have been exploited in many ways. In recent years, coral reefs and beaches are being developed for beach resorts. Human impact on coral reefs (physical damage, changes in the deposition / erosion environment, overexploitation, and chemical pollution) is most evident in Indonesia, Thailand and Malaysia (Morgan & Valencia, 1983). Reefs that have been damaged by human activities, in areas of heavy seas or within the reach of overwash processes remain the most vulnerable to a rise in sea level. They are unable to increase their height with a rate of sea level rise of 5mm/yr. The rise of 0.2m in sea level is likely to affect resorts established near to the high tide level.

Beach ridges, barriers and spits

These features are associated with coastal stretches that have an excess sediment supply and are characterized by a seaward fringe of beaches, some of which have been developed for recreation and tourism. Wide series of beach ridges are related to Holocene sea level fluctuations. Some ridges have aeolian cappings.

1. East coast, Peninsular Malaysia

Sandy beaches are found along 90% of its length and during the rainy northeast monsoon, coastal erosion prevails. Based on field observations made in 1975-76 and 1985-88, the barrier at Terengganu seems to be at equilibrium while erosion has increased elsewhere on the east coast. There is an increased incidence of coastal erosion at beach resorts and coastal erosion has begun at resorts previously unaffected (Wong, 1988). It is difficult to establish whether this is under the influence of a sea level rise without independent confirmation from tidal records. This seems to be a common difficulty in the East Asian Seas region.

2. Southern coast, Java

Compared to the northern coast, the southern coast of Java is smoother in outline due to higher wave energy and steeper seafloor topography. Although the sediment loads of rivers flowing northward and southward are similar, the higher wave energy leads to a distinctive distribution of the sediments on the south coast. The coarser sediments are in the beaches and dunes. The finer sediments are in the swales between the ridges or carried out to sea (Bird & Ongkosongo, 1980). West of Parangtritis, the coastal dunes are active, a phenomenon that is quite anomalous in a humid tropical environment (Bird, 1985b). The predicted rise in sea level would increase the erosion potential in this high wave energy coast.

3. Padang Bay, Sumatra

The beach ridges of this area are built from volcanic material. The whole coastal plain could be subsiding according to Verstappen (cited in Bird & Ongkosongo, 1980). With a rise in sea level, erosion of the subsiding coastal plain would accelerate.

Lagoons

In the case of lagoons, a rise in sea level would lead to expansion of the lagoon area and vegetation changes along their shores. Infilling depends on sediments brought down by the streams and overwashes, which are likely to increase.

1. Tenasserim coast, Burma

Rapid silting takes place in many estuarine lagoons which have been converted into mangrove swamps and saline marshes (Bird, 1985a). This process is likely to continue because of the sediments brought down by the rivers.

2. Eastern peninsular coast, Thailand

Several features are of interest here: a coastal sand barrier, shallow lagoons undergoing rapid sedimentation, spits and beach ridges, and tidal flats and sand banks (Pitman, 1985). A rise in the sea level would bring about changes in the sedimentary processes along this complex coast.

Artificial coasts

Most artificial coasts are likely to withstand a rise in sea level of 0.2m and the consequent increase in wave height. As the structures protecting these coasts are being maintained, redesigned or replaced, the rise in sea level can be accommodated. However, unprotected or unarmoured reclaimed coasts, e.g. the east coast of Singapore, would be subject to coastal erosion as the sea level rises. If defence or mitigation measures are required, these have to be site specific and cannot be developed on the basis of generalizations for a country or a region.

CONCLUSION

A variety of coastal types can be found in the East Asian Seas region. The impact of a sea level rise on the coastal geomorphology of this region would depend on several factors including coastal type, tidal range, exposure, sedimentation trend, etc.

A rise in sea level of 5mm/yr or 0.2m by 2025 may not be considered serious enough by small coastal communities on lowlying coasts to take long-term defensive action. These communities are more likely to take short-term measures, e.g. build higher bunds around cultivated land and ponds, raise the floors of structures, to mitigate the increased incidence of flooding.

Coastal cities, because of a need to protect development, are more likely to take action which would be defensive as part of the maintenance or building of coastal infrastructure.

Policy makers face a difficult task in planning long-term measures to mitigate the impact of a rise in sea level. More detailed information of the impact of the rise in sea level on various types of coast is required. 'There is a need for site-specific predictive studies of the physical and ecological consequences of a sea level rise on various types of coastlines' (Bird, 1986). Typical coastal transects within the East Asian Seas region should be selected for more detailed geomorphological investigation. In this way, coastal geomorphology can help in providing better planning of measures and policies related to a rising sea level.

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6. IMPLICATIONS OF GLOBAL SEA LEVEL RISE ON COASTAL EROSION AND SALTWATER INTRUSION

K.C. Sieh & S.C. Lee

Coastal Engineering Technical Center
Drainage & Irrigation Department
Jln. Sultan Salahuddin
50626 Kuala Lumpur
Malaysia.

INTRODUCTION

This report provides an overview of the efforts of countries in other regions made in response to a projected global sea level rise and consequent coastal erosion and saline intrusion. The emphases at this stage are on the assessment and prediction methodologies employed by advanced countries and the subsequent evaluation of the applicability of these techniques to conditions prevailing in the East Asian Seas region. In the course of reviewing the current literature, an arsenal of of potential responses appropriate for particular settings were identified and are enumerated in the report, forming the main basis upon which an appropriate action plan for the ASEAN countries will be charted.

Following a description of the physical setting, particularly those features that are pertinent to the processes of coastal erosion and saline intrusion, the report identifies coastal areas that are likely to suffer grave consequences from a global rise in sea level. Based on the assessment / prediction methodologies outlined in earlier sections, and an evaluation of the implications, quantification of induced changes is provided where field data are available. An outline of further work required toward further refinement of the study results is also suggested.

OVERVIEW OF SEA LEVEL RISE STUDIES

United States

By far the most detailed efforts in sea level rise studies are found in the United States. These efforts are spearheaded by the US Environmental Protection Agency (EPA), which initiated a series of area-specific studies usually in concert with the regional planning / water basin authorities concerned. Following several studies on projected increases in the rate of eustatic sea level rise (Hoffman et al., 1983), a series of reports has been published (Kana et al., 1986) which, among other things, examine the causal relationships between the greenhouse effect, sea level rise, and coastal erosion and saline intrusion. More recently, other regional/national organizations have undertaken similar work (National Research Council, 1987; San Francisco Bay Conservation and Development Commission, 1987; 1988)

While other studies are site-specific and examine only subsets of the possible impacts relevant to the areas studied, the multi-disciplinary study conducted by the National Research Council (1987), which culminated in the publication entitled "Responding to Changes in Sea Level -- Engineering Implications", contains conclusions and recommendations that are more general in nature and bear repeating here. Amongst others, the study concluded that large, short-term (2 - 7 years) fluctuations in world-wide sea level are related to meteorological phenomena such as the ENSO events that may cause rise or fall of mean sea level by 15-30cm over a few years. The study also noted the dearth of appropriately sited tide gauge stations that could yield relevant information to assist in evaluating long-term regional trends in relative mean sea level, especially in areas where subsidence may mask the nature of a global sea level rise.

The risk of accelerated mean sea level rise is sufficiently established to warrant consideration in the planning and design of coastal facilities according to the study. In this respect, while acknowledging that accelerated sea level rise would lead to exacerbated beach erosion, the study did not rule out the fact that anthropogenic effects, especially along artificial coastlines, may engender enhanced erosion rates that are much larger than would naturally occur, hence reducing the role of of sea level rise into a secondary one for some years into the future.

While noting that coastal stabilization and strategic retreat (especially in low development coasts) are two viable response options to sea level rise, the study expressed optimism that there does not now appear to be reason for emergency action and that the effects of sea level rise could be accomodated during maintenance periods or upon redesign and replacement of most existing strutures/facilities. More importantly, the study favoured site-specific defensive or mitigation strategies rather than nation-wide blanket generalizations.

Some of the findings enumerated above will be further examined in relation to conditions in the East Asian Seas region. Some specific US examples are provided as background to the regional review.

Perhaps nowhere in the world is the saga of land loss to marine transgression more acutely felt than in the Mississippi delta. It has been reported that the rate of wetland loss in Louisiana is 130km^2/yr (US EPA, 1987). While the underlying causes go beyond merely a relative rise in sea level, what is currently occurring there could well be taken as an analogue for other coastal lands under threat from a projected sea level rise.

Some of the factors causing subsidence on Isle Dernieres, which forms part of the barrier reach along the Mississippi Delta, include sea level rise, compaction geologic downwarping, and extraction of hydrocarbons from subsurface strata (Meyer-Arendt & Wicker, 1982). But of the 1.2m/century relative sea level rise experienced in this area (Baumann, 1980), only 10% is attributed to eustatic sea level rise (Nummedal, 1983).

More recently, a study by Britsch (1986) revealed that the four principal mechanisms that control shoreline change of Island Dernieres, namely, overwash, tidal currents, longshore drift and subsidence, have switched places in terms of dominance since 1850s, with subsidence playing an increasingly important role in modern times.

Despite the lead role assumed by the US scientific community in sea level studies, there seems to be ambivalence on the part of the public sector in factoring rise in sea level into either planning/design or regulation of coastal development. Government agencies that have shoreline jurisdiction such as the Federal Emergency Management Agency (FEMA), the California Department of Water Resources and the California Regional Water Quality Control Board have not adopted enforceable regulations or policies concerning a relative rise in sea level, largely because of the uncertainty of future sea level based on climatic warming scenarios (San francisco Bay Conservation and Development Commission, 1988). Even the US Army Corps of Engineers are adopting a wait-and-see attitude as far as incorporating the effect of accelerating sea level rise in their planning/design is concerned (Converse, 1987).

On the other hand, the San Francisco Bay Conservation and Development Commission is taking positive steps to address accelerated sea level rise by effecting amendments to the Bay Plan. Likewise the California Coastal Commission "staff has proposed to the Commission that it considers sponsoring legislation that would direct the Coastal Commission to prepare a report on the problem of sea level rise and the implications for the planning and regulation of the California Coast" (San Francisco Bay Conservation and Development Commission, 1988).

The Netherlands

In August 1986, a workshop organized by the Delft Hydraulics Institute developed a concept which establishes linkages among scenario variables, impact area characteristics and response strategies, for impact assessment studies related to sea level rise. The concept, which is entitled "Impact of Sea Level Rise on Society" (ISOS), was applied to the Dutch coast in four distinguishable segments (intertidal, urban / industrial, agricultural and environmental). By assuming certain damage functions resulting from coastal flooding and saline intrusion, various damage reduction measures (investments) were assessed vis-a-vis monetary losses. The basic concept is now further expanded with the signing of the Memorandum of Understanding between the United Nations Environment Programme (UNEP) and the Netherlands the hope that this will lead to realistic policy options to cope with the problem of sea level rise (Delft Hydraulics Institute, 1988).

In a general discourse on the impacts of sea level rise , Delft Hydraulics Institute (1988) has made specific references to the Southeast Asian region. As mentioned also in other reports, the coastal areas that will first bear the full brunt of the impacts are low-lying coastal plains. Increased overtopping of existing sea defence and coastal flood protection systems, enhanced storm-surge frequency and augmented saline intrusion are perceived as critical problem areas.

Beach nourishment is viewed increasingly as an appropriate replacement for traditional coastal protection measures involving hard solutions. Developed countries can well afford a relatively wider choice of response options in maintaining on-going shoreline processes, since they are justified by the intensively-developed nature of the coastal zone. In contrast, a policy of adaptation of social and economic patterns is likely to prevail in developing countries, Southeast Asian nations (with the possible exceptions of Singapore and Brunei) included. Shifts in land use and economic functions envisaged for developing countries include partial replacement of agricultural by aquacultural activities, increasing abandonment of paddy cultivation due to heightened salinity and diminished freshwater irrigation supply, and reduced mangrove acreage due to its failure to continue reaward colonization. The shores of the Gulf of Thailand are singled out as an area vulnerable to the impacts of a relative sea level rise.

Other UNEP-Sponsored Studies

The United Nations Environment Programme is recognized as a pre-eminent international organization that supports climatic change impact studies in developing countries. Geographical coverage of such studies to date include the Mediterranean Sea, the Caribbean, South East Pacific, South Pacific, East Asian Seas (under which this report is prepared) and South Asian regions. Preliminary findings from one such study conducted for the Nile Delta (UNEP, 1988a) indicate that other than accentuating problems of local coastal erosion, it is considered that "a sea level rise of 10-20cm in the next 2-3 decades (similar to the stated scenario in this report) would be of little consequence generally". This is despite the fact that the lower Nile Delta contains large areas that are under 1m elevation with parts below the present sea level. The saving grace is felt to be the continuous diking system that separates the cultivated lands from the sea. Thus, "the impact of sea level rise will be mainly on the financial resources to carry out protection (redeployments, and especially headlands, lagoon outlets), adjustments to harbour infrastructures." A higher sea level rise scenario (30-50cm) would generate more serious effects, necessitating the need for extensive protection measures. The Nile Delta report finally states that "present territorial planning that involves population and natural resources and covers time spans of 2-3 decades, will have to take the longer-term climatic changes into account".

A similar UNEP-sponsored study conducted for Northern Tunisia (UNEP, 1988b) arrived at a similar conclusion, i.e., "the sea level rise, acting on its own, is not likely to have a significant impact on either the Lake of Bizerte or Garaet El Ichkeul" (northern shore of Tunisia), under similar sea level rise scenario as adopted for the Nile Delta study. Under the adopted modest sea level rise scenario, it is felt that the planned development (dam construction) in the river catchment will result in the same deleterious impacts with or without the accompaniment of the projected sea level rise.

Other countries

At least one coastal hazard management plan in New Zealand (at Hokitika) has explicitly included projected long-term erosion and coastal flooding resulting from an anticipated rise in sea level in delineating various coastal risk zones for management purposes (Gibb, 1987). Similarly, Kuo (1986) recommends that engineers around the world take "future sea level into consideration ... to avoid designing a system that may become prematurely obsolete".

Some useful findings with interesting observations and practical recommendations came from the Conference on **the Effect of Ozone modifications and Climatic Change**, which among other things, examined the effects of the rise of sea level (Vol. 4, Bruun, 1987). While Goemans (1986) has estimated that the cost of raising the Dutch dikes for a one-metre rise in sea level is less than 0.05% of their Gross National Product for a single year and hence concludes that there is no need to anticipate such a rise because they could keep up with the projected rise, he is perturbed by the two-metre rise scenario due to the inherent inertia of the government machinery, which demands long response time. Nevertheless, he senses a positive development in that the Dutch engineering experience accumulated over a long period of constant territorial battles waged against the sea could be readily marketable.

At the other extreme, a picture of gloom was painted for Bangladesh. It is estimated that 12 to 28% of its total area, which currently houses 9 to 27% of its population would be lost to the sea (Bruun, 1987). Futhermore, floods could penetrate further inland repeating the widespread devastation sustained in the early 1970s.

Concluding remarks

From the experiences in other countries as discussed above, it is clear that the impacts of sea level rise are site-specific, and any attempt at generalization could yield erroneous predictions. At least two studies have indicated that the stated rise in sea level of 20 cm by the year 2025 is unlikely to bring about significant changes to shoreline response, given the heavy developmental stresses on river catchments or marked land subsidence. There is a strong plea to include consideration of sea level rise in coastal planning, and an equally strong conviction that such changes can be accommodated without the need to institute drastic modifications to prevailing management patterns, at least for the initial phase of the accelerated rising trend, say up to the year 2030.

THE RELATIONSHIP BETWEEN SEA LEVEL RISE AND COASTAL EROSION

Causes of coastal erosion

The sea attained its present level as a sequel to the world-wide Holocene marine transgression, the sea level rise that began about 18,000 years ago, when the cold global climates of the Pleistocene ice age started to become warmer. It is important to realize that the existing world coastline has been shaped largely within the last 6,000-year period, with the sea at, or close to, its present level in relation to the land. During the various periods of lower sea level in the Pleistocene Era, there was deep weathering of the exposed continental shelf which generated large quantities of sediment. Subsequently, when sea level rose, this material was reworked in the transgressing shore zone and redeposited as an extensive plain of coastal accumulations.

Based on the analysis of a large amount of data collected from over 200 correspondents representing 127 coastal countries, on the nature, extent, and history of coastline changes, Bird (1985) reported that erosion has been more extensive than deposition around the world's coastline in recent decades, especially on low-lying sandy coasts. A number of factors have contributed to the preponderance of erosion episodes in modern times. He also pointed out that in our present state of knowledge of the world's coastline, any attempt to derive globally valid generalizations from research on any one section of coastline is hazardous.

Coastal erosion from anthropogenic causes has long been recognized as a critical problem afflicting a large proportion of coastal countries. Similarly, natural coastal hazards such as storms, typhoons, and tsunamis have left their indelible marks in the memories of coastal inhabitants and tell-tale scars on the surface of the earth. On the other hand, coastal erosion induced by a rise in sea level is much less understood, a situation not helped at all by the gradual, but insidious, translation of the sea level rise to physical shoreline retreat.

Thus, one of the most important and yet least obvious agents of shoreline erosion is the slowly rising level of the sea (United Nations, 1982). While individual estimates vary, some researchers agree that over the past 14,000 to 18,000 years, the sea has risen about 100 m. While the average long-term rise worked out to be about 6mm/year, this rate of rise has been decreasing. For one year the seemingly small rise would not pose a hazard, but on a sustained basis stretching over a longer time span, the cumulative effect can bring about widespread coastal erosion.

Physical Impacts of Sea Level Rise

While a sea level rise can lead to inundation of previously subaerial coastal lands, the resulting damage can never match that caused by catastrophic tidal waves and storm induced flooding with its attendant loss of life and physical destruction such as have devastated unprotected coastal lowlands of Bangladesh. The accelerated rise in sea level will result in a proportionate increase in the magnitude, frequency and extent of these hazards, particularly flooding.

A rise in sea level leads to direct submergence of low-lying coastal lands and loss of coastal lands due to increased wave erosion impacting previously subaerial sediments exposed by relative land subsidence. While the former is a hydrostatic effect, the latter is the translation of increased wave energy to sediment deficit. The effect is further accentuated if there is a concurrent land subsidence, which could be attributed to a variety of causes. Naturally, the land could undergo tectonic submergence, which is a large-scale downward geologic displacement caused by sedimentary loading and associated settlement processes. On a much shorter time scale, the physical weight of the overlying stratum, subsurface withdrawals for oils, gas and groundwater, dewatering due to lowering of water table by drainage and the resultant biochemical oxidation, soil shrinkage, wind erosion, and even marsh burning of the dewatered upper soils also contribute to the lowering of the land surface, which translates into a relative rise in sea level through consolidation and compaction.

Assessment and Prediction Methodologies

The Bruun Rule

The rate of shore retreat caused by sea level rise can be computed using the Bruun Rule, which states that "for a shore profile in equilibrium, as sea level rises, beach erosion takes place in order to provide sediments to the nearshore so that the nearshore seabed can be elevated in direct proportion to the rise in sea level" (Bruun, 1962).

Bruun (1962) has developed a mathematical relationship between relative sea level rise and shoreline recession based on a consideration of sediment balance between erosion and deposition:

$$\text{Shoreline recession} = \frac{(a) \times (b)}{(h + d)} \qquad (1)$$

where a = relative change in sea level

b = distance from shore to 18-m depth contour which represents the limit between nearshore and deep sea littoral drift phenomena

h = dune height

d = (depth) beyond which little sediment turbulence takes place (Meyer-Arendt & Wicker, 1982).

The value of 18m (which represents the limit between nearshore and deep sea littoral phenomena) was determined by Bruun (1962) by averaging data obtained using the Atlantic, Pacific and Gulf coasts. This expression has been employed by Britsch (1986) in the study on the migration of Isle Dernieres mentioned earlier.

More recently, Bruun (1983) determined a more general but practical approximation of shoreline movement to be:

$$\text{shoreline movement} = \frac{(l) \times (a)}{h}$$

where l = length of profile of exchange

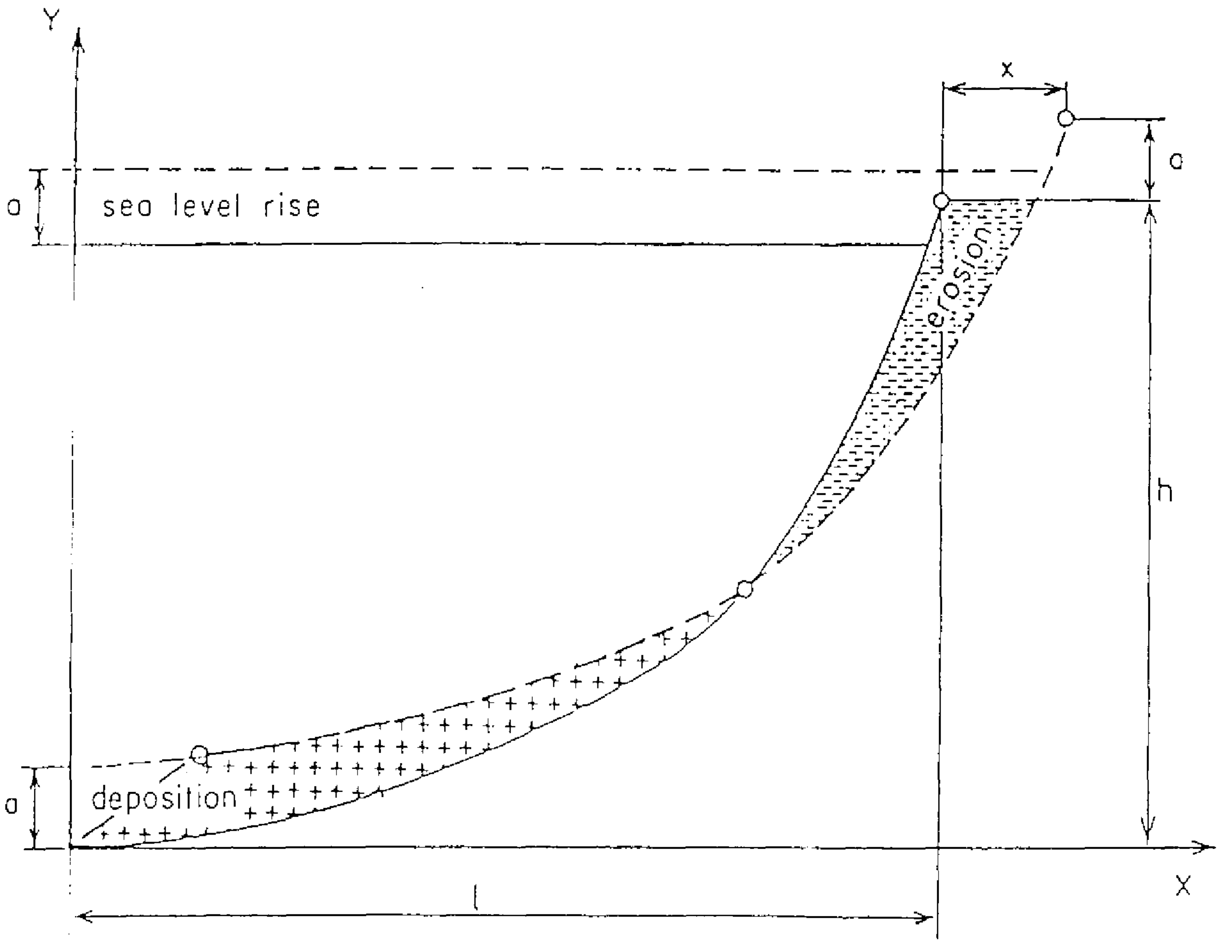
a = rate of sea level rise

h = maximum depth of exchange (closure depth) between nearshore and offshore sediments

Gibb (1987) has used the above expression, which is represented graphically in Fig. 6.1, in formulating a coastal erosion management plan for Hokitika, New Zealand in which he chose to consider two scenarios of sea level rise, namely, 0.6m (1986- 2025) and 1.5m (1986-2100). The planning he adopted encompass the useful life of coastal facilities and allow both for the occurrence of short-term episodic erosion-accretion cycles and for the averaging out of long-term sea-level trends and fluctuations in sediment supply. Thus, he explicitly ties the enforcement of construction setbacks to site susceptibility and vulnerability to coastal erosion.

In his case, h and l are difficult to determine because no off shore data are available. Instead, a theoretical procedure based on the use of wave and sediment parameters is used to calculate the closure depth (Hallermeier, 1981a; 1981b), which yields a value of 11m at an offshore distance of 850 m for Hokitika. h is then the depth contour referenced to Mean Sea Level plus the average height of the present-day foredune above MSL.

Figure 6.1 Bruun's effect of the translation of the beach profile during sea level rise (after Gibb, 1987).



Limitations of Bruun Rule

The Bruun Rule is a simplification of what transpires at the land-sea interface and has been criticized in the literature (Dean, 1987). Assumptions include an "equilibrium profile", that the shoreline is in longshore quantitative equilibrium, and consequently the material for deposition necessarily comes from the "corresponding shore area by movement of material by transversal (rip) currents", and that the phase difference between the rise of sea level and its influence on erosion is relatively small.

Dean (1987) noted the absence of trailing ramps of slope along three shore profiles along the Florida coast, which would have existed if the active portion of the profile moves upward and landward in response to sea level rise as predicted by the Bruun Rule. In reality, most surf / beach processes are three-dimensional in nature, and the Bruun Rule is two-dimensional in concept (Wiegel, 1989).

In a published response to Dean's reservations, Schwartz (1989) reiterates the inherent assumptions in Bruun's approach as explicitly stated Bruun (1962). Elsewhere, Everts (1985) found that a key assumption in Bruun's approach that the shoreface is in dynamic equilibrium with the sea surface is reasonably accurate.

There is no denying that, the above relationship linking sea level changes to the advance and retreat of shorelines omits other potentially significant factors, especially cross-shore and longshore movements of sediments. But it remains the only practical way of yielding a rapid, semi-quantitative assessment of shore response to a rise in sea level. As Hands (1977) so eloquently put it, "Bruun's concept is straightforward and intuitively appealing".

Based on the approach of sediment balance, the Bruun Rule is deemed appropriate to sandy coastlines where the concept of sediment budget is eminently applicable. The same cannot be said for mud coasts. It is recognized that there is a basic difference between the dominant processes involved in wave-sand and wave-mud coast interaction. This fundamental difference precludes the direct application of basic concepts concerning coastal processes on sandy coastlines to coastal margins comprising fine-grained cohesive sediments. Without venturing any quantitative relationship, Bruun (1962) did cite "the possibility of much higher recessions in marsh and other low shore areas" in the event of a sea level rise.

Midun & Lee (1989a) describe three possible mechanisms for mud coast erosion in Malaysia: underwater migration of mud waves, demise of mangroves, and wave-induced scouring due to lower intrinsic mud strength in sea-water. They conclude that even though research efforts in cohesive sediment dynamics, especially in developed countries, have picked up in response to the need for wetland protection and expansion into marginal areas, a better understanding of the mechanics of mud coast erosion is unlikely to emerge in the immediate future. This is especially so in developing countries such as Malaysia.

Appropriate responses

In the Conference on **the Effects of Ozone Modification and Climate Change**, Bruun (1986) also espouses the use of large scale profile nourishment by which the entire active shore profile from the dune down to the level of "active movement of material in the profile" (erosion) is nourished simultaneously, as against the conventional beach nourishment with subsequent wave-induced profile adjustment. Noting that shoreface adjustments are necessary to maintain an equilibrium profile, Everts (1985) views sand replenishment as "probably the most realistic method to stabilize a shore against the effects of relative sea level rise". Weggel (1986) went one step further in proposing beach nourishment in combination with terminal structures in order to increase residence time of the sand on the beach as the cost of suitable beach sand increases.

Similarly, Broadus et al. (1986) conclude that the vulnerability of Bangladesh to a rise in sea level will depend in large measure on whether future water projects disrupt land-creating sediment washing down the Ganges. This is in concurrence with the view of Titus et al. (1984) that "sedimentation can offset the impact of sea level rise". They write that "if sea level rises slowly enough for sedimentation and peat formation to keep pace, the marsh can maintain its position at the seaward edge and expand inland". However, they view this somewhat balanced situation as likely only for major river deltas given the accelerated rise in sea level after 2050.

On tidal wetlands, the San Francisco Bay Conservation and Development Commission (1988) study asserts that the key to understanding the effect of rising relative sea level is to know the rate of sedimentation and its spatial distribution within the Bay. If sedimentation keeps pace with relative sea level change, tidal marshes will maintain equilibrium. Similarly, the options considered for curtailing coastal erosion in Louisiana's coastal wetlands include marsh building and restoration (sediment replenishment), marsh management (water flow management), regulatory measures, and diversion of water (US EPA, 1987).

The Relative Significance of Sea Level Rise in Causing Erosion

It has been reported that of the about 20% of the world's sandy coastline that is backed by beach ridges, dunes, or other sandy depositional terrain, more than 70% have exhibited net erosion over the same time period. In attempting to offer plausible explanations for the predominance of beach erosion, Bird (1985) expressed doubt on whether the small historic rate of sea level rise is sufficient to account for the prevalence in beach erosion, given that it occurs at different times in different places. The dynamic shift in the relative importance of factors contributing to beach erosion has prompted him to suggest that "explanations of erosion should be presented in terms of a ranking of these factors for each coastal sector". But in the light of the recent evidence on the acelerating rise of sea level, its effect could well overwhelm the other causes cited such as human intervention and increased storminess.

On the other hand, Gibb's (1987) computations indicate that the rate of shore retreat due to sea level rise ranges from 0.50m/yr (0.6m rise) to 0.75m/yr (1.5m rise), which far surpasses the historic rate of erosion (0.02mm/yr) and completely overwhelms the historic accreting rates in some places. Similarly, Everts (1985) found that sea level rise accounts for about 53% of the total shore retreat of 5.5m/year measured at Smith Island, Virginia, and for about 88% of the measured 1.7m/yr retreat of the barrier island south of Oregon Inlet, North Carolina.

On mud coasts, the episodes of erosion are more readily attributed to a rise in sea level, augmented by land subsidence (Bird, 1985).

Positive Impacts of Sea Level Rise

In fairness, it has to be recognized that some ameliorating or at least moderating effects do result from a global rise in sea level. In Hong Kong, it has been reported that the physical reduction of the water area within Victoria Harbour due to reclamation has reduced the tidal flushing and augmented pollution due to sewage discharge. The rise in sea level is likely to increase the action of tidal flushing due to a corresponding increase in the tidal prism, which in the process ameliorates pollution build-up. The increased water depth also facilitates navigation, and possibly reduces maintenance dredging requirements.

Nonetheless in comparison, it is evident that the negative impacts of a global sea level rise far outstrips the advantages that it might bring. For example, in port development, the rise could necessitate raising the elevations of quay walls and expansion areas for port operations.

THE RELATIONSHIP BETWEEN SEA LEVEL RISE AND SALINE INTRUSION

Past Studies

A rise in sea level also increases the salinity of estuaries, which may threaten drinking water and both freshwater and brackish aquatic ecosystems. The increased saline intrusion may reach existing pumping stations and wreak havoc on the pumping installations. This is possible if the rate of sediment deposition is less than the rate of sea level rise, in which case the river remains partly drowned, i.e., the base of the river channel remains below the sea level for large distances inland. The basic mechanism at work is that higher density salt water intrudes into the estuary helped by high tides, but this is balanced by the average seaward freshwater flow velocity. Coastal aquifers recharged from rivers may also be contaminated.

For fewer studies have been devoted to investigating the effect of sea level rise on the movement of saline wedges in rivers and the contamination of coastal aquifers than have been concerned with coastal erosion. In one of the few studies which was conducted for the Delaware Estuary, it is estimated that a 73cm rise in sea level would send the salt front 11km further up river while a 250cm rise would push the salt front another 27km upstream (Hull & Titus, 1986). The projected increased salinity concentration would render the existing water intake dysfunctional during a greater part of the tidal cycle, especially in times of drought. Similarly, coastal aquifers that are recharged from rivers would be contaminated by increased salinity. But the study also pointed out that planned reservoirs with adequate maintenance flow releases could offset salinity increases. At the same time, possible shifts in precipitation resulting from the greenhouse warming could also overwhelm salinity increases induced by sea level rise.

In San Francisco Bay, increased saline intrusion is viewed as the most significant biological problem in wetlands management (San Francisco Bay Conservation and Development Commission, 1988). Again the preferred countermeasure is increased freshwater supply, which, coupled with the concomitant costs for raising and reinforcing coastal dikes, may be expensive to implement.

Assessment and Prediction Methodologies

Compared to the Bruun Rule used for predicting the rate of shoreline retreat induced by sea level rise, the available methodology for evaluating saline intrusion is more theoretically rigorous, but at the same time, it is also much more mathematically involved. Apart from the usual continuity and momentum equations commonly used in open channel hydraulics to determine the time-dependent water surface elevation and the time-varying velocity field, a salt balance equation is introduced to map the salinity field. The later equation, which expresses conservation of salt, usually takes the form of a diffusion equation (Hull & Titus, 1986):

$$\frac{d(A_t s)}{dt} + \frac{d(Qs)}{dx} = (A_t E)\frac{ds}{dx} \qquad (3)$$

where
- d = partial differentiation operator (del)
- A_t = cross-sectional area
- s = cross-sectionally averaged salinity
- t = time
- Q = cross-sectional discharge
- x = longitudinal distance
- E = longitudinal dispersion coefficient

The above one dimensional salt balance equation is obtained from spatially integrating the three-dimensional convective-diffusion equation for turbulent flow. The longitudinal dispersion coefficient is a necessary product of cross-sectional averaging and incorporates also the turbulent and molecular diffusions and tidal effects. The factors that influence the longitudinal dispersion coefficient are manifold and so are its parameterized formulations. It is not very far from the truth to state that a universal predictive formula for the longitudinal dispersion coefficient does not exist (Coles, 1979).

From the above cursory examination, it can be seen that while saline intrusion essentially depends on the relative magnitudes of the driving force (tidal propagation and density difference between salt and freshwater) and the restraining force (river flow velocity) its assessment demands substantial input information. Such necessary information includes:

a) Topography and geometry of river channel

- depth and distance of river bed relative to sea level
- cross section area
- hydraulic properties
- roughness

b) Tidal influence

- tidal range
- tidal propagation (distance and magnitude of tidal effects)

c) Low flows

- magnitude and duration of low flow velocities

Correlation/regression techniques might also be attempted to "model" salt movement. However, not much work has been concentrated on this method and it is expected that predicted results may be dubious. The main attraction of these techniques is that they generally do not have to be based on physical and chemical laws. Instead, they can be based on response functions that are judged to apply over the range of previous experience. Thus, they may not be appropriate for determining the effect of scenarios that lie outside the zone of validity.

A semi-empirical approach to computing the longitudinal dispersion coefficient as developed by Sanmuganathan & Abernethy (1975) where the relevant source code is available from Coles (1979) for adaptation will be used in the present study in cases where the relevant data are available.

Appropriate responses

The penetration of sea water as a "salt wedge" along the bottom of a river channel is severely restricted during periods of heavy river discharge and it may be completely pushed back to sea. Thus, salinity increase could be offset by scheduled releases of water from upstream reservoirs. On the other hand, adapting to increased salinity is seen as another appropriate response to the problem. Potential measures include physically shifting pumping intakes to upstream locations (which also means closer to the sources of pollution), relocating water-dependent industries to locations where fresh water is available, modified pumping pattern (selected pumping during periods of low salinity), water conservation measures, and preventing rivers from recharging aquifers using physical barriers, extraction barriers, freshwater injection barriers and increased recharge from sources other than the estuary.

IMPACTS OF SEA LEVEL RISE ON ASEAN COUNTRIES

Physical Setting

"The coastal regions of the large proportion of developing countries that border on oceans and seas include many of those countries' major population centers. In fact, well over 50% of the world's people live either at the coasts or at adjacent coastal lowland areas. Coastal lands and waters also comprise substantial quantities of the nations' agricultural, mineral, and living resources, so that coastal degradation problems such as erosion, decreased water quality, and the destruction of living resources are issues of major concern."

The above quotation from the summary report entitled "Coastal Resource Development and Management Needs of Developing Countries", which was prepared by the National Research Council, USA (1982), is an eminent reflection of the developmental stresses impinging on the coastal zone of the littoral states comprising the Association of Southeast Asian Nations (ASEAN). More so because the need for development in ASEAN countries is an urgent priority.

The ASEAN countries are located between the Asian and the Australian continents, and bounded by the Indian and the Pacific Oceans on the west and east respectively as shown in Fig. 6.2. While Thailand and Peninsular Malaysia are part of the Asian land mass, the others are islands (about 20,000 of them) that form archipelagoes and span the length and width of Southeast Asian waters. These waters, which cover 8.95 million km^2 and represent 2.5% of the world's ocean surface, comprise the Andaman Sea, the Straits of Malacca, the Straits of Singapore, the South China Sea, the Java Sea, the Flores Sea, the Banda Sea, the Arafura Sea, the Timor Sea, the Celebes Sea, the Sulu Sea and the Philippine Sea in generally west-to-east direction.

Table 6.1 lists the main physical characteristics of each of the ASEAN countries. Indonesia has both a land area and coastline that are larger than the combined totals of the other ASEAN countries. Together with Singapore and the Philippines, it also has one of the highest coastline to land area ratio due to its archipelagic formation. In terms of developed coastline per capita, none can match that of Singapore where the entire coastline is more or less developed.

Table 6.1. Physical Characteristics of ASEAN Countries

Country	Population (x 10^6)	Area (km^2)	Length of Coastline (km)
Brunei	0.2	5,776	161
Indonesia	168.4	1,906,240	80,791[1]
Malaysia	15.8	332,556	4,809[2]
Philippines	58.1	300,440	22,540
Singapore	2.6	621[3]	281[4]
Thailand	55.0	512,820	3,219
Total	300.1	3,058,453	111,832

(Sources: Samson (1983) except where updated below)
1 (Soegiarto & Polunin, 1980)
2 (Economic Planning Unit, Malaysia, 1985)
3,4 (Chia *et al.*, 1988)

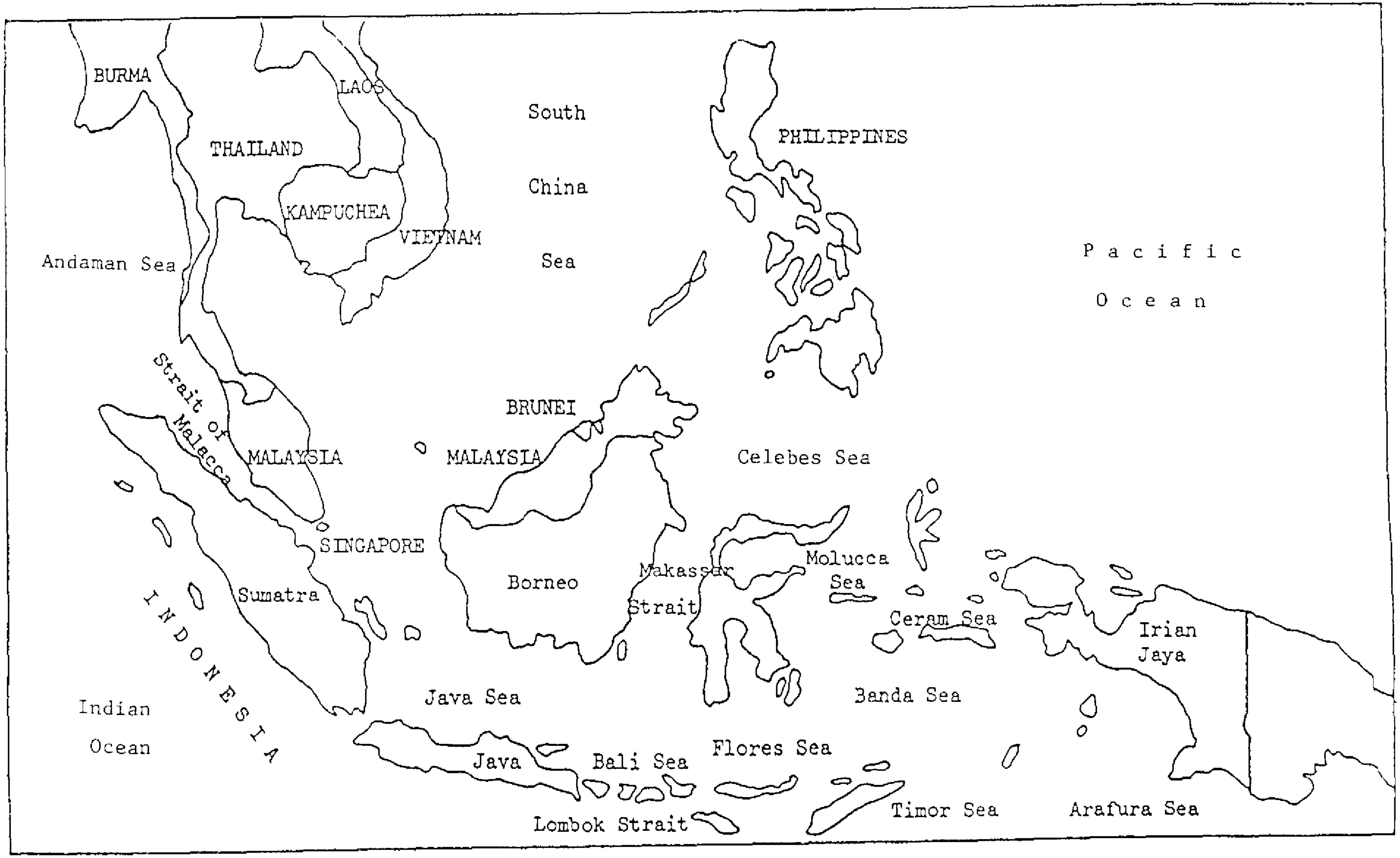


Figure 6.2 Location of ASEAN countries

Asean countries are littoral states, with populous cities dotting the coastal areas. Thus, a majority of the roughly 300 million inhabitants in the region (more than 70%) are coastal dwellers. As these nations approach the dawning of the 21st Century, it is likely that the coastal zone will be more intensely developed to cater for residential, commercial, industrial, port/harbour, and recreation facilities necessitated by the projected population increase.

Such intensive use of the coastal zone is evidenced by the fact that few segments of natural coastline remain in Singapore while in the larger countries, modification of coasts is most pronounced at population centers. In Indonesia, the official government "transmigration" programme, to relocate people from crowded areas in Java, Madura and Bali to less populous regions, places major emphasis upon reclaiming tidal swamp areas for agricultural resettlement (Burbridge, 1988). In Sumatra, there are plans to expand the area of fish ponds in Acheh and North Sumatra by a further 78,000 hectares, and it is likely that a majority of these ponds will be located in areas converted from mangrove (Burbridge, 1988). In Malaysia, there are proposals to allocate a further 20-25% of the remaining 113,348 hectares of mangrove in Peninsular Malaysia to aquaculture (Snedaker, 1984).

Evidence of Sea Level Change

Evidence of climatic change in ASEAN countries is scarce due to a paucity of historical information and monitoring efforts. Where such information exists, the results are at variance. For example, analysis of tide gauge records at North Point, Hong Kong for the period 1977 - 1985 indicates no obvious trend (Gomez et al., 1988). A similar conclusion has also been reached regarding the movement of Mean Sea Level at Cebu, Philippines, where 80 years of tide gauge data are available. A similar effort at analyzing sea level change based on Mean Sea Level data generated over a 41-year period from 29 stations in the Gulf of Thailand concluded that no trend is readily recognized, though the data exhibit various fluctuations (Gomez et al., 1988).

But an increasing trend is discerned in the records for Manila and Davao, which evinces a rising rate of 20mm/yr (1965 - 1985) and 5mm/yr (30 years) respectively (Gomez et al., 1988). These variations are largely attributed to land subsidence caused by human activities such as coastal reclamation and excessive groundwater withdrawal. A slight rise is also noted in three tidal stations in the vicinity of Bangkok where subsidence is marked due to heavy groundwater abstraction (Gomez et al., 1988).

In Malaysia, long-term continuous recording of tidal elevations with a view to establishing the mean sea level for a complete tidal epoch (18.6 years) only commenced in 1984. While the record length may be too short for prediction purposes, comparison with earlier records may yield some identifiable trend in the level of the contiguous seas, if there is any.

Coastal Erosion

An examination of the problems of environmental degradation afflicting the six pilot sites studied under the ASEAN-US Coastal Resources Management Project reveals that only in the site in Malaysia (South Johor) and to a lesser extent, that in Brunei Darussalam, is the problem of coastal erosion explicitly stated as such (Chua et al., 1987; Chua & Agulto, 1987). Similarly, Malaysia is also the only ASEAN country where the problem of coastal erosion has been studied on a country-wide scale and a national coastal erosion plan formulated. While this is not to be construed as indicating the lack of such concern in other ASEAN countries, it does indicate that at least the problem of coastal erosion has not been perceived by the governments concerned as reaching a crisis situation and hence, requiring a conscious effort on a national scale towards its mitigation. The following account of the shoreline conditions and vulnerability to coastal erosion in the ASEAN countries is largely based on the work of Bird (1985), unless otherwise stated and except for Malaysia which is based on a completed comprehensive coastal erosion study (Economic Planning Unit, Malaysia, 1985).

Indonesia

The coastline of Indonesia is generally steep, with little or no basal cliffing which indicates slow shoreline change. But changes in deltaic coasts are rapid, usually prompted by upstream channel capture and the consequent cessation of fluvial sediment supply. Progradation is especially evident along the northeast coast of Sumatra. The effect of vulcanicity is local, a notable example is the island of Krakatau, which has been completely reshaped by the 1883 eruption. But the resulting tsunami caused shoreline erosion on the western part of Java. Bird & Ongkosongo, 1981 report that erosion of agricultural lands is causing a great deal of concern.

Thailand

The Thai coast fronting the Andaman Sea consists of island fringed steep coast with embayments and beach frontage south from the Burmese border to Phangnga Bay, and thereafter extensive mangrove forests as far as Satun. While the cliffed coast and embayed beaches show slight erosion in recent decades, the mangrove-fringed coast has prograded in some places.

On the eastern side, beaches predominate along the shores of the Gulf of Siam, broken only by minor rocky promontories and river inlets. Shore advance has occurred along many sectors as evidenced by the continuous growth of sand spits and the series of successive shore-parallel beach ridges. Shoreline retreat is primarily a local phenomenon, e.g., along pocket beaches hemmed in between rocky headlands. Elsewhere mangroves are advancing on sheltered bay shores.

The deltaic coastline at the head of the Gulf of Thailand is prograding at about 5m annually; sand bars are built up by wave action about 1.5km offshore to form a sheltered environment in which fluvial silt and clay settle, and as this land is formed it is reclaimed for agricultural uses. Moreover, the heavy fluvial load also causes estuarine shoaling. Land subsidence and severe flooding on the Bangkok plain are also the result of excessive groundwater withdrawal and heavy load of sediment of the Chao Phraya River (Siripong, 1988).

Singapore

The coast of Singapore Island has been greatly modified by humans in the past 20 years, obliterating much of the previous shoreforms such as cliffs and mangroves in the process. Except along parts of the sheltered coast fronting the Straits of Johore, there has been a conscious effort to expand the land boundary seaward all round, often protected on the new seaward margin by artificial means such as revetments, seawalls and breakwaters.

The coast here is characterized by accumulation rather than erosion. This net depositional environment is made possible by the presence of low wave and tidal energy conditions (Swan, 1971) resulting from the surrounding land masses.

Philippines

The Philippine islands are generally hilly with steep coasts, and plains. The active volcanoes have supplied beach building sediments either directly or through fluvial sediment transport to river mouths. Certain stretches of the coastline have also been modified by earthquake-induced landslides on steep coasts. Mangroves flourish on sheltered inlets and embayments, and generally constitute a depositional environment. Large scale conversion to fish ponds is prevalent along mangrove coastline with widespread embanking. Overall there is a preponderance of progradation, with marine erosion and shore retreat confined to cliffed shores.

Several regions within Southeast Asia are vulnerable to the impact of tropical cyclones. The greatest probability of occurrence exists for the Northern Philippines, and decreases in the southerly direction. Only a few of the typhoons in any one year directly affect South China and the Gulf of Thailand. No typhoon occurs south of about 5°N latitude (Siripong, 1988). Natural hazards such as volcanic eruptions, storm surges and tidal waves have caused profound impacts on coastal areas in the Philippines.

Malaysia

Malaysia is comprised of two regions, Peninsular Malaysia and the States of Sarawak and Sabah (collectively referred to as East Malaysia) on the northern coast of the Borneo Island. These regions are separated by 640km of South China Sea.

Peninsular Malaysia abuts the South China Sea on the east and fringes the Straits of Malacca on the west. The South China Sea is the largest expanse of water facing the Malaysian coast, including East Malaysia, while the Straits of Malacca is a narrow waterway separating the peninsula from the island of Sumatra, Indonesia. Geographically, the South China Sea allows an unobstructed passage for over-water wind movement with a fetch distance ranging from 360km in the north to 1,240km in the south. In contrast, the average fetch distance over the Straits of Malacca is only 130km.

Physiographically, the coastline of Malaysia is of varied character and configuration. The 860km east coast of Peninsular Malaysia consists of a straight sandy shore in the north whilst the southern half is comprised of a series of large and small hook- or spiral-shaped bays. On the other hand, the west coast, which is 1,100km long, is made up of low elevation coastal plains formed from a deep marine clay stratum. Very few areas of sandy beach are found here and where they occur are in the form of pocket beaches hemmed in between rocky headlands.

The 1,800km coastline of Sabah is characterized by rugged formations, sheltered by numerous offshore islands and coral reefs, and many bays of a variety of sizes and shapes. The coast is evenly divided between sandy beaches and mud coast, which dominate the north-eastern and south-eastern parts of the coastline respectively. The dominance of the same two physical formations is also apparent in the 1,040km coastline of Sarawak. In this case, a long straight sandy shoreline is found on the eastern half with a mangrove fringed coast on the western half.

The coastline of Malaysia consists of two widely different physical formations: the mangrove- and nipah-fringed mudflats, and the sandy beaches. The principal soil type of the mud coast is marine clay. Thus, coastal processes on the east and west coasts of Peninsular Malaysia are governed by two distinctly different mechanisms as alluded to in earlier sections. As far as coastal erosion is concerned, the west coast, which is anchored by dense mangrove swamps and sheltered by Sumatra Island, has little in common with the east coast. While the mechanism of coastal erosion along mud coasts is less well understood, the mud coasts are also those that are extensively reclaimed and developed for agriculture.

The National Coastal Erosion Study (Economic Planning Unit, Malaysia, 1985) reveals that of the 4,809km of shoreline in Malaysia, about 1,300km (27%) are presently subject to erosion of varying degrees of severity. Based on the consideration of the rate and imminence of erosion, and the economic values of the human activities threatened, coastal erosion sites have been classified into the following three categories:

(i) 145km of critical erosion areas where shore-based facilities are in imminent danger (Category 1);

(ii) 246km of significant erosion areas where the facilities are expected to be endangered within 5 to 10 years if no remedial action is taken (Category 2); and

(iii) 975km of acceptable erosion areas that are generally undeveloped with consequent minor economic loss if coastal erosion continues unabated (Category 3).

The spatial distribution of the eroding areas is shown in Table 6.2. Of the 47 critically eroding sites, agriculture features as the dominant human activity (in 19 of the sites), followed by housing (15), transportation (8) and recreation (5). This may not be surprising considering the fact that the majority of the land use in the coastal area is agriculture-related as indicated in Table 6.3.

Since January 1987, the Government has adopted a two-pronged strategy for coastal erosion control. The immediate objective is to protect existing facilities and properties in the Category 1 eroding areas, subject to the test of economic viability. Hence, this immediate goal is construction-focused and reactive in posture. On the other hand, due consideration is given to the consequences of coastal erosion in coastal planning, development and construction though a coordinated and integrated development strategy constitutes the long-range objective of the coastal erosion control plan. This long-term goal is management-focused, and aims to obviate the need for expensive protective works in future. Hence, it is proactive in posture.

Table 6.2. Spatial Distribution of Eroding Coastline of Malaysia

Area	Total length of coastline (km)	Category 1 (km)	Category 2 (km)	Category 3 (km)	Total (km)	Length of Eroding (%)
Peninsula	1,972	131 (41)	213 (57)	651 (58)	995 (156)	73
Sabah	1,802	6 (3)	10 (7)	310 (14)	326 (24)	24
Sarawak	1,035	8 (3)	23 (11)	14 (7)	45 (21)	3
Total	4,809	145 (47)	246 (75)	975 (79)	1,366 (201)	100

Note: The figures in parentheses refer to the number of sites.

Table 6.3. Summary of Land Use in the Coastal Area of Malaysia

Land Use	Peninsular Malaysia	East Malaysia	Total for Malaysia
	(percent of length of coastline)		
Agriculture	49	47	48
Housing & Transportation	22	9	14
Recreation	5	1	2
Undeveloped (1)	24	43	36
Mangrove-fringed	40	61	52

(1) Includes forests reserves where forest management and harvesting are practiced.

The pattern of shoreline behaviour of west-facing mangrove-fringed mud coast alternates between erosion and accretion in the same way as along the north coast of Java, Indonesia. Thus, prograding and regressing environments are found side-by-side. The rate of shoreline retreat can reach as much as 100m a year along the west coast of Penang Island.

Over 90% of the east coast of Malaysia shows evidence of the Holocene progradation described in earlier sections, but within the past century only a small part has continued to advance. Accordingly, this coast, facing the South China Sea, is one where, despite a substantial fluvial sediment yield, the trend from the earlier progradation to more recent retreat of sandy coastline is clearly discernible (Teh, 1985). The pattern of deltaic change is similar to that in other places discussed earlier, i.e., deltaic contraction where there is diminution of fluvial sediment supply either due to stream capture or dam construction, and progradation where increased watershed activities bring about increased sediment yield. Numerous river inlets are seasonally closed due to imbalance between longshore and hydraulic forcing. Most of the coastal erosion occurring here can be attributed to improper siting of shore structures and a general straightening of the shoreline due to longshore gradients in littoral drift.

Occurrence of Extreme Events

Since coastal erosion is governed largely by episodic events, the occurrence of extreme events becomes an important parameter in the overall assessment. The treatment so far has been confined to gradual morphological response over a long time span as befitting the concept of equilibrium profile. Increased frequency of extreme meteorological events may disrupt the gradual post-storm recovery such that the rate of shoreline recession may be way above that predicted from sediment redistributed resulting from a projected sea level rise.

For the ASEAN region, a parallel study conducted by the Malaysian Meteorological Service (1989) on greenhouse-induced climate change reveals that over the Pacific rim of the ASEAN region, the wind speed is projected to increase by 20% for the months of March to May and September to November while the corresponding effect on storm tracks is not known. On the other hand, the study also reveals that the surface pressure pattern, which may indicate enhanced typhoon systems if accentuated pressure troughs were to occur due to greenhouse-induced global warming, "does not seem to show corresponding significant changes." The study, concludes, therefore, that "there is not enough evidence to conclude that the typhoon activity increases or decreases in the region after the greenhouse warming." However, the recent occurrence of typhoons (Elsie & Gray), which slashed across northern Philippines and Southern Thailand may serve as grim reminders of the possibility of such a change.

Concluding Remarks

In general, the modern pattern of coastline change is related to the proximity of fluvial sediment sources. However, previous phases of coastal advances occurred during the Holocene Marine Transgression when the rising sea swept weathered, wave-worked sand landward to form beach ridges, and during a succeeding emergence which results in the construction of further sequences of beach ridges seaward of those formed previously.

Generally, the so-called mud or swamp coasts fringing Southeast Asian waters exist as a consequence of the low wave energy environment. This is aided by the sediment trapping coastal vegetation, principally mangroves. The sheltering effect of the surrounding land mass ensures a constant wind passage that is fetch-limited and relatively independent of the rise in sea level. Unless the wind pattern is drastically changed, it is unlikely that the incident wave energy will differ substantially from the present pattern.

On the other hand, the mangrove-fringed mud coasts are facing unprecedented development pressure for conversion to other economic pursuits. In such coastal development, the coastal area is invariably embanked with nominal dyking on the seaward edge to prevent or control saltwater ingression. The nominal dyking was made possible by the protective barrier of the seaward mangrove strip.

In its natural state, most salt-tolerant coastal vegetation such as mangroves would gradually moves landward following a zonation pattern based on the salinity gradient in response to a sea level rise. Unfortunately, the presence of coastal development, which more or less anchors the landward edge of mangroves, has deprived the mangroves of this latitude in colonization. In the event of a rising sea level, it is highly probable that the mangrove buffer may vanish altogether, which would then expose the hitherto protected coastal development to sea attack.

The episodes of erosion that ensue could also be unrelated to a global sea level rise. In any event, the exposed earth dykes are armoured with rock surface in order to protect the investments already poured in. This continuous line of hard defence can be seen along the northwest, central, and southwest coastline of Peninsular Malaysia. Except for the northwest area, the breaking wave condition used for design is approaching the deepwater wind waves. Consequently, even though a rise in sea level could theoretically result in larger nearshore waves based on wave breaking criteria, in reality the resultant increase in nearshore wave height, if there is any, tends to be insignificant.

Thus, the main concern is likely to be whether the dyke height is adequate to prevent wave overtopping. For a modest rise in sea level, the near-term impact could be either catered for by the normal freeboard and the conservatism inherent in the extreme events adopted for design; or easily incorporated into routine maintenance in dyke raising, usually carried out to compensate for anticipated settlement of the underlying soft stratum. Geotechnical stability then becomes the overriding criterion since any topside weight increases the driving force for rotational slip. Provided the dyke raising is completed in increments, such tendency for slip development could conceivably be arrested by flattening the seaward slope or incorporating a stability berm on the seaward toe. Such an incremental technique in responding to a gradual sea level rise has been successfully employed in the Netherlands.

Along the more exposed sandy beaches, both aggravated coastal erosion and increased wave overtopping are likely. Again shoreward migration of beach profile through overwash deposition is restrained by coastal development on the landward side. Thus, the width of the protective beach will likely reduce. Along developed coasts, the natural sand dune formation which affords protection against wave overtopping and provides a reservoir of sand for littoral transport, suffers little natural blowout. Instead, it is artificially flattened or removed thus subjecting the coast to wave overtopping. In subsequent sections, computation of shore retreat based on the Bruun Rule will be carried out at selected eroding sites to assess the magnitude of the shore retreat induced by a sea level in relation to the historical rates.

Saline Intrusion

The distribution of salinity in Southeast Asian waters is extremely variable. The high rainfall and run-off cause the low surface salinity in this area. Generally, it is high in winter (33.29ppt) and lowest in autumn (32.65ppt). For horizontal surface distribution, it is low near the Equator and higher at higher latitudes. The yearly average is 33.03ppt (Siripong, 1988).

In Thailand, dam construction across the upper reaches of the rivers of Chao Phraya and Mae Klong for hydroelectric power generation and irrigation supply for rice cultivation has allowed further penetration of saline water inland. The owners of shrimp farms and fruit orchards on the deltaic areas of the major rivers of the Upper Gulf of Thailand have bad experiences from the penetration of the salt water wedges nearly every year. This augmented saline intrusion has not only damaged orchards on both sides of the rivers, but also contaminated artesian wells (Gomez et al, 1988).

A potential solution is suggested by the observation that the Mae Klong residents seem to suffer from intrusion effects much more than the Chao Phraya residents due to the greater discharge of the latter river. Consequently, judicious manipulation of the hydrologic cycle by releasing larger flows at specific times from regulating reservoirs could offset some of the deleterious impacts brought about by a rise in sea level.

Singapore currently imports more than half of its water from Johore in Peninsular Malysia. The prospects of obtaining groundwater is bleak due to unfavourable geologic formations. Historically, the marine sands on the outlying islands provided an important source of freshwater, but it was reported to be affected by intrusion during the drier periods of the year (Chia et al., 1988). In general, the problem of saline intrusion does not seem to be significant for Singapore.

In Malaysia, an appreciable part of the water supply to coastal cities comes from river pumping. In coastal settlements far away from viable reservoir supply, direct pumping from rivers or wells constitutes the primary and sometimes the only source of water supply. Under the Malaysia Rural Water Supply Project, a source evaluation is being conducted for all the States and where viable, infrastructure work is being constructed. For example, in Sarawak, the concentration is on locating local sources in order to serve the rural communities that line the coastal belt. In this respect, salinity surveys have been conducted in order to develop a relationship between distance from the river mouth and antecedent river discharge for a particular salt concentration. Such information is useful for calibrating predictive models used in assessing salinity variations under different scenarios of drought occurrence and even sea level rise.

In Sarawak, the maximum tidal range is approximately 4-5m in the western part of the state and approximately 2m in the eastern part of Sarawak. In general, saline intrusion regularly penetrates 2/3 of the length of the tidal estuary in the western part of the state and 1/2 the tidal length in the eastern part of the state.

Sea Level Rise Impacts

As mentioned earlier, the impacts of sea level rise are necessarily site-specific. But a general impact assessment based on a physiographic classification of coasts is deemed capable of indicating the relative significance of the above impacts, thereby enabling judicious scrutiny of a reduced geographical coverage. Thus, those coasts that are judged to be appreciably insensitive to the impacts of sea level rise would have to be omitted due to time constraints.

Cliffed Coasts

The rates of erosion on cliffed coasts are dependent on a host of intrinsic (rock structure, geologic structure) and extrinsic factors (dimensions of fronting beach, shore profile, surface run-off, incident wave energy, and degree of modification). Generally the rate of shore/cliff retreat along such coasts is small.

Deltaic Coasts

Deltaic coasts are typically depositional environments where accretion is the norm. In tropical deltas, evidence of deltaic progradation up to 180m/yr has been reported in Indonesia (Verstappen, 1966). Such progradation is highly dependent on deposition from river floods where the deltaic deposits slowly fan out seaward. When fluvial sediment supply is diverted, as occurred in the Kelantan delta in Malaysia, the accreting coast retrogresses.

Mud / Swampy Coasts

Another depositional environment is the low energy sheltered coast where the shore advances by the seaward spread of sediment trapping mangroves. A more than casual relationship between coastal bunding and mangrove recession has been observed along the southwest coast of Johore, Malaysia (Drainage and Irrigation Department, Malaysia, 1988). As far as the stability of fluvial sediment-maintained coast is concerned, the only seemingly beneficial human intervention in upland areas is perhaps such catchment activities as deforestation, over-grazing and cultivation of steep lands, which increase fluvial sediment supply to the coasts. Notable examples are the Jakarta Bay and Segara Anakan Lagoon, Java, Indonesia.

Beaches and Spits

Sandy beaches are more amenable to sediment budget analysis than are mud coasts. Some results of computation using the Bruun Rule for certain stretches of sandy coasts in Malaysia are presented below, primarily because the relevant field data are readily available.

CASE STUDIES

Coastal Erosion

Two eroding shores along the northeast coast of Peninsular Malaysia where feasibility-level-studies have been completed (Economic Planning Unit, Malaysia, 1986) are selected for illustrative purposes. They are the coastline immediately south of the river mouth of Trengganu River in the State of Trengganu, and further north, the Beach of Passionate Love, which is located on the southern lobe of the Kelantan River Delta as shown in fig. 2.6.3. Both sites are significantly influenced by fluvial sediment supply from the Trengganu and Kelantan River respectively.

Based on Equation (2) above, the tabulated results are as shown in Table 6.4, where the same notations are used. In the computation, a two metre height of the beachcrest, above the Mean Sea Level has been added to the depth of closure. Three scenarios have been used -- a rise of 20cm by the year 2025 (A), and a rise of 1 m by the years 2090 (B) and 2050 (C) -- reflecting three possible rates of sea level rise. It can be seen from the last column that the rate of shore retreat induced by the stated rate of sea level rise is less than 10% of the historical rate of shore retreat in both cases for a rise of 20cm by the year 2025 (Scenario A). This despite the fact that the historical rate of retreat has probably slowed down due to the intense coastal development which has already taken place in recent years, and which restricts further shoreward retreat. Equally obvious is the result that the rate of sea level rise-induced coastal erosion is highly dependent on the rate of sea level rise itself. Both Scenarios B and C show increases of 100% and 200% respectively in the rate of sea level rise-induced erosion over that of Scenario A.

Table 6.4 Computation of the rates of shore retreat induced by sea level rise.

Name of reach	x (m/yr)	a (m/yr)	h (m)	l (m)	s = (l) (a) / h (m/yr)	% = s / (x) + (s) x 100
Terengganu A	4	0.0057	7	450	0.37	8%
B	4	0.0100	7	450	0.64	14%
C	4	0.0170	7	450	1.09	21%
Kelantan A	7	0.0057	6.5	460	0.40	5%
B	7	0.0100	6.5	460	0.70	10%
C	7	0.0170	6.5	460	1.20	15%

Notes : x - Historical rate of shoreline retreat based on time-separated shoreline analysis for the past 30 years or so.

a - rate of sea level rise
= 200 mm/(2025 - 1990) for Scenario A,
= 1,000 mm/(1090 - 1990) for Scenario B,
= 1,000 mm/(2050 - 1990) for Scenario C.

h - maximum closure depth based on analysis of shore-normal profiles.

l - length of profile change based on average offshore profile.

s - rate of shoreline retreat induced by sea level rise.

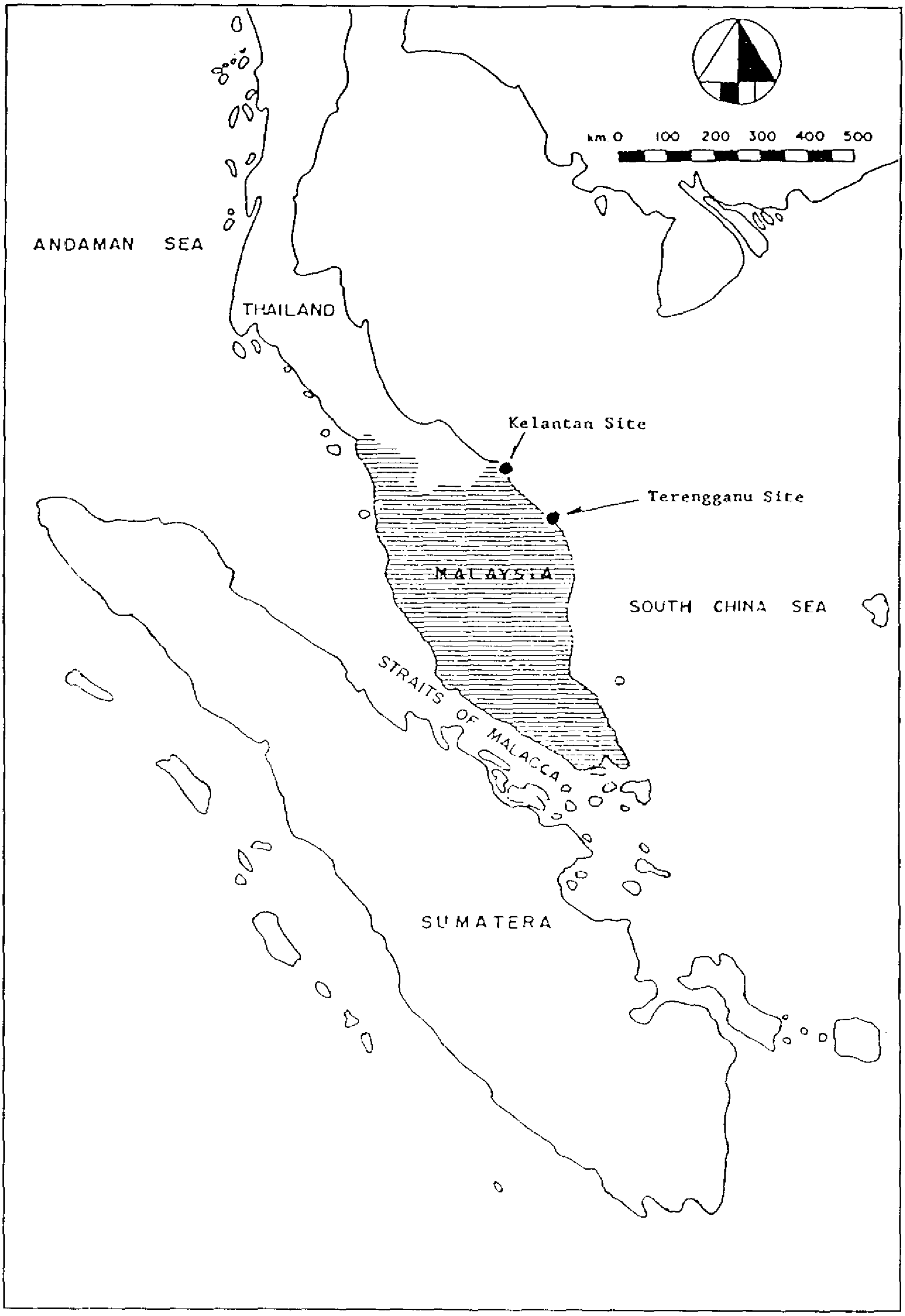


Figure 6.3 Location map for eroding sites in Malaysia

Another point to bear in mind is that tha rate of sea level rise is unlikely to be linear, but is more likely to be that of a letter "S" that is stretched out laterally. The rate of rise is small initially, which could be due to the inertia of the ocean body in responding to thermal excitation, and picks up sharply thereafter. The tapering towards the end of the sea level rise curve at a higher plateau has not been forecasted in any of the results of climate modelling efforts, perhaps because the time frame of such an eventual state is beyond the model durations. However, it can be contended that such an eventuality is not improbable, judging by changes in past millenia. For the moment, our interest lies on the first half of the curve. Thus, in the foreseeable future, it is probable that the rate of sea level rise is likely to accelerate and so is the rate of sea-induced coastal erosion.

It should be borne in mind that most of the input parameters contain inherent uncertainty as a lot of engineering judgement has to be exercised in estimating their values. For example, the representative base of the shoreface (the concave upward part of the inner continental shelf) has to be determined from a set of shore-normal profiles. The shore face is generally considered the active part of the inner continental shelf, despite the fact that extreme waves can set fine-grained sands in motion over much of the continental shelf. Additionally, both the eroding reaches suffer from a longshore sediment deficit of the order of 100,000m^3/year. This longshore sediment imbalance in itself has already violated a key assumption in the Bruun Rule. In addition, a pre-existing equilibrium profile, another key assumption of the Bruun Rule, is not and cannot be present on an eroding coast.

There is no denying that the Bruun Rule omits other potentially significant factors, such as the cross-shore and longshore movements of sediments. But it remains the only practical way of yielding a rapid, semi-quantitative assessment of shore response to a rise in sea level. An alternative that has been suggested is akin to the concept of transposition applied in hydrological studies where available recorded hydrological data are transposed to ungauged but hydrologically and physiographically similar sites. In this case, the likely shore response under an increased water depth and hence, intensified wave action, of a particular site can be projected from another site that is induced or otherwise. Although this suggestion has technical merits, it remains to be tested in the field where diversity in geology, shore material, wave climate, and anthropogenic influences are the rule rather than the exception.

With mounting awareness of environmental conservation, it can be reasonably predicted that human intervention which disrupts coastal processes, be it in the catchment, the coast or offshore areas, will diminish. Compounded with the non-linear rate of the rise of sea level mentioned earlier, it may be expected that the contribution of sea level rise to inducing coastal erosion along Malaysian coasts will assume greater importance in the future.

The exclusion of mud coast areas from the above analysis using the Bruun Rule is deliberate, for the reasons discussed above.

Midun & Lee (1989a) describe three possible mechanisms for mud coast erosion in Malaysia: underwater migration of mud waves, demise of mangroves, and wave-induced scouring due to lower intrinsic strength of mud in sea-water. They conclude that even though research efforts in cohesive sediment dynamics, especially in developed countries, have picked up in response to the need for wetland protection and expansion into marginal areas, a better understanding of the mechanics of mud coast erosion is unlikely to emerge in the immediate future. This is especially so in developing countries such as Malaysia.

From the above discussion, it can be generalized that the high risk areas are those with low coastal relief, erodible substrate, extensive shoreline retreat, and high wave energy. The first three characteristics are typical of the mangrove-fringed mud coast while the last two are the norms along sandy coast. Watershed development also has a strong bearing on the stability of east coast Peninsular Malaysia, especially around river mouths. It has been suggested that the impacts of a sea level rise may be contained if shore progradation from fluvially supplied sediments can keep up with the rising sea. The direct relationship between upstream sediment diminution due to dam construction and coastal instability is all too well known. The primary reason for the recent spate of coastal erosion on the coastline south of the Kelantan River mouth (where the Beach of Passionate Love is located) can be traced back to the capture of the old river course that originally discharged to the South China Sea south of the Beach of Passionate Love prior to 1926. This short-circuiting deprived the Beach of Passionate Love of the northerly moving littoral sediment supply. More recently, the ebb-tidal delta at the Trengganu River mouth is also showing signs of disintegration subsequent to the completion of a dam upstream. The reduction of sediment input has profound influences on beaches that are fed by river-borne sediments as well as urban deltas, which hitherto afforded wave protection by tripping early wave breaking further offshore, may allow the full brunt of wave action to be expended right on the shore.

Despite the foregoing reservations, the impacts of sea level rise in aggravating erosion in currently eroding areas, at least in the two areas examined above, are likely to be minimal and dwarfed by other factors currently operating such as reduction in sediment supply due to human activities.

Saline Intrusion

As mentioned in previous sections, assessing the impact of sea level rise on saline intrusion requires substantial information and mathematical modelling effort. Acquiring site specific information has proved difficult, even in Malaysia, largely due to a dearth of relevant information. What is presented below is taken from the national assessment of the implication of greenhouse-induced sea level rise for Malaysia (Midun & Lee, 1989b).

The Government of Malaysia aims to provide its population with an adequate and safe water supply. In line with the noble target as declared when the decade 1980 - 1990 was designated the UN Drinking Water Supply and Sanitation Decade, plans are afoot to expand and increase water supply facilities to meet the growing demands of rapidly growing urban centres and increase water supply coverage to the rural areas. Table 6.5 shows the present water supply coverage for Malaysia.

Table 6.5. Overall water supply coverage (%)

Location	Urban Centers	Rural Areas	Overall
Peninsular Malaysia*	94	65	77.5
Sarawak**	n.a.	~30	50
Sabah**	n.a.	~30	52

(Source : Ibrahim, 1987)
Notes: * 1986 data; ** 1985 data; n.a. not available.

Areas not yet served with public water supply still depend on natural sources such as streams and wells for their daily needs. Also, an appreciable part of the water supply to coastal cities comes from river pumping. In coastal settlements far away from viable reservoir supply, direct pumping from rivers or wells constitute the primary and sometimes the only source of water supply.

In siting water intakes for potable water supply, salinity consideration usually precludes the choice of unsuitable sites and tidal reaches are avoided. In larger schemes, salinity surveys are usually conducted to develop a relationship between distance from the river mouth and antecedent river discharge for a particular salt concentration. Such information is used in calibrating predictive models for assessing the salinity variation under different scenarios of drought occurrence. However, the tidal elevation control is rarely varied to investigate the implication of augmented tidal forcing, and hence further penetration of salt wedges upstream, that may result from a rise in sea level.

At present, there are few reported cases of saline water being pumped by river intakes. Two known cases, both occasioned by the occurrence of severe droughts, have been dealt with through structural means. The first one, which occurred at the Kuantan River on the east coast of Peninsular Malaysia, has been overcome through the construction of a downstream barrage. The second one occurred at Kg. Panchor intake along the Muar River flowing into the Straits of Malacca and has been prevented by periodic releases from an upstream reservoir.

The present trend is toward the use of impounding reservoirs as the most easily developed surface water sources. It is fortuitous that such a move pre-empts the threat of contamination posed by a rising sea level. In addition, the projected increase in precipitation will generally offset some, if not all, of the effects of augmented saline intrusion caused by a projected rise in sea level.

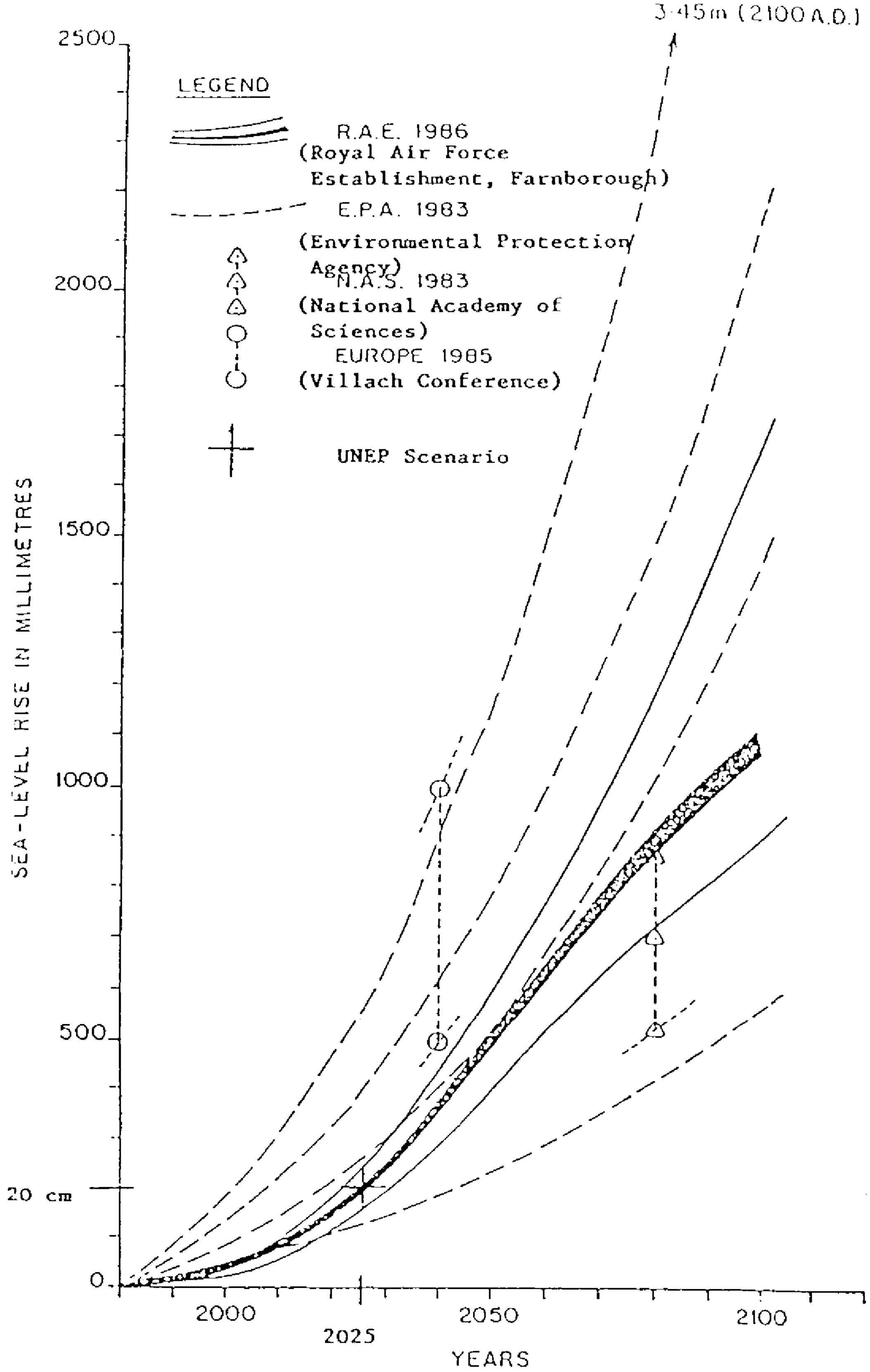
Streams or rivers with or without impounding reservoirs contribute about 97% of the raw water supply sources in Malaysia while underground water, which accounts for the remaining 3% is not widely used due to its limited availability (Ibrahim, 1987). Currently the use of underground water is mainly confined to the states of Kelantan and Perlis. There are isolated cases of saline intrusion into pumping wells due to overpumping. Hence, the intrusion of sea water into freshwater aquifers due to excessive pumpage is likely to occur before the anticipated effects of a sea level are realized. At any rate, a 3% contribution does pale in the scheme of things.

The above less-than-critical picture painted for Malaysia may not reflect the situation in other ASEAN countries, notably around Bangkok, Thailand. However, it can be reasonably concluded that the projected rise in sea level will aggravate the existing problem of saline contamination wherever it occurs.

Comments on the Choice of the Stated Scenario of Change

Preliminary findings indicate that the impacts of a 20cm rise in sea level by the year 2025 are likely to be insignificant in comparison with other factors operating in the coastal environment. But the results may be different if the impacts due to a higher magnitude of sea level rise were to be examined. In this respect, it may be worthwhile to present the stated scenario in comparison with a spectrum of forecasts put forth by various researchers. Fig. 6.4 does just that. As indicated, the stated scenario of a 20cm rise by the year 2025 is at about the mid-range scenario of the predictions by both Royal Air Force Establishment, Farnborough and the National Academy of Sciences, but still lower than or at the lower end of the predictions by the Europe Conference at Villach and US EPA respectively. In fact, as discussed

Figure 6.4 Sea level rise predictions for the next century (1986-2100 AD) (after Gibb, 1987).



in the previous sections, some of the current rates of relative sea level rise are already equal to, if not exceeding, the stated scenario of rise. This would help to put the results of the current task into perspective lest the "optimistic" predictions are accepted with complacency.

RESEARCH NEEDS / FUTURE WORK

Our understanding of coastal processes, especially along mud coasts, is still too inadequate to permit quantification of the likely shore response in the event of a projected rise in sea level. Apart from this fundamental deficiency, there is also the problem of aggregating discrete impacts in order to yield an overall assessment. Furthermore, the fragmentary nature of available data requires an inordinately long time for collation. Over and above this are the forecasting problems associated with large-scale climatic modelling.

It should be borne in mind that the impacts examined above relate to physical impacts. Other potential impacts of a sea level rise on fishery resources, other coastal ecosystems such as corals, seagrass and even port and shipping industries may also be significant. Additionally, the role of extreme events, which can cause episodic but catastrophic damage, has not been examined. It is possible that increased storm surges may ensue and result in greater devastation.

As alluded to in the previous sections, further refinement of physical impacts and economic implications can only be achieved by zeroing on representative sites. The regional assessment has revealed particularly high risk areas that are most worthy of attention. It is expected that future work will concentrate on those manageable sites where the scope of study can be expanded to include policy exercises. It is hoped that questions on institutional mechanisms, funding allocation and public participation can be explored through these policy exercises.

CONCLUSIONS

The report has examined the implications of a 20cm rise in sea level on the East Asian Seas region in two areas: coastal erosion and saline intrusion. Based on a rough approach and the use of Bruun's Rule, it is suggested that coastal erosion ranks as the more severe consequence, with further aggravation of existing problems of coastal erosion. Coastal areas that are low-lying, of erodible substrate and presently display extensive erosion are most vulnerable to the threats posed by a projected rise in sea level. Preliminary findings indicate that the impacts of a 20cm rise in sea level by the year 2025 are likely to be insignificant in comparison to other factors operating in the coastal environment. But the results may be different if the impacts due to a higher magnitude of sea level rise were to be examined. It is possible that increased storm surges may ensue and result in greater devastation.

On saltwater intrusion, a general assessment in the case of Malaysia indicates that the situation may only worsen locally due to the present trend toward the use of impounding reservoirs since the more easily developed surface water sources have been developed. This less-than-critical picture painted for Malaysia may not reflect the situations in other ASEAN countries, notably around Bangkok, Thailand. However, it can be reasonably concluded that the projected rise in sea level will aggravate the existing problem of saline contamination wherever it happens.

Notwithstanding the above discussion, it is contended that the long lead time required to transform policy into reality does not permit a wait-and-see attitude as regards addressing the implications of sea level rise. Careful planning for future events is a prudent move. We should begin to find ways to incorporate the concern engendered by a rise in sea level into development and land use planning.

Admittedly our understanding of the mechanics of air-land-ocean interaction and mud coast processes still leaves much to be desired. However, this deficiency does not preclude adoption of a proactive posture in parallel with on-going research aimed at improving our basic knowledge regarding climate change impacts. We should provide information based on logical projections, and alert the decision-makers of the likely consequences in a rational manner so that informed decisions can be made.

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7. IMPLICATIONS OF EXPECTED CLIMATIC CHANGES ON NATURAL COASTAL ECOSYSTEMS IN THE EAST ASIAN SEAS REGION

H.T. Yap

Marine Science Institute
University of the Philippines
Diliman, Quezon City, Philippines

INTRODUCTION

The present report consists essentially of two aspects: published or otherwise available information on the distribution of important natural coastal ecosystems of the East Asian Seas, and scientific "guesses" as to the possible effects on these resources of the expected climatic changes. The projections are based on what is currently known of the biology and ecology of natural ecosystems, and the results of experiments dealing with the specific environmental factors which would be directly operative in the event of significant climate change.

An integration of the different resource and activity maps should yield a composite picture of areas and activities that would be vulnerable to the combined effects of sea level rise, temperature elevation and increased intensity of rainfall, as well as the nature and extent of impact. Specific projected responses are outlined in the different sections. Only the major natural ecosystems are considered in this report.

In general, effects are outlined for a whole community or ecosystem. It should, however, be borne in mind that all associated organisms would be affected. Thus, the destruction of coral reef, sea grass or mangrove habitats would also mean the disruption of associated fisheries.

The assumptions for global climate change in this paper are those stipulated by UNEP for the Task Team, having been drawn from the International Conference in Villach on 9-15 October 1985. These are a temperature elevation on a global scale of 1.5°C and a sea level rise of 20cm by the year 2025. Additional data confirm observations of a steady increase in ambient temperatures over the past years (Strong, 1989).

The phenomenon of simultaneous land subsidence in certain localities should also be taken into account. This results in an even higher relative rise in sea level locally. Examples of affected areas are Manila and Bangkok.

Of all the shallow-water or coastal ecosystems in the tropics, coral reefs have received the most attention in the scientific literature with respect to the possible effects of global climatic change. In particular, the consequences of a rise in sea level have been examined in detail because this has implications for the actual continued existence or survival of these habitats. It should be emphasized, though, that most of the speculation on reef response to sea level rise is based on retrospective analyses of ancient reefs, or how reef growth has been affected by sea level fluctuations over geologic time.

Relatively few investigations have as yet been conducted on the possible fate of the other coastal ecosystems. However, it still seems realistic to draw conclusions based on existing knowledge of ecological trends.

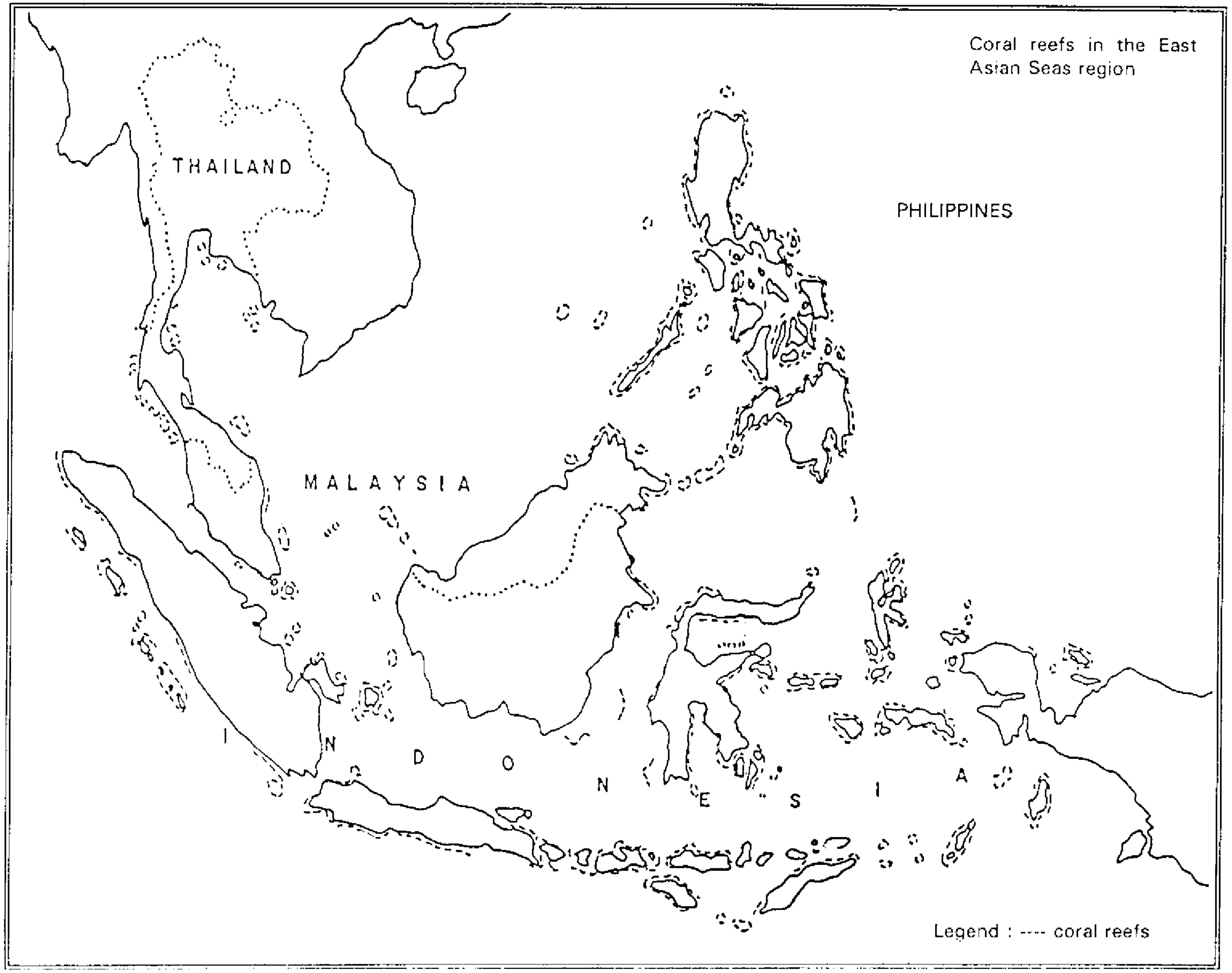


Figure 7.1 Distribution of coral reefs in the East Asian Seas region (after Gomez 1980c).

CORAL REEFS

The distribution of coral reefs in Southeast Asia is shown in Fig. 7.1. As a rule they are of the fringing type, being directly adjacent to land masses. The zone of active coral growth is generally separated from the land by a more or less extensive, shallow reef flat averaging 1m in depth, though it could be as much as 6m deep in some localities.

The reef flat, being relatively shallow, is subject to more stressful factors than are the deeper zones of the reef. These factors include more intense light, higher temperatures and greater water turbulence. As a result, the abundance of corals is less, and those species that do occur are of types more resilient to environmental stress.

The average depth limit of Southeast Asian fringing reefs is considered to be 20m, although isolated coral patches or heads may be found in deeper waters. It is not easy to separate the factors responsible for this lower boundary. They include light penetration, water turbulence, sediment load and substrate. Species that exist at the lower depth limits of fringing reefs are adapted to the corresponding levels of these environmental factors so that deep-water coral associations are consequently different from shallow-water facies.

Effects of sea level rise

The value adopted from the Villach report yields a rate in sea level rise of 5mm/yr. This is less than the value believed to have characterized Holocene sea level rise, which varied from 10 to 6mm/yr over time (Kinsey & Davies, 1979), and much less than the predicted rate of 15mm/yr accepted by many coral reef researchers as probably occurring over the next century (Buddemeier & Smith, 1988; Hopley & Kinsey, 1988).

Present knowledge of reef dynamics indicates that modern coral reefs will be able to cope with a rise in sea level of 5mm/yr. Estimates of calcium carbonate production and deposition (Smith & Kinsey, 1976; Hopley & Kinsey, 1988) aid in the determination of vertical accretion rates in reefs. Recent approximations of the latter range from 0.4 to 7mm/yr (Hopley & Kinsey, 1988). These values are based on calcium carbonate deposition rates of various reef substrate types, with 100% hard coral or algal zones having a maximum postulated production of 10kg $CaCO_3/m^2/yr$, and sand and rubble having the lowest at 0.5kg $CaCO_3/m^2/yr$.

In other words, given their metabolic potential, present day reefs may very well keep up with the postulated sea level rise. In fact, increases in sea level are believed to provide the necessary environmental conditions for reefs to optimize vertical structure and orientation, or to achieve a "self-determined morphology" (Kinsey & Davies, 1979).

In any case, different parts or zones of a reef will respond differently to rises in sea level. Local factors such as substrate type, nutrient levels, salinity, temperature, depth, water clarity, tides, and wave and current regimes will all exert significant influences on the responses of the affected communities (Davies et al., 1985; Buddemeier & Smith, 1988).

One example of a negative outcome would be a certain manifestation of sea level rise/topography feedback effects in the case of lagoons (Neumann & Macintyre, 1985). In instances where lagoons broaden as sea level rises, the flushing of warmer and less saline water over the reef may cause stress and possibly even mortality. Another negative impact would result if sea level rise were to increase coastal erosion which could again be detrimental to corals (Snedaker & de Sylva, 1987).

On the whole, the factors controlling the relationship between reef growth and sea level, aside from the rate of sea level rise, include antecedent topography, the aforementioned sea level rise/topography feedback, and other parameters such as the physical energy to which the reef is subjected over its growth span (Neumann & Macintyre, 1985).

The predicted rise in sea level would probably shift the zonation of reefs landward. Corals may settle and communities start to develop on the inundated coastal areas (the newly created reef flats), provided suitable substrate is available, and salinity and water quality are optimal. Very deep coral associations may perish because their environmental thresholds would be exceeded.

On the whole, the effects of a rising sea level would be first discernible where rates of vertical accretion are slowest, and where water level fluctuations are of the lowest amplitude and variability (Cubit, 1985). In this respect, present day reef flats may show the most remarkable and visible effects of a rise in sea level. This would be brought about largely through a change int he frequency and duration of subaerial exposures (Cubit, 1985).

Many reef areas in the Philippines and elsewhere in the region appear to have attained their maximum limits of growth under present conditions. Many reef parts have reached sea level so that they are subject to intense water turbulence and are frequently exposed to the atmosphere during low tide. As a result, there is extensive mortality of corals and associated organisms especially during summer, when exposure to air is aggravated by intense insolation. The regeneration of the coral veneer during more favorable times of the year probably just about offsets the loss during the more stressful periods, although it seems reasonable to postulate that, given present trends and if sea level and other climatic conditions were static, fringing reefs would erode down to levels which would once again permit net accretion.

As habitats, reef flats may therefore be considered as generally depauperate. The immediate effect of a rise in sea level would be reduced mortality from subaerial exposure, and an increase in abundance of typical reef flat organisms (Cubit, 1985). The net effect would be a rejuvenation of these habitats, especially since known optimum depths, particularly for coral growth are between 2m and 15m (Hopley & Kinsey, 1988). A possible scenario would thus be a reef growth of initially 3mm/yr, then increasing to about 7mm/yr with greater submergence and the attainment of 100% coral cover (Hopley & Kinsey, 1988).

Although perhaps not relevant given present (the Villach) assumptions, it would still be useful at this point to address the question of reef response if the rate in sea level rise were significantly grater than reef growth. A postulated rate of 15mm/yr (Buddemeier & Smith, 1988; Hopley & Kinsey, 1988) exceeds the estimated maximum potential for vertical reef accretion of 7mm/yr (Hopley & Kinsey, 1988) or even 10mm/yr (Buddemeier & Smith, 1988). Given this assumption, reef flat organisms will become reduced in abundance over the long term (Cubit, 1985). However, even at these projected rates, it would take centuries before reefs are submerged to depths (10-20m) that are limiting to productivity and net accretion (Buddemeier & Smith, 1988; Hopley & Kinsey, 1988). This entails a geological rather than a historical perspective, and within this time frame, factors other than greenhouse warming may become significant (Hopley & Kinsey, 1988).

Three basic reef growth histories have been established in the geologic record (Neumann & Macintyre, 1985). The first involves reefs that "kept up" with sea level rise. These structures were essentially located at shallow depths (<15m). The second describes reefs that "caught up" with sea level, even if they were initially situated in deeper water (>30m). The third type covers reefs that "gave up", or drowned because vertical accretion was much slower than sea level rise. Grigg & Epp (1989) have defined a "critical depth" below which coral reefs cannot maintain a positive net rate of upward accretion. This is believed to lie at 30-40m. The success or failure of coral islands thus appears to be determined by the depth of antecedent topography relative to critical depth and rate of sea level rise (Grigg & Epp, 1989).

Thus far, only natural factors governing the relation between sea level rise and reef response have been considered. Human impacts on reefs, however, certainly exert a significant influence on the nature of the latter's response to large-scale environmental forcing. More specifically, reef areas that are severely damaged will require time for the restoration of normal populations that contribute to net accretion. Such habitats may be unable to keep up with sea level rise over the short term, or may lag behind altogether.

Anthropogenic causes of reef destruction range from destructive fishing methods making use of dynamite or cyanide, to the influx of large amounts of sediment into coastal waters which render the substrate unsuitable for benthic settlement (Yap & Gomez, 1985). Possible reasons for a lag in reef initiation include lack of suitable substrates, exceedingly high nutrient levels, or the absence of larval replenishment centers (Davies et al., 1985). Human disruptions of the environment may contribute to any or all of these factors at a given site.

Effects of elevated temperatures

Even with a widely accepted estimated global temperature rise, it is very difficult to predict subsequent local ambient temperatures in Southeast Asia. It should be borne in mind, however, that water ameliorates temperature extremes, and that the range of temperatures in the air would not have be as great in the sea.

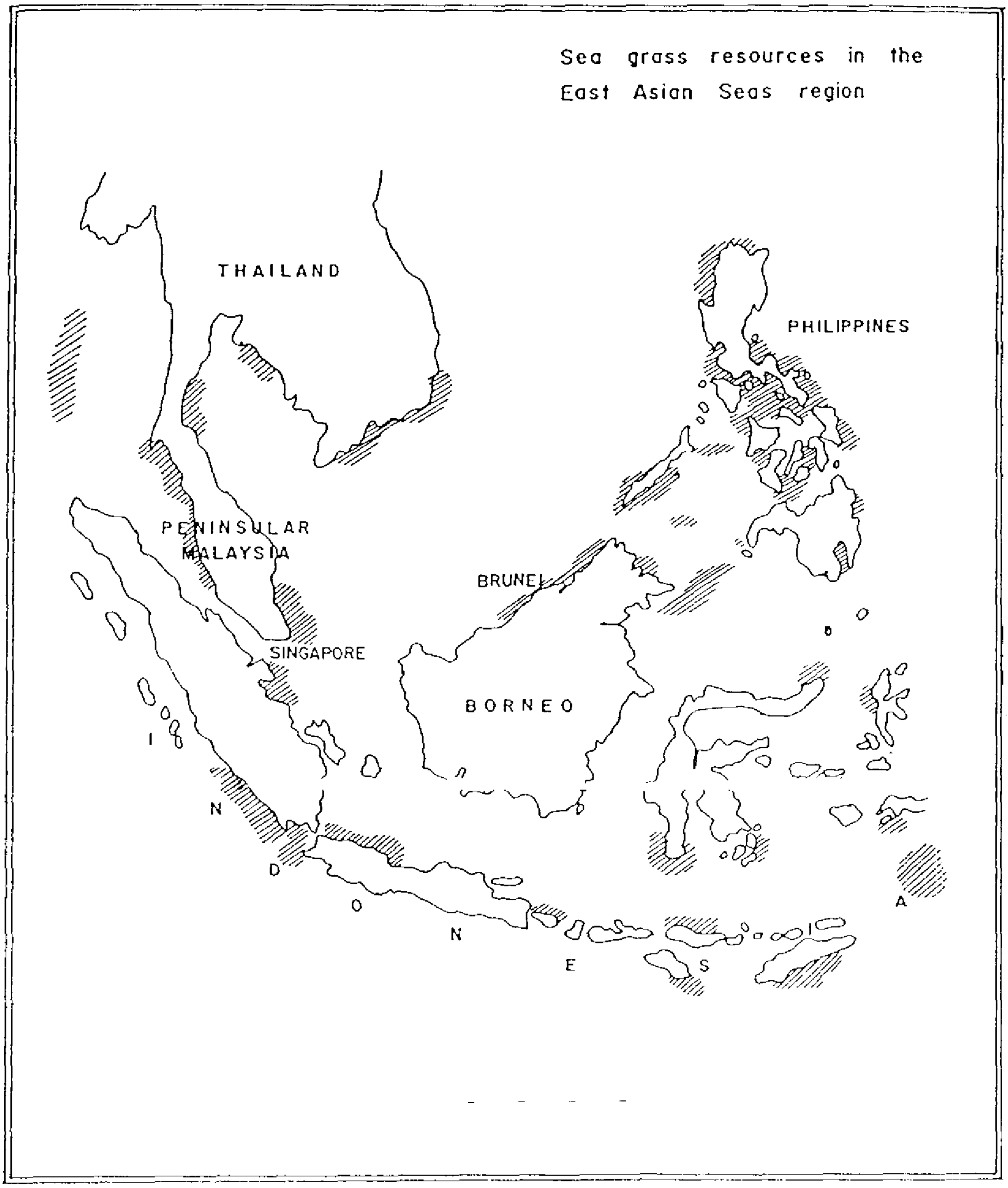
The colonization of organisms on previously dry areas which would be submerged would be significantly restricted, however, if temperatures were to rise simultaneously. Being extremely shallow, the newly created intertidal and sublittoral areas would be subject to impacts of higher temperatures.

It has been shown that tropical organisms such as corals live very close to their upper thermal limits for survival (Coles et al., 1976). Therefore, any upward shift in temperature by a few degrees may cause extensive stress and, subsequently, mortality in shallow regions (Hopley & Kinsey, 1988). Yap & Gomez (1984; 1985) observed positive correlations between temperature and mortality in several species of hard coral. Snedaker & de Sylva (1987) go so far as to postulate a poleward extension of coral reef distribution with increased global temperatures.

Effects of increased precipitation

Increased rainfall would bring about reduced salinities in the coastal areas concerned. This would be through greater freshwater runoff from the land. Coastal areas that are already wet, such as estuaries and sites of land drainage, would become wetter if affected by the new rainfall regimes. It is assumed that communities of plants and animals located in such regions of significant runoff are already adapted to large salinity fluctuations. It is therefore uncertain if a limited increase in freshwater input would have any considerable impact on such euryhaline populations.

Figure 7.2 Distribution of sea grass resources in the East Asian Seas region (courtesy of Dr. M.D. Fortes).



Extensive coral reef development generally occurs in areas situated away from any significant land runoff. Unless drastic changes in coastal topography alter patterns of land drainage, whatever reductions in surface salinity that are brought about by precipitation would be short term and relatively quickly ameliorated by oceanic mixing.

However, if reduced levels in salinity were to hold for relatively long periods, coral communities would be adversely affected. Scleractinian corals are extremely sensitive to salinity and can tolerate only a narrow range of values. Prolonged periods of low salinity would bring about some local mortality. If such episodes were recurrent in an area, existing coral communities may die off.

SEA GRASS BEDS

A map depicting relative distributions of sea grass beds in Southeast Asia is shown in Fig. 7.2. These habitats are very closely associated with land and may be abundant even above mean low water, in the intertidal zones. They are thus frequently exposed at low tide for relatively long periods during the day or night.

Effects of sea level rise

Like corals, sea grass species display zonation according to light, depth, water turbulence and substrate. Present-day distribution patterns reflect adaptations achieved over the long term to prevailing climatic and sea conditions.

As with the case of coral reefs, a rise in sea level of the projected magnitude (though local ranges are unknown) would bring about a gradual shift of sea grass occurrence landward. However, the colonization of newly submerged shore areas would occur relatively slowly. This would be contingent upon the availability of substrate suitable for the primary settlement of spores and seedling. For example, beaches are relatively depauperate of nutrients and organic matter because of active drainage between the coarse particles. A minimum of nutrient and organic carbon stores would be needed to sustain new plant growth to any extent.

Sea grasses, being photosynthetic organisms, are light-sensitive. Their distribution, especially at depth, is largely dependent o this factor. A rise in sea level, if it exceeds a critical magnitude locally, may bring about the loss of deep-water sea grass associations and shift their occurrence towards shallower parts.

In the short term, however, sea grass species which are already abundant subtidally may simply extend their distributions if sea level rises (Cubit 1985). This would be true for Thalassia testudinum, for example. A higher water level may also bring about increased wave energy which may erode or redistribute sand where this species and other psammophiles are rooted (Cubit, 1985).

Effects of elevated temperatures and increasing precipitation

Being frequently exposed at low tide, extensive beds of sea grass throughout the East Asian Seas region would be vulnerable to atmospheric phenomena such as rising air temperatures and increased rainfall.

Since Southeast Asia is situated in the tropics, sea grass beds exposed at low tide are also subject to more intense insolation. This constitutes a form of stress to which the organisms have gradually adapted. If local temperature elevations are such that environmental thresholds are exceeded, the incidence of sea grass mortality due to desiccation may increase.

Sea grasses, being marine organisms, are sensitive to salinity fluctuations. Reduced salinities for prolonged periods may have disastrous effects. This would be the case if exposure during low tide coincided with increased rainfall. Again, the crucial factor would be tolerance limits of the organisms -- whether the environmental changes still lie within or exceed these thresholds.

The above considerations would hold for sea grass associations that are located in present-day littoral or intertidal areas. If it occurred simultaneously, a rising sea level would cause less and less of these sea grass communities to be exposed, so that the harmful effects of desiccation or reduced salinities during rain would be offset. However, in this case, and as discussed in the preceding section, different factors would then operate. Less atmospheric exposure, reduced light, increased depth and different turbulence patterns would induce a gradual change in species composition to those types best adapted to the new environmental conditions.

In all cases, faunal associations would also correspondingly change. This may have implications for certain economically important fish and shrimp species.

ALGAE

The algae under consideration here are the macrophytic forms growing in intertidal or subtidal areas. Because of similar habits and ecological requirements, their responses to climatic change would be similar to those of sea grasses.

Species that have been investigated experimentally with respect to the possible effects of sea level rise are Acanthophora spicifera, Gelidiella acerosa, Laurencia papillosa, and Halimeda opuntia (Cubit, 1985). The first three species appear to be restricted to shallow habitats. A rise in sea level may increase their abundance initially, then reduce it over the long term.

H. opuntia, on the other hand, is abundant subtidally. It is believed that this species may prosper if sea levels rise, provided there is adequate stable substrate (Cubit, 1985).

MANGROVE FORESTS

The distribution of mangrove forests throughout Southeast Asia is depicted in Fig. 7.3. Mangrove trees occupy intertidal areas which are also under some freshwater influence, so that they are subject to fluctuating regimes of saltwater inundation and freshwater dilution. As a result, a distinctive zonation develops with characteristic species occupying recognizable zones from the seaward to the landward side. Each zone is characterized by definite ranges in chemical parameters. An example is shown in Fig. 7.4. Salinity is particularly critical, in determining zonation.

Theoretically, mangroves can migrate landward in response to a rising sea level (reviewed in Snedaker & de Sylva, 1987). This, however, presupposes an adequate freshwater supply.

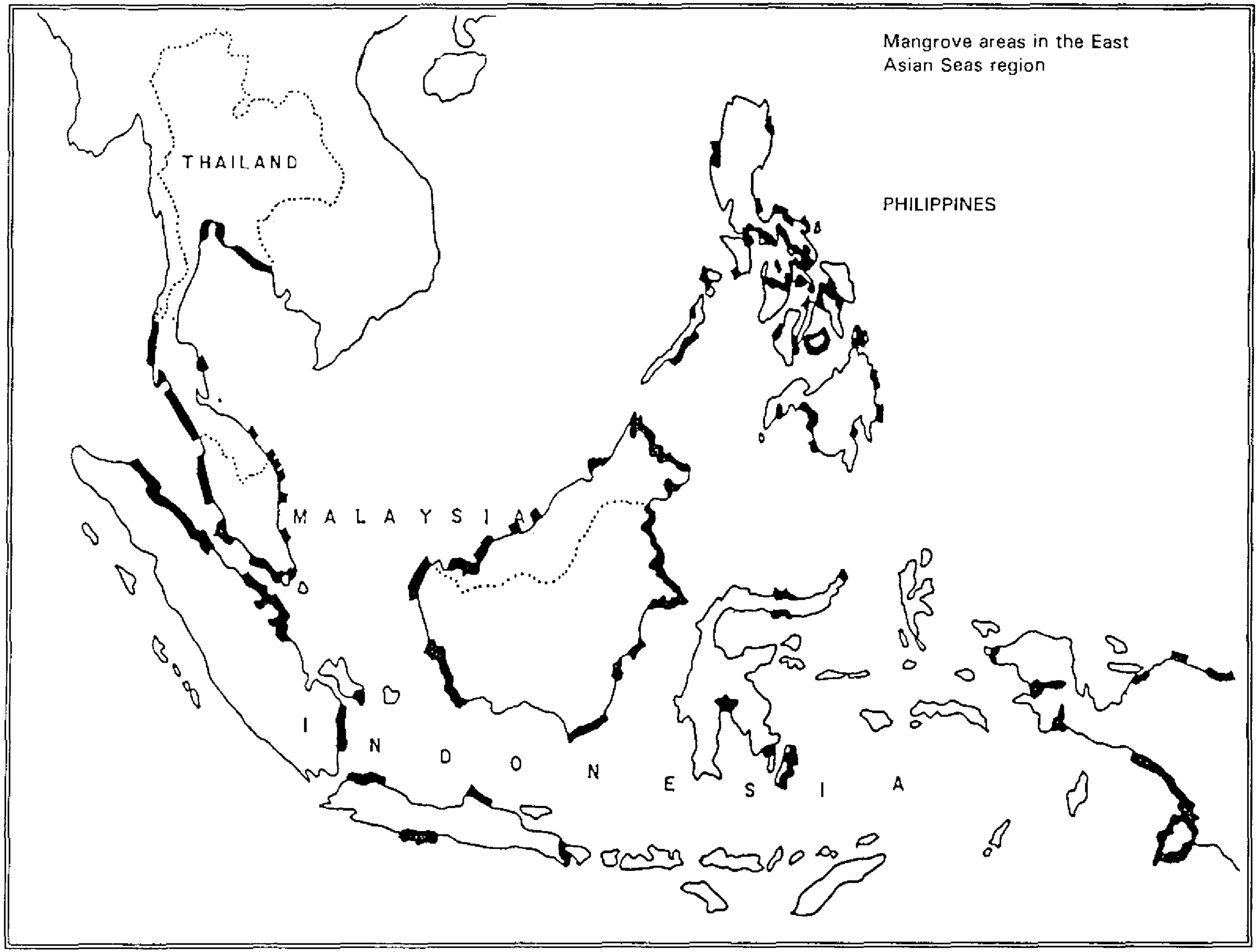
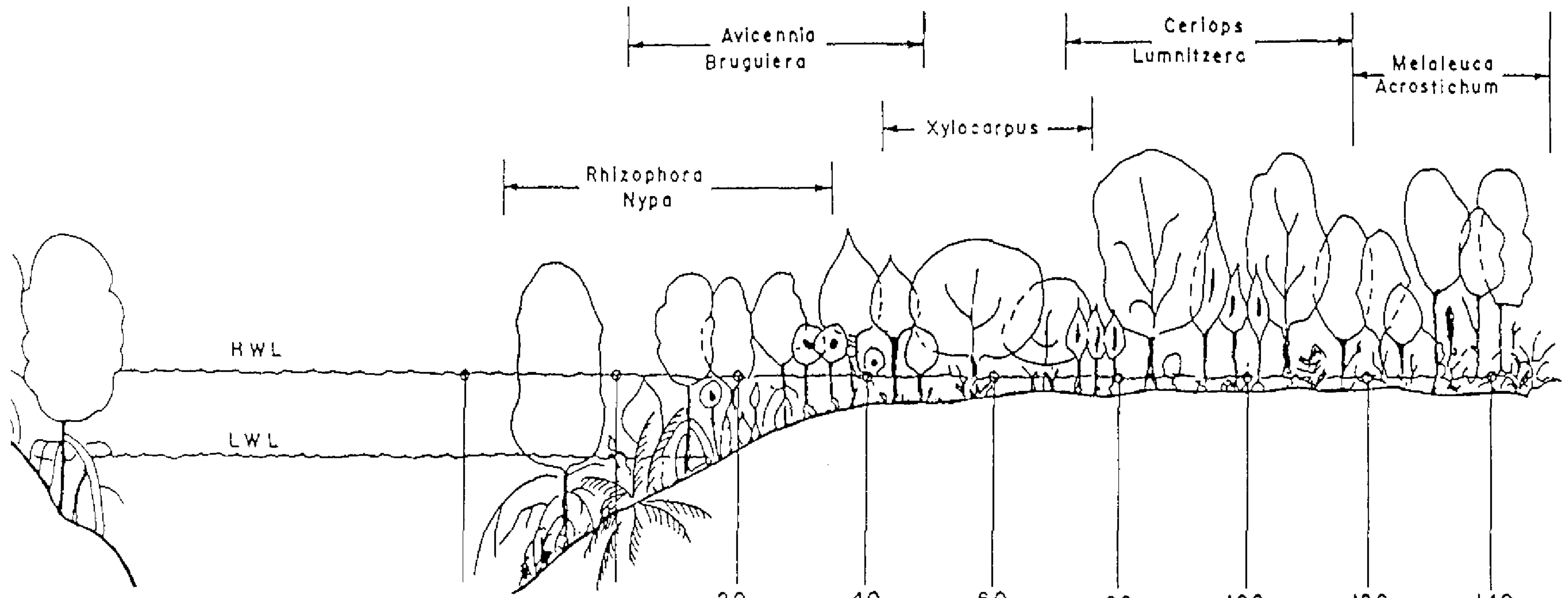


Figure 7.3 Distribution of mangrove areas in the East Asian Seas region (after Gomez 1980a, b; Sasekumar 1980)



Water Properties	Open area	Forest margin	20	40	60	80	100	120	140
Temperature, °C	29.50	29.10	28.70	82.20	27.90	27.80	27.60	27.50	27.60
pH	7.20	7.00	6.90	6.80	6.70	6.70	6.70	6.60	6.60
Salinity, ‰	22.21	22.04	21.46	21.18	20.96	20.67	19.87	18.62	19.49
Dissolved oxygen, ml/l	4.40	3.37	2.99	2.68	2.36	2.15	1.99	1.55	1.70
COD, mg/l	16.00	17.91	18.88	17.73	16.48	16.82	19.88	19.82	20.62
PO_4, μg-at P/l	1.179	1.290	0.967	0.966	0.823	0.838	0.869	0.834	0.859
NO_3, μg-at N/l	2.025	2.220	2.388	2.533	2.418	2.365	2.461	2.407	2.590
SiO_2, μg-at Si/l	87.570	94.330	94.730	91.610	99.720	92.460	103.310	100.820	107.840

Fig. 7.4 : Zonation in a mangrove forest (after Aksornkoae et al., 1979 In : Piyakarnchana, 1980)

A rise in sea level would slowly bring about higher levels of salinity in the seaward zones of mangroves in the affected areas due to sea water encroachment. Increased salinity constitutes a stress factor to the mangrove trees (Snedaker & de Sylva, 1987). The tolerance of the individual species towards higher salinity would determine whether the seaward zones of a forest remain intact, or if they slowly die off. In the case of mortality, the net result would be a decrease in overall mangrove cover.

Higher sea levels may also subject mangrove forests in certain areas to increased physical exposure. A loss in cover may result if the trees are unable to withstand greater wave action (Cubit, 1985). On the other hand, species with pneumatophores may simply drown. A loss in mangrove cover will result in a release of sediment and nutrients (Cubit, 1985).

Increased rainfall in specific localities would have consequences for salinity patterns. The effect on a mangrove forest would again depend on the specific tolerances of individual species to decreasing salinities. A drastic plunge is salinity over the long term may exert significant impact. Mangrove physiology would once more determine if the affected zones survive or perish.

Table 7.1 Inundation classes for Malaysian mangroves (from de Haan, 1931 in Snedaker and Snedaker, 1984).

	Flooded by	Height above admiralty datum (feet)	Times flooded per month (Watson)	Days flooding per month (de Haan)
1.	All high tides	0 - 8	56 - 62	20+
2.	Medium high tides	9 - 11	45 - 59	10 - 19
3.	Normal high tides	11 - 13	20 - 45	4 - 9
4.	Spring high tides	13 - 15	2 - 20	2 - 4
5.	Abnormal or equinoctial tides	15	2	2
6.	Seasonal in wet season only			seasonal flood

Table 7.2 Requirements of mangrove species on the west coast of Malaysia (from Chapman, 1976 in Snedaker and Snedaker, 1984).

Species	Inundation class (Watson)	(de Haan)	Soil and position
Acanthus ilicifolius	4,5	1(?)	Loam, clay on rive banks and in clearings
Acrostichum aureum	3-5	3, 4	Almost everywhere if light
Aegiceras corniculatum	3,4	1(?)	Riverbanks, loam not far from sea
Avicennia alba	2	-	Deep mud, brackish
marina	2,3	1	Firm mud, sea face
lanata[1]	2,3	-	Sandy mud
officinalis	3,4	-	Stiff mud, river banks

(Cont.)

Table 7.2. (Cont.)

Species	Inundation class (Watson)	(de Haan)	Soil and position
Brownlowia lanceolata	4	-	River banks, open spaces
riedelii	5	-	River banks, sandy mud
Bruguiera cylindrica	4	3,4	New stiff clay
sexangula	3,4	5	Loam, wetter soils near back
gymnorrhiza	3,5	2,3	Loam-sandy mud, drier areas
parviflora	3,4	1,2	Anywhere if well drained
exaristata[2]	4,5	-	Rear swamps and along creeks
hainesii[2]	5	-	Dry, very high spring tides only
Calophyllum inophyllum[1]	6	-	Loam, inland river banks
Xylocarpus moluccensis	4,5	3,3	Loam near tidal limit
granatum[1]	3-5	3	Sandy mud, near river banks
Cerbera manghas			
(- C. lactaria)	4,5	5	River banks near tidal limit
Ceriops tagal	3,4	3	Loam brackish
decandra[2]	5	3,4	Land fringe
Derris heterophylla	4,5	3	Loam on river banks
Excoecaria agallocha	4,5	3	Clay
Heritiera littoralis	5	3	Sandy loam; river banks (brackish) and in land areas
Hibiscus tilliaceus	5	6	Loam, river banks inland
Cynometra ramiflora	5	5	
iripa	5	6	
Kandelia candel	4	-	River banks
Lumnitzera littorea	4,5	4	Loam, inland edge
racemosa	4,5	-	Clay
Nypa fruticans	3,5	3,5	River banks where fresh water
Oncosperma horrida			Clay/loam at and above tidal limit
(filamentosa)	5	5	
Rhizopora apiculata	3,4	1,2	Deep soft mud, not on sea face
mucronata	1,2,3	1,2	Firm deep mud, creeks and rivers
stylosa[2,3]	2-4		Sandy shores, open sea face
Scyphiphora hydrophyllacea	3,4	4	Loam, sandy mud, river banks
Sonneratia ovata	3,4	Loam	Loam
caseolaris		2,3	
(- S. acida)	4,5	4,5	Loam, near river water
alba	2,3	1	Rich mud-sea face, river banks
Terminalia catappa	-	4	Loam, river banks

Note :

1. X. mekongensis also occurs in this area and the requirements of the three species need to be worked out.
2. Species not in Watson's original lost; data derived from Van Steenis (1958).
3. Species perculiar to east coast.

To be able to make meaningful predictions of climatic effects on this ecosystem, it would be necessary to examine specific cases where the exact species composition and zonation of a forest are known, and where adequate information on physiology, such as salinity tolerance, exists.

There is as yet no global picture of mangrove species zonation with respect to tides (Snedaker & Snedaker, 1984). The major factors that operate and should be considered are sea level, tidal inundation, soil drainage, salinity, and actual location, such as with respect to river mouths. Periods of atmospheric exposure associated with the occurrence of precipitation are important for seedling survival. Existing schemes are shown in Table 7.1 which depicts inundation classes for Malaysian mangroves, and Table 7.2 listing environmental requirements for various mangrove species, also in Malaysia.

Mangrove species would generally be stressed by an increase temperature (Snedaker & de Sylva, 1987). However, as with coral reefs and other benthic ecosystems, rising ambient temperatures may induce a poleward extension of mangrove forest distribution (Snedaker & de Sylva, 1987).

ESTUARIES

Estuaries very frequently serve as nurseries for economically important fish species. A rise in sea level may significantly alter the morphology of existing estuaries. More specifically, sea water may penetrate further into these areas, changing salinity patterns and "drowning" nursery grounds. However, the adaptation of organisms should be such that breeding and nursery areas would simply be relocated over the course of time, although this is of course contingent upon the availability of suitable habitats.

In general, a rise in sea level would be expected to alter river courses and subsequent patterns of discharge. Sedimentation regimes, in particular, would be affected. This would have a bearing on existing structures in the vicinity of estuaries, including bridges, dykes and fish ponds. If sedimentation patterns were changed, certain marine communities may be affected, i.e., they may be buried or experience increasing stress.

TIDAL FLATS AND BEACHES

An example of the distribution of extended mud flats is given for Thailand in Fig. 7.5. Many coastal populations in Southeast Asia are dependent for their livelihood on gleaning, or the harvesting of edible organisms on mud and sand flats exposed during low tide. Such activities yield a variety of seaweed, bivalves, gastropods, sea urchins and sea cucumbers. Undoubtedly, such organisms are extremely sensitive to atmospheric exposure, and in the course of geologic time have developed mechanisms to help them withstand various stress factors such as insolation, desiccation and inundation by freshwater. It is probable that they would be vulnerable to a rise in ambient temperatures or to a significant increase in rainfall.

The area of currently productive tidal flats and beach areas would be reduced by a rise in sea level. The increase in wave and current action higher up the coast would cause greater erosion. The extent of such an occurrence remains largely speculative, and depends ont he coastal morphology and hydrographic patters of specific localities.

UTILIZATION OF COASTAL HABITATS: MARICULTURE

The importance of mariculture along the coastlines of the East Asian Seas region is illustrated by the situation in Thailand as given in Fig. 7.6.

Coastal aquaculture would almost certainly be affected by phenomena associated with climatic change such as a rise in sea level, temperature elevations and increased precipitation. Mariculture facilities are carefully situated at sites which are optimal in terms of depth, salinity, runoff and turbulence (e.g., adequate tidal flushing). They need to be accessible at all times because they require constant servicing, cleaning and repair.

Mariculture organisms are extremely sensitive to environmental factors. Particular levels in parameters such as salinity and temperature serve as triggers for crucial events such as breeding and spawning. Because of this, it is not difficult to see how an elevation in local ambient temperature by a few degrees could cause stress and disrupt reproductive cycles. The fact that cultured organisms are sessile renders them all the more vulnerable since they could not relocate themselves to more suitable areas.

With respect to salinity, prolonged periods of exposure to reduced levels due to increased precipitation in certain localities may cause similar disruptions in biological cycles upon which mariculture is so dependent.

If relative sea level in certain critical localities were to rise significantly, existing mariculture areas would be threatened. Fish ponds may effectively "drown" if the construction of adequate infrastructure to counteract this trend does not prove feasible.

Fixed structures for the culture of seaweeds and bivalves in reef flats and lagoons may have to be relocated to shallower regions. This may not be as simple as it sounds because substrate, and tidal and current patterns may also change so that suitable substitute areas may not be readily available.

CONCLUSION

The above predictions are based on insufficient data concerning the exact climate and climate-related changes that will occur, the coastal profiles of countries in the East Asian Seas region, and the responses of natural ecosystems. However, on the basis of available information and known trends, it is felt that a climate change over the next century of the projected magnitude would have a significant impact on the natural coastal ecosystems of Southeast Asia. The development of proper policies and mitigation measures thus merits the highest priority.

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Figure 7.5 Location of extensive mud-flats in Thailand (after Piyakarnchana, 1980).

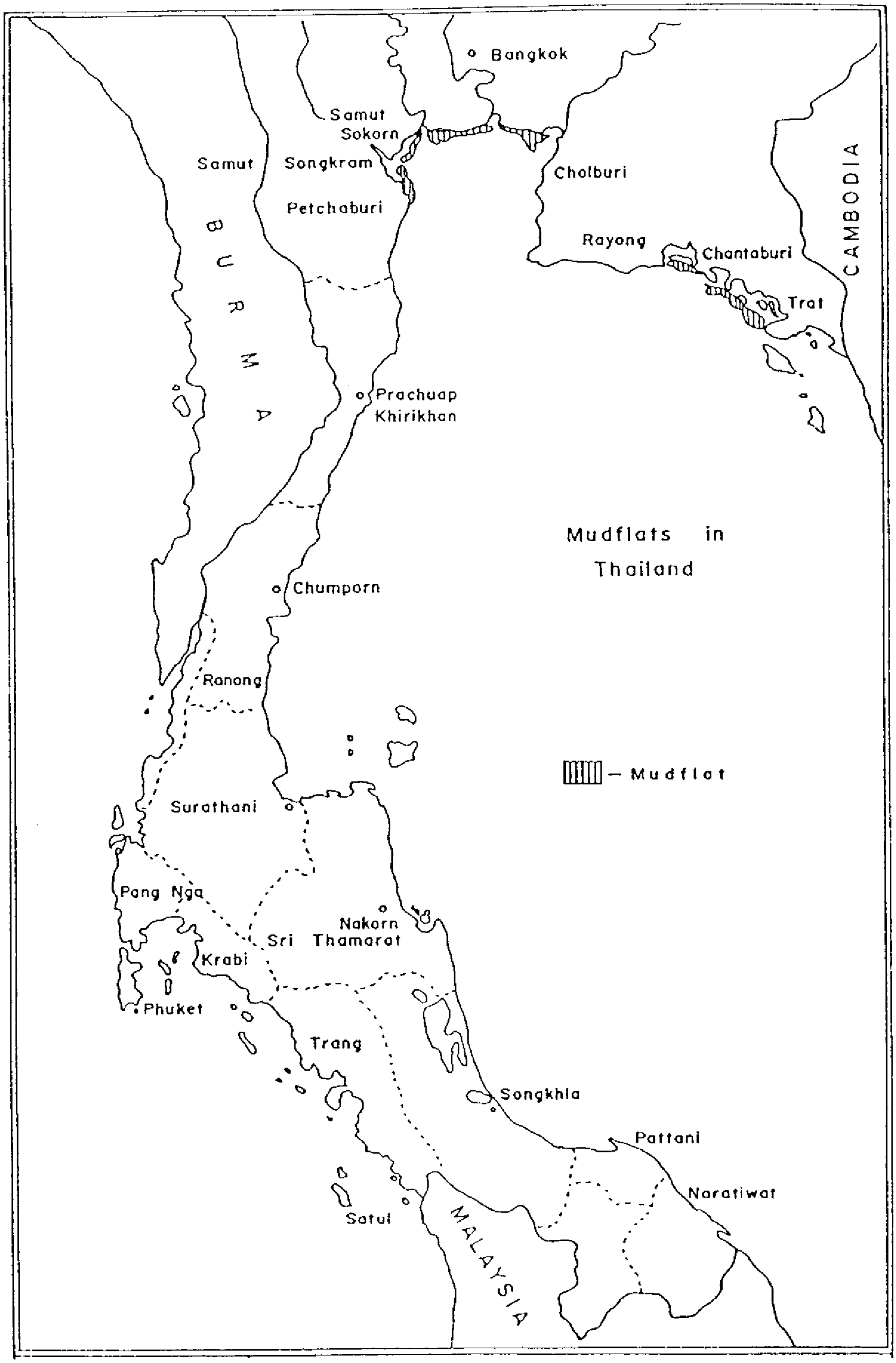
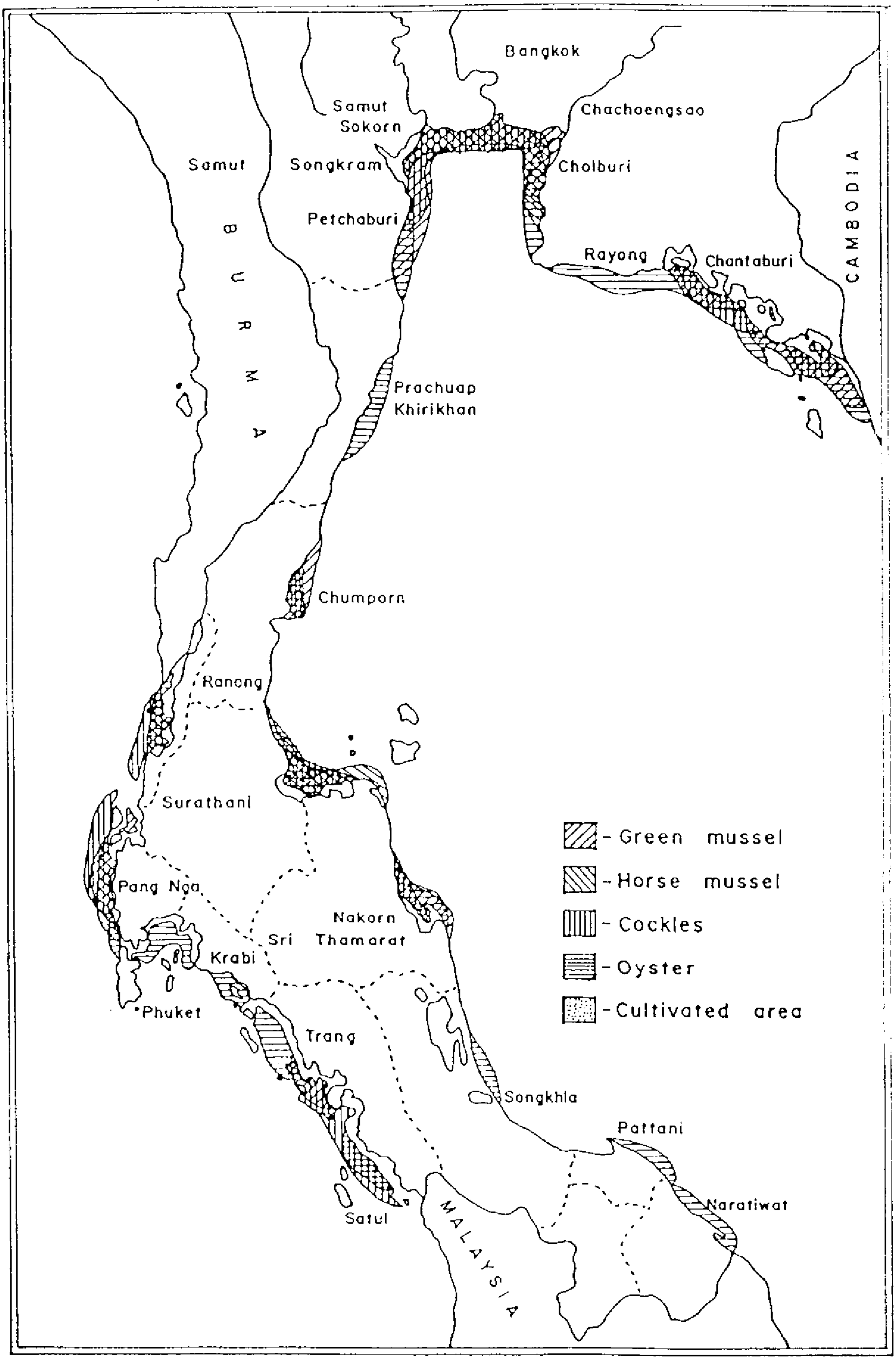


Figure 7.6 Mariculture profile (potential sites) along the coastline of Thailand (after Piyakarnchana, 1980).



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8. TEMPERATURE AND CARBON DIOXIDE CHANGES OVER THE LAST CENTURY IN THE PHILIPPINES: A BASIS FOR PREDICTING EFFECTS OF FUTURE CLIMATIC CHANGE ON HERMATYPIC CORALS

(A case study based on the work of J. Pätzold, 1986)

H.T. Yap

Marine Science Institute
University of the Philippines
Diliman, Quezon City, Philippines

INTRODUCTION

For purposes of predicting the degree of impact of future climate change, UNEP has adopted the assumptions of a rise in mean global temperature of 1.5°C and an increase in mean sea level of 20 cm by the year 2025. In order to make meaningful predictions of the effects of these changes on living coastal ecosystems, it is necessary to have an understanding of current responses and adaptations to present-day climatic forcing. However, since entire ecosystems have developed over a geologic time scale, it is not always realistic to consider instantaneous reactions to episodic events, but rather integrated responses to environmental forcing over periods of years, decades, or even centuries.

Unfortunately, records of climatic trends in the tropics are incomplete, despite current technological advances. Data on ecosystem dynamics, particularly in relation to variations in climate, are even more scarce.

Since ecosystem development is basically a result of the sum total of responses to both internal and external change over geologic time scales, a historical perspective is essential when attempting to predict future responses to expected climatic changes. In other words, ecosystem dynamics over the geologic past must be used as a basis for extrapolation to future trends. In this way, the consideration of human impact as an additional external factor bringing about change could also be analyzed more effectively.

Certain ecosystems lend themselves naturally to such retrospective analysis because they preserve biological records of past climatic trends along with specific organismal responses. Examples of such ecosystems are forests and coral reefs.

In the present work, a synthesis will be made of the study of Pätzold (1986) on "Temperature and carbon dioxide changes in tropical surface waters of the Philippines during the past 120 years: record in the stable isotopes of hermatypic corals." The original version is a doctoral dissertation in German done at Kiel University in West Germany. It constitutes a case study dealing with particular aspects of climate change in the Philippines as recorded by corals that had grown in a specific locality.

MATERIALS AND METHODS

The corals investigated grew on a typical reef flat in the vicinity of the Biological Station of San Carlos University on Mactan Island in Cebu, the Philippines (124°E, 10°17'N). In addition, coral material was obtained by coring directly into the substrate at Cabuyan Reef, Calituban Reef, and Olango Flat. Cabuyan and Calituban Reefs form a double barrier reef system parallel to the northwest coast of the island of Bohol which is located east of Cebu (Fig. 1 in Pätzold, 1986).

An average of three cores, each with a diameter of about 3cm, were taken from three colonies (or, in some instances, microatolls) of Porites lobata on the reef flat of Mactan Island. The colonies were located 400m from the shore in about 2m of water. Colonies A, B and C were 60, 120, and 150 years old, respectively, and had greatest diameters measuring 1.6, 3, and 3.5m, respectively. The coring was accomplished with a hydraulic-powered portable underwater drill operated by two divers. For drilling directly into the reef substrate, a floating platform and a conventional "core wire-line system" were utilized. The greatest core depth was 11m.

The cores were analyzed for a number of parameters. However, only those relevant to the objectives of this case study will be considered here. These include variations of the stable oxygen isotope ^{18}O in order to infer past seasonal temperature trends, and the carbon isotope ^{13}C to derive patterns of change in atmospheric carbon dioxide.

As a preliminary step, the different cores were sectioned and then x-rayed to determine skeletal banding patterns which are analogous to the growth rings of trees. The bands of coral skeletons are deposited chronologically, and differ in width and density according to the nature of growth that took place within the particular period of skeletal deposition. In turn, the growth of the coral during that time is determined by the then prevailing environmental parameters. The latter include temperature, light intensity and precipitation.

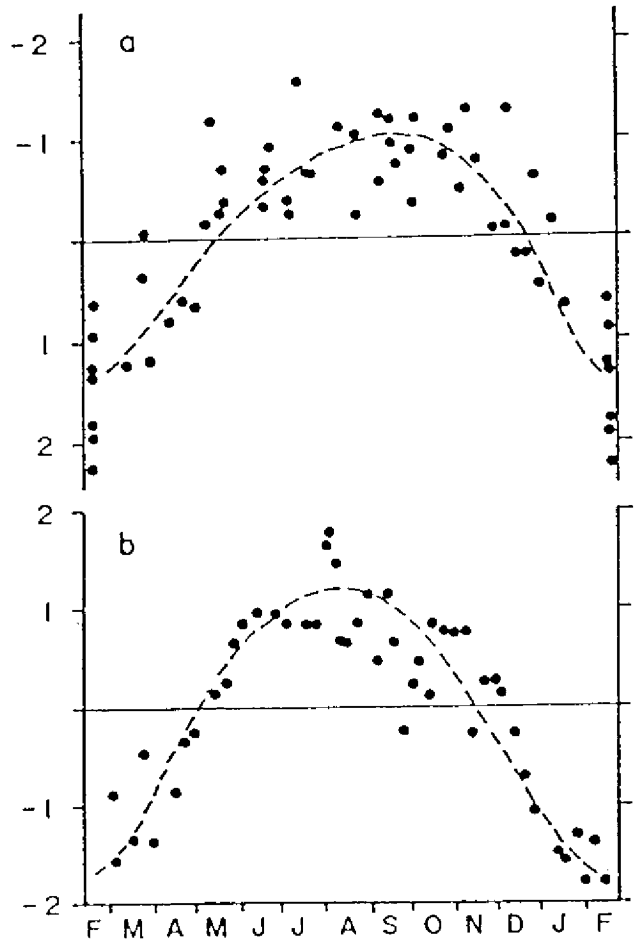
Details of methods of sectioning, x-ray analysis, and isotope analysis are given in Pätzold (1986). The results obtained were compared with the available records of climatic variables during the period concerned, namely, the past 120 years. Needless to say, most records pertained to higher latitudes, or could at best be extrapolated to the tropics in the form of global averages.

Characteristics of the coral skeleton, when analyzed together with the isotope data, also yield information regarding possible climatic variables prevalent during the time of deposition. The density of skeletal material varies on a small spatial scale in a colony, indicating differing depositional patterns over time. Highsmith (1979) in Pätzold, 1986) suggested that temperature influenced the density (indicative of growth rate) of coral skeleton deposited. Pätzold (1986) established a negative correlation (-0.7) between coral growth rates as inferred from skeletal patterns and ^{18}O values. Given the above relationships, it would be possible to deduce temperature patterns simply by studying oxygen isotope data as recorded in coral skeletal material.

More importantly, however, the proportions of stable oxygen isotopes in hermatypic corals are believed to be directly dependent on temperature (discussed in Pätzold, 1986). Recent data have indeed demonstrated a parallelism between the behavior of temperature and seasonal values of ^{18}O (Fig. 8.1). A number of equations have also been developed relating temperature to values of ^{18}O in the water or in carbonates of hermatypic corals (compiled in Table 4 in Pätzold, 1986). In the determination of absolute temperature, a correction factor is necessary since corals preferentially deposit ^{16}O.

In the case of carbon, values of ^{13}C in the coral skeleton are believed to reflect carbon isotope composition of the atmosphere at the time of deposition. This is because dissolved carbon dioxide in surface waters of the ocean is in equilibrium with atmospheric carbon dioxide. Although several fractionation processes take place from the atmospheric stage to the deposition of calcium carbonate, changes in average ^{13}C values in the coral skeleton should correspond to changes in the isotope composition of the atmosphere. This is the basis for deriving past atmospheric carbon dioxide trends from skeletal carbon isotope data. Hermatypic corals provide suitable material for this purpose because of their relatively long life spans, regular growth patterns, and the relative ease in determining their ages.

Figure 8.1 Comparison of seasonal $\delta\ ^{18}O$ values with water temperatures. a) Normalized trend in 18O values between 1972 and 1980. b) Normalized trend in water temperatures between 1977 and 1978 (from Pätzold, 1986).



RESULTS AND DISCUSSION

Temperature

An example of trends in average yearly $\delta\ ^{18}O$ values as derived from the analysis of a coral skeleton core from Mactan Island, Cebu is depicted in Fig. 8.2. Patterns obtained from analyses of the other material were similar. The most significant result that may be gleaned from the data is a rise in the $\delta\ ^{18}O$ curve by 0.3‰ starting from the turn of the present century. Calculations using certain assumptions discussed in Pätzold (1986) show that this variation corresponds to a warming of 1.5°C.

The reason for a global temperature rise since 1900 is unclear, although a "greenhouse effect" caused by increased emission of carbon dioxide into the atmosphere with the onset of the industrial revolution may be a factor.

The rather high increase in yearly average temperature in Cebu could, in addition to a general global warming, also be a result of a slight shift in the seasonal position of the Intertropical Convergence Zone (ITCZ). In the beginning of the present century, the ITCZ appeared to have been located further south. A small northerly shift of the ITCZ would have resulted in a reduced period of the northeast monsoon in the affected areas. An increased influence of the southwest monsoon would be a consequence. Since the latter monsoon is characterized by the highest seasonal temperatures, a prolonging of this season would lead to increased yearly average temperatures. All these observed climatic phenomena would be related to anomalies in the wind systems of the eastern equatorial Pacific Ocean.

Carbon Dioxide

Results of analyses of the yearly average content of the carbon isotope ^{13}C in a coral colony from Mactan Island, Cebu over the period 1858-1980 are shown in Fig. 8.3. In general, they depict a decreasing trend from -0.5 to -2.0%o. A similar pattern has been derived from analyses of a second colony.

The above results are indicative of a rise in the carbon dioxide concentrations of the atmosphere over the period concerned. This may be due to increased emissions of this gas into the atmosphere, which is to be expected from growing industrialization and a change in the nature of resource use on a global scale. However, a higher atmospheric carbon dioxide content explains only part of the observed variations, so that the exact relationship between ^{13}C values in the coral skeleton and the carbon dioxide content of the surface water is still unclear.

Figure 8.2 Trends in yearly average $\delta\ ^{18}O$ values between 1858 and 1980 in Core III, and between 1940 and 1980 in Core IV, from the <u>Porites lobata</u> colony B from the reef flat of Mactan Island, Cebu, Philippines (from Pätzold, 1986).

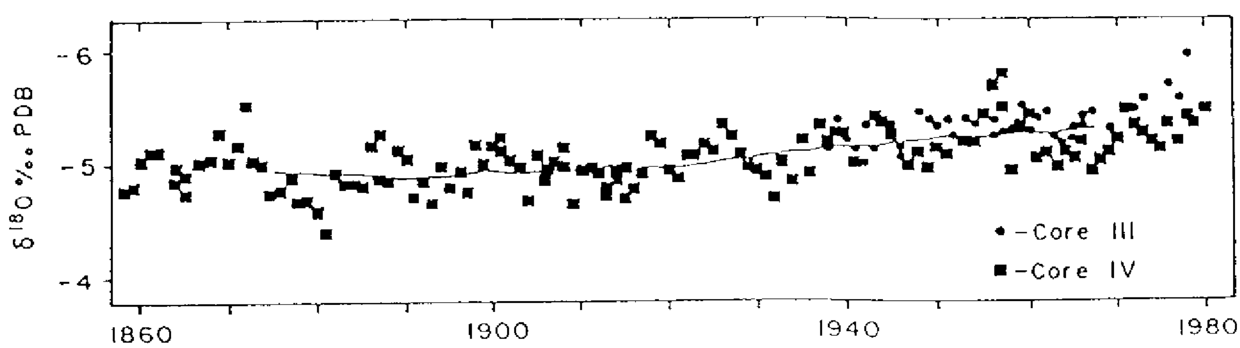
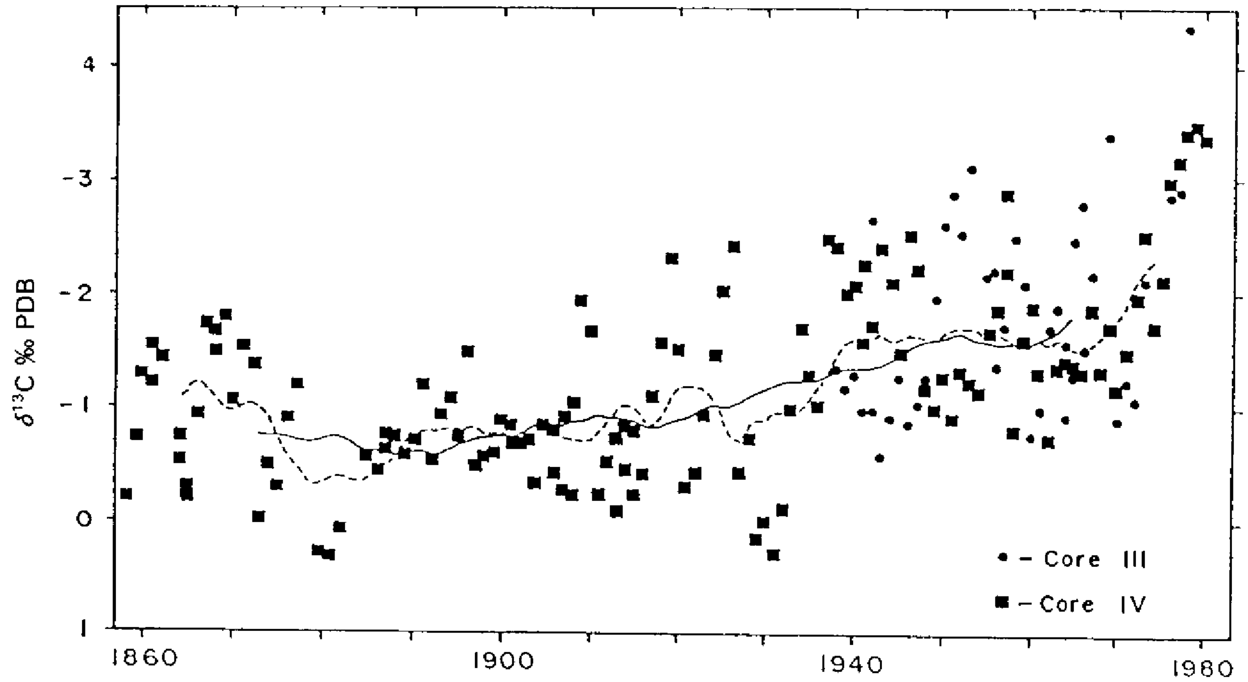


Figure 8.3 Trends in yearly average of $\delta^{13}C$ between 1858 and 1980 in Core III, and between 1940 and 1980 in Core IV, from the Porites lobata colony B from the reef flat of Mactan Island, Cebu, Philippines (from Pätzold, 1986).



CONCLUSION

The foregoing case study is of a rather limited scope. However, some conclusions may be drawn from it as regards to the possible effects on coral reef ecosystems of the predicted climate change by the year 2025, given its assumed magnitude, and based on past ecosystem responses as recorded in the coral skeletons. It may be seen from the results of Pätzold's investigation that a temperature increase of the same magnitude as that predicted for the future has occurred within the recent past (i.e., within the last century). However, since the time periods involved are different, the **rates** of temperature change would be different. Also, the absolute values of temperature attained after each period of change would differ.

At any rate, it is obvious that corals, and presumably their associated organisms, have been able to cope with past increases in temperature. The question now is if the new values attained after continued warming would still lie within the organisms' ability to cope and adapt. It should be considered in this case that tropical organisms in general already live close to their upper limits of tolerance with respect to temperature.

An increase in atmospheric carbon dioxide in the recent past does not seem to have affected hermatypic corals adversely, and is not expected to have any direct influence in the future, even should present trends continue. Carbon dioxide is incorporated into the coral skeleton as calcium carbonate. In response to changes in atmospheric carbon dioxide content, it would basically be the stable carbon isotope composition in the coral skeletons that would vary.

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9. IMPLICATIONS OF CLIMATIC CHANGES ON MARINE PRODUCTIVITY

S. Sudara[1] & L.M. Chou[2]

1. Department of Marine Science
Chulalongkorn University
Bangkok 10500, Thailand.

2. Department of Zoology
National University of Singapore
Kent Ridge
Singapore 0511

INTRODUCTION

The East Asian Seas region is characterized by a great number of seas in close association with numerous land masses. All the seas are influenced to a great extent by the discharge of the many river systems. Even the largest, the South China Sea which is bordered by major land masses, is rich in sediment brought down through river outflow. The warm climate and high level of nutrient input have contributed towards the high productivity of the marine environment, particularly the nearshore areas, and natural coastal ecosystems. The region is also recognized as a center for species diversity.

In reviewing oceanic productivity data on a global scale, Koblentz-Mishke et al (1970) showed that high primary production rates characterized the East Asian Seas. A large portion of the South China Sea supported a primary production rate of between 150 to 250 mg $C/m^2/day$, while the rest of it together with the remaining seas supported primary productivity of more than 250 mg $C/m^2/day$. This high productivity of the region's marine environment is important in maintaining fish populations. Fish provides the major source of protein for the region and forms more than half of all animal protein consumed. The annual marine catch from the region's seas in the mid-eighties amounted to almost 7 million tones.

There is sufficient evidence suggesting that habitat degradation and resource over exploitation is already affecting marine productivity. The situation is expected to be further complicated by climate change and sea-level rise. This chapter examines the possibilities of these influences, both direct and indirect, on marine productivity.

DIRECT INFLUENCES

Temperature change can have a stronger effect on certain areas than on others. In the higher latitudes of the East Asian Seas, temperature rise can be expected to encourage higher rates of productivity since temperature appears to be the main limiting factor there, provided that light intensity remains adequate. Temperature rise may not be as critical a factor on the productivity of tropical seas as these areas are already subjected to a warm, constant climate which supports high productivity.

Plankton primary productivity

Planktonic organisms are normally distributed throughout latitude belts that are determined by temperature, although community structure of assemblages will typify particular surface water masses. Evidences of changing water temperature can ben seen from fossil records of planktonic organisms eg. from Pleistocene glacial and interglacial periods. Such evidence can be used to investigate the movement of cold high-latitude expansion towards the equator and the concentration of temperature in the mid-latitudes when ice coverage was still abundant. Gates & Mintz (1975) showed that the high temperature latitude belt at present is much broader than it was 18,000 years ago (Fig. 9.1). Phytoplankton distribution at present reflects this latitude belt. Diatoms which are very important in the higher latitudes constitute 60% of the total phytoplankton, while in the tropics they form only 5% except at the equatorial belt. In contrast, dinoflagellates and coccolithophores increase in importance towards the lower latitudes.

In the tropics, evidence for predominant maxima and minima of plankton standing stock appears to be lacking (Sournia, 1969; Blackburn et al, 1970). There is instead a series of small oscillations in plankton standing stock throughout the year which is influenced mainly by localized weather conditions and movement of water masses.

Warming of the oceans in the future would have an impact on the distribution of the primary production in the oceans following change of the latitude belt. Stronger changes can be expected in the higher latitudes.

Atmospheric warming will result in warming of the surface of the seas. This will increase vertical stability of the already stable water column in the tropics and to a lesser extent in higher latitudes. Vertical stability will prevent vertical mixing of water and prevent the deeper nutrient-rich waters from rising to the surface.

The rise in sea level together with the increase in freshwater discharge from coastal runoff through increased precipitation can create density currents which would have an impact on nearshore currents. It will also have a strong impact on the shift in location of convergence-divergence areas which will affect downwelling and upwelling areas. Some upwelling areas on the continental shelf at present result in primary productivity of 500-700 mg C/m^2/day up to a maximum of 1.25 kg C/m^2/day, with an average of 625 mg C/m^2/day. When these upwelling areas change in location, productivity reduction occurs in the original areas which will affect fisheries production there. At present, fisheries production from upwelling areas constitutes as much as 50% of the world's total fish production.

INDIRECT INFLUENCES

Change in weather patterns resulting from the greenhouse effect will result in increased rainfall in some areas and drought in others. The loss of coastal land to sea level rise will also affect marine productivity as the inward shift of the land-sea interactive zone reaches areas with different soil characteristics.

Increased rainfall

Salinity reduction as a direct consequence of increased precipitation will cause a decline in productivity of the local waters at that time. Heavy rainfall will cause erosion and transport high levels of sediment into the seas. Sediment acts initially as an inhibitor to marine productivity by reducing light penetration, but together with the sediment are increased levels of nutrients which in the longer term contribute towards enhanced productivity. It can then be expected that productivity may increase in some areas and decrease in others. This will affect the distribution of marine species which use high productivity areas as spawning and nursery grounds. The highly productive estuarine waters will also be affected by increased salinity from sea water intrusion as the level of the sea rises.

Fransz (1986) stated that freshwater from rivers maintained high levels of nutrients along the dutch coast which enhanced biomass and production of algae and copepoda. The highest plankton biomass coincided with the highest temperature and Fe concentration. The outflow of the Zambezi in Central Mozambique was demonstrated by da Silva (1986) to have an influence on the recruitment strength of the shrimp Penaeus indicus. It was also shown (Marshall, 1986) that the Chesapeake Bay plumes continually seeded the waters of the continental shelf with a mixture of estuarine and coastal species as they moved across the shelf. Many of these species now appear more common over the shelf indicating the possibility of increasing shelf eutrophication. Based on observations such as these, increased discharge of river outflow caused by increased rainfall will have an impact on the productivity of coastal waters. Among the conclusions reached at the workshop on the role of freshwater outflow in coastal marine ecosystems held in Norway in 1985 (Skreslet, 1986) was that runoff may significantly affect both the community structure and the productivity of the phytoplankton.

Unusually high rainfall in some areas has been accompanied by resultant blooms of "red tides". The devastating floods in the south of Thailand in 1989, resulted in red tide blooms along most of the western coast of the Gulf of Thailand. Blooms of non-toxic species will affect fish by clogging their gills or depressing dissolved oxygen levels. this has a great impact on areas where net-cage mariculture is practiced. Red tides due to toxic species are dreaded as they can cause human mortality. In an overview of Pyrodinium red tides in the Western Pacific, Maclean (1989) indicated that red tide incidence appears to be associated with monsoons and that upwelling caused by winds may be an important factor in the initiation of blooms. Major outbreaks of red tides in the region also appear to be correlated with ENSO events (El Nino Southern Oscillation). While the causes of red tides need to be fully understood, it is clear that climatic factors play an important role. The high economic and social costs of red tide outbreaks must be recognized.

Coastal ecosystems

The coastal ecosystems within the region are known for their high levels of productivity. Birkeland & Grosenbaugh (1985) indicated primary productivity rates of mangrove systems ranging from 2.3 to 5 kg $C/m^2/yr$, and for coral reefs, above 4.2 kg $C/m^2/yr$. For seagrass beds which are excellent nursery grounds for commercially important species of fish and shrimps, productivity of Thalassia testridinum is 3 kg $C/m^2/yr$, and Zostrea maria, 3.6 kg $C/m^2/yr$. Macroalgae also contributes to the primary productivity of shallow waters. Laminaria longiceris has an average production of 3.2 - 3.6 kg $C/m^2/yr$. Possible responses of these coastal ecosystems to climate change and sea level rise are discussed in another chapter. The productivity of these ecosystems will change in response to changes in community structure and extent of zonation, and together these changes will have an impact on the production of commercially harvestable species associated with them.

Open ocean productivity

Although rainfall may cause some dilution to the surface layers of open waters, productivity of the oceans is usually not as high as in nearshore waters, and substantial changes are not expected.

Figure 9.1 Maps comparing the distribution of surface temperatures in the Northern Atlantic summer (a) at the present time and (b) 18000 years ago. Isotherms are in °C (from Gates & Mintz, 1975).

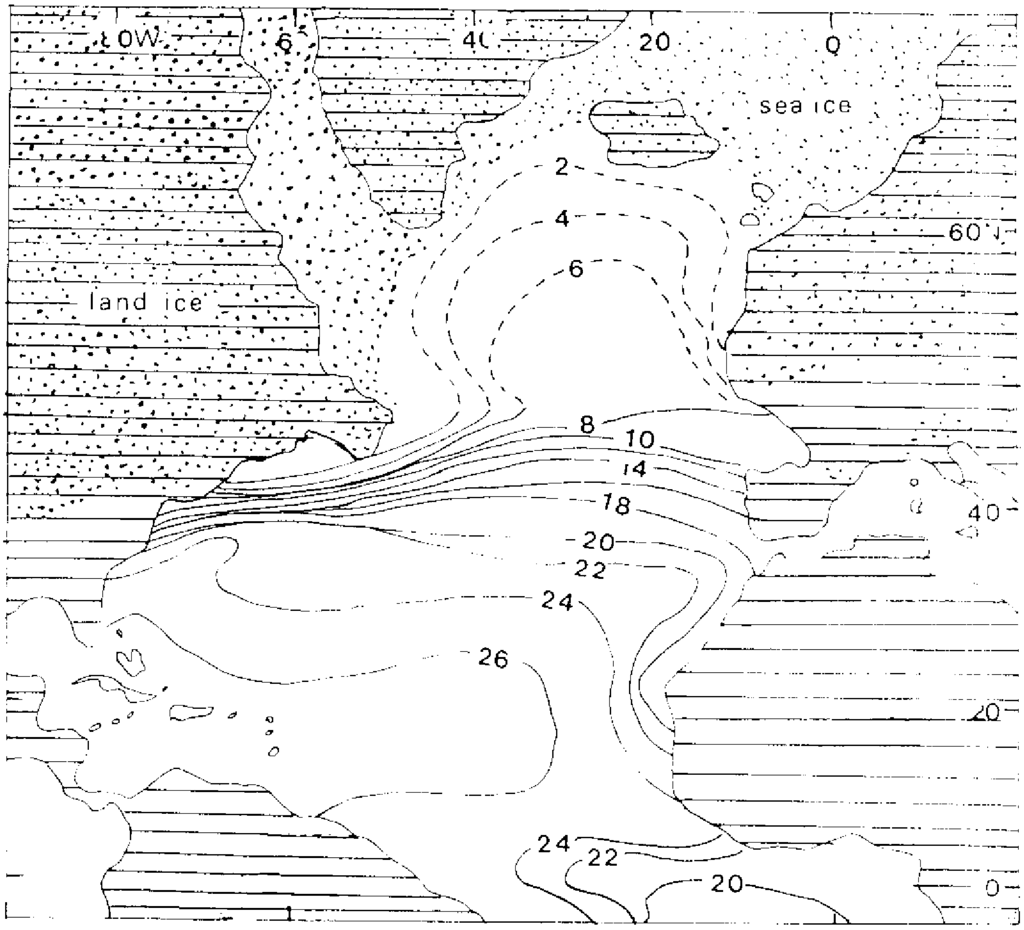
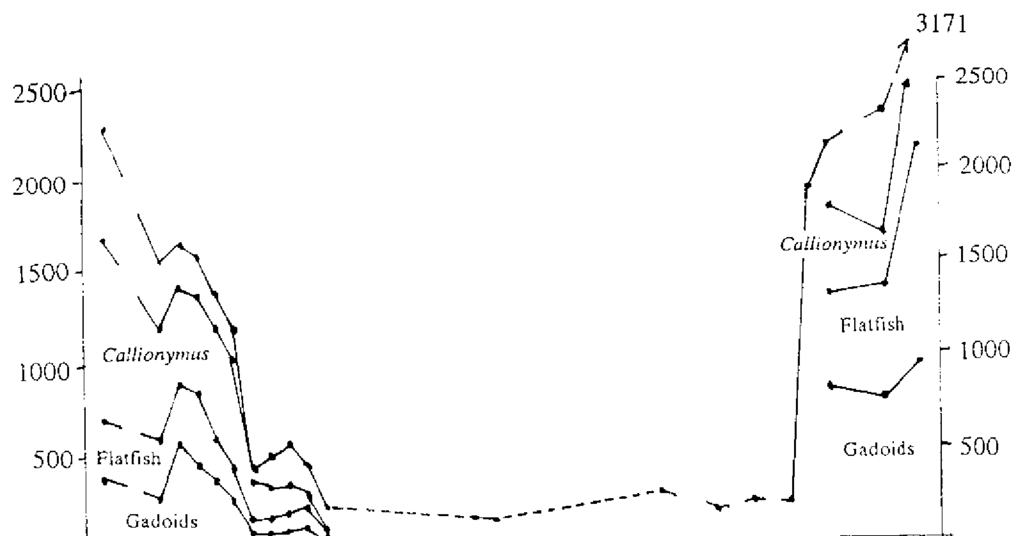


Figure 9.2 The sums of the monthly averages of planktonik stages of teleostean fish off Plymouth, from 1924 to 1971 (from Russel, 1973).



Fisheries

It is difficult to identify the precise impact of climate change and sea level rise on fisheries production. The distribution patterns of species will change together with abundance. Fish larval stocks are likely to be affected. Southward (1974) showed that dominant groups of fish larval stocks are influenced by temperature. Russell (1973) also showed that when current patterns change in response to changing temperature, nutrients are transported into the bay off Plymouth, resulting in a tremendous increase in fish larval (Fig. 9.2). Sinclair et al (1986) in assessing effects of freshwater runoff variability on fisheries production in coastal waters, concluded that physical oceanographic processes of advection and diffusion can directly affect population abundance of zooplankton as well as the early stages of fish, without any links to primary production.

Sea level rise is expected to cause changes in fisheries production of the nearshore areas:

1. More shallow areas will be created for fisheries operations.

2. Land-based mariculture operations may be reduced due to inundation and lower availability of coastal land. Mariculture operations will have to depend more on sea-based techniques.

3. Economically important species being farmed may have to be changed to those which will grow well under the changed conditions.

CONCLUSION

Marine productivity levels will change in response to climatic change particularly within the coastal areas. They are usually associated with sea level rise and increased precipitation. These impacts are likely to be localized and dependent on a multitude of factors including the geomorphological features of the area. More research is required in order to understand these processes which will be useful in managing these coastal living resources in the event of sea level rise and climate change.

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B. SOCIO-ECONOMIC IMPLICATIONS

10. ASSESSMENT OF CLIMATE CHANGE IMPACTS ON AGRICULTURE AND FORESTRY IN THE SOUTHEAST ASIAN COUNTRIES

S. Panich[1]

National Environment Board
60/1 Soi Pracha Sumpun 4
Rama IV Road, Bangkok 10400, Thailand

INTRODUCTION

The Southeast Asian countries of the East Asian Seas (Brunei, Indonesia, Malaysia, Philippines and Singapore) lie in the tropical region and with the exception of Singapore, have a large percentage of people involved with the agriculture sectors as well as significant forest resources. The economic growth rate for Thailand and Singapore is high, stimulated by the rapid pace of industrialization. However, the impacts of climate change will still be significant to the majority of people in these countries.

A simple scenario of temperature increase and sea level rise is not adequate to assess the potential impacts of climate change on agriculture and forestry, as there are more factors which have to be considered, such as the anticipated change in precipitation, the changing pattern of rainfall, and soil moisture, all of which are vital for plant growth and yield and plant ecosystems. We thus specify the scenario of temperature increase according to results of the latest available global circulation models, mainly the GISS which also has monthly predictions of temperature and rainfall, with the prediction of temperature rise in this region of 0-6°C (2-4°C in general), and the sea level rise estimated to occur within 10-50 years of 20-50 cm, which are within the earlier prescribed scenarios of 1.5°C increase in temperature and 20cm sea level rise by the year 2025.

PROFILE OF THE REGION

World Resources Institute has published a report for 1988-1989 which provides figures for basic data of the countries in this region, as shown in Table 10.1.

Agricultural profile of the region

While rice is the main staple of the people in these five countries, there has been diversification into crops such as soybean, maize, tapioca and sugar cane. With rice prices at the lowest level recently and monocropping of rice resulting in resistant pests, soil degradation and other problems, farmers diverted to other crops depending on market demand and the suitability and availability of land. In Indonesia and Thailand, farmers adapted very quickly to changing situations. It should also be noted that the success of the Green Revolution did not extend to rainfed cropland very much and the majority of the cropland area is not greater than irrigated cropland for several reasons. The growing season can be affected by climate variability, such as at the start of the season when is required a certain amount of precipitation and soil moisture are required to sustain growth.

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1 Present affiliation : Environmental Research Institute, Department of Environmental Engineering, Chulalongkorn University, Bangkok 10330, Thailand

Table 10.1. Basic data for five countries in Southeast Asia
(Data for 1984-86 unless otherwise stated)

Indicator Unit	Indonesia	Malaysia	Philippines	Singapore	Thailand
GNP M US$	82100	29500	31820	19160	42440
GNP/capita US$	500	1850	570	7410	810
% GDP as agriculture	26	n.a.	26	1	17
Population M (1989)	179	17	60	2.7	55
Land area 1000 Ha	181157	32855	29817	57	51177
Cropland 1000 Ha	20680	4353	10150	6	19553
Pasture 1000 Ha	11867	27	1140	0	308
Forests 1000 Ha	121898	20677	11783	3	15267
Cereal Kg/Ha yield	3458	2772	1852	n.a.	2075
Root/tuber Kg/Ha yield	10304	9653	5895	11144	13731
Fertilizer Kg/Ha Uses	81	119	33	869	23
% irrigated land (of cropland)	33	8	18	n.a.	19

n.a. = not available
M = Million
Source : World Resources Institute, World Resources, 1988-1989

It can be concluded here that the major crops in the region consist of rice (all countries), maize (Thailand), rubber (Thailand, Malaysia), pineapple (Thailand, Philippines), soybean, coffee and cocoa (Indonesia), sugar cane (Thailand, Philippines) and coconut (near the shoreline). Due to favourable conditions the region can grow almost any kind of plant, the limitations being the markets, both domestic and world. Rubber and pineapple are good examples of export products that depend on the world rather than the domestic market. It is very likely that future climate change impacts on agriculture in other parts of the world may also play a very important role in this region's agricultural pattern. Diminishing rice production in other regions could raise the rice price on the world market so that rice will become attractive to the farmers of S.E. Asia. At the same time the region will have to import certain grains and products from other regions which can increase their production (such as the expected wheat production in the presently cold region of Canada).

The differences in altitude of the region are not great, and the crops are mostly lowland, with the exception of northern Thailand and the Philippines, which still cannot be differentiated agriculturally from lowland as the diversity of plants is similar. Highland areas consist generally of forests and are protected for water resources or as national parks. Their yield seems to be of little significance to the country's needs, but are important to local people. Effects of climate change such as temperature increase, for example, may force people in the highlands to change to other crops rather than to cope with increased stress on the plants caused by higher temperature.

Most of the crops are inland and overall there is going to be only a minor loss of land area for agriculture, with possible heavy losses in coconut and other coastal plants due to sea level rise. As sea level rise will be rather gradual, growers will have time to adapt. Major impacts will occur on sources of freshwater inland such as river basins, lagoons with inflows from inland areas from which water for agriculture is being drawn. As sea level rises salinity intrusion may become a problem as salt water penetrates upstream for additional kilometres, thus affecting agriculture along the riverbanks and canals. Vulnerable areas include Chao Phraya River basin in Thailand which is very flat and salinity intrusion is already a problem.

Forestry profile of the region

At present, countries in the region are more concerned with the anthropogenic deforestation which is evident from Table 10.2. By using the word "deforestation" we mean unsupervised and unselective logging which results in clear-cutting and destruction of thousands of species. Kaufman & Lacroix (1979) state that:

"in the tropical forests of this region there are many species in the same area. For example there may be as many as 500 species of trees in Malaysian forest of five square miles, while the canopy may be made up with only one species of tree such as Shorea albida in the peat swamps of Borneo. The type of forest is closed broadleaf (such as family of Dipterocarpaceae) in Sumatra, peninsular Malaysia and Borneo."

Table 10.2. Basic data for forestry in the region

Indicator Unit	Indonesia	Malaysia	Philippines	Singapore	Thailand
Open forest 1000 Ha	3000	n.a.	n.a.	n.a.	6440
Closed forest 1000 Ha	113895	20996	9510	n.a.	9235
Deforestation %/year	0.5	1.2	1.0	n.a.	2.4
Plant species	5000	8500	9000	2030	12000
- rare plant species (approximate)	100	300	73	15	40
Soil erosion tons/Ha/yr					
- Chao Praya River					21
- Brantas River	43				

Source : World Resources Institute: World Resources, 1988-1989

Climate in the tropics is not as variable as in temperate zones, but periods of drought are not uncommon. These may cause herbaceous plants to drop their flowers, abort fruit and slow down the rate of production of new foliage, even though it is often hard to see the gross responses to extreme climate events. Cyclones and tropical storms can cause damage especially to the tops of tropical mountains where the rate of plant growth is very slow. This devastation however occurs only once every few hundred years and the vegetation will remain in a permanently disturbed state. Cold is another damaging factor that can detrimentally affect many species.

Local micro-climate is also regulated by tropical forests, which supply moisture to the atmosphere through evapotranspiration and absorb rain from the soil. Without the forest, the land becomes drier and the albedo of the surface increases. This will disrupt convection patterns, wind currents and rainfall in areas even at some distance.

Rainfall is the major supplier of water, with as much as one to three metres in 6 to 8 months and not at all during the remaining months, during which forest fires can occur to clear the underbrush. The dry season promotes flowering and fruiting while the wet season encourages leaf and branch production. Photosynthetic rate increases during the dry season due to increased sunlight, and some new foliage replaces that consumed by animals and pests.

The Ministerial Conference on Atmospheric Pollution and Climatic Change at the Hague, Netherlands in 1989, released the results of a study that showed that about 50% of the rain in the forest is the result of the forest's own transpiration. Thus, it is predicted that precipitation will decrease as climate change progresses. Forest fires and disruption of forest cycles may be severe enough to kill off forests in the tropics, especially those in marginal lands and nutrient poor areas. However, it is evident that forests in this region are already facing man-made deforestation at a very alarming rate.

Tropical soil is nutrient poor, so that after clear-cutting it takes several years to regenerate secondary vegetation of only a few metres tall. The higher the altitude, the lower the production so that cleared land on a mountain could be bare of vegetation for many years. Since the remaining forests in this region which are still pristine and unexploited are in mountainous areas, (in Indonesia, Malaysia, New Guinea, Thailand) the destruction could be followed with very slow recovery.

Another type of forest is the mangrove forest which is most abundant in Indonesia (2.5 million ha in Irian Jaya and Sumatra), and Malaysia (0.67 million ha). In Thailand, it is being destroyed rapidly for shrimp farming and other purposes. Bamboo forests are confined to areas in continental Southeast Asia (Thailand).

Philippines and Thailand lose their forest to agriculture as in the case of Kalimantan and Sumatra in Indonesia. These three countries have a high rate of shifting cultivation (slash and burn), 12 million people in Indonesia, 0.4 million in Sabah, 0.3 million in Sarawak, 0.83 million in the Philippines, 1 million in Thailand and 1.64 million in Malaysia, affect areas of 35 million ha in Indonesia, 4 million ha in Thailand, 4.7 million ha in Malaysia, and 2 million ha in the Philippines. Timber logging and fire also contributed heavily to deforestation, such as the 300,000 ha fire in Indonesia. Pests can be a major factor such as the recent defoliation of 12,000 ha of peat swamp in Brunei and Sarawak.

Soil erosion

Implications on agriculture and forestry will need to include consideration of soil erosion. In this region, erosion is caused by rain which loosens soil particles, making them more vulnerable to transportation in runoff. Erosion rate is greatest during the peak rainy season, but the organic matter of soil will hold the particles together. If the forest cover is removed, soil can deteriorate rapidly, leaving only sand which is worthless for agriculture.

The steeper the gradient of the land, the greater the erosion. With crops like maize, the gaps between plants are large so that the soil is more exposed to the rain. More rain due to climate change, or increased intensity of rain will affect mountainous places such as in the Philippines and northern Thailand, which have been deforested and are being replanted with species which cannot prevent further erosion. In Indonesia there are also vulnerable areas in Sumatra and Kalimantan, and less so in Sulawesi and Malukku in the east.

In Malaysia, erosion results mainly from mining and logging as well as clearing of forest land for agriculture and settlements. In Sabah, erosion is also caused by shifting cultivations as well as logging.

Salinity of soil

Increased salinity can result from irrigation mismanagement which causes water buildup in the soil that rises towards the surface to evaporate and deposit salt on the soil. This will happen in areas having poor drainage systems that cannot cope with heavy rainfall. In Indonesia, Thailand, and Malaysia, ESCAP data indicated 13 million ha, 1.5 million ha, and 3 million ha respectively are affected by saline concentration of 0.5 to 1.5% in the root horizons (1-1.5m), which produces 30 - 60% lower yield than nonsaline soils. Salinity intrusion in the case of sea level rise will be an issue in areas near the rivers (but which can be compensated by increasing water released from upper reservoirs to repel the salt water or by salinity barriers, although these schemes can be costly).

Past historical records

In order to assess the potential and likely impacts of climate changes to this region, the case of the 1982-83 El Nino-Southern Oscillation which had produced drought effects in Indonesia, can be used to demonstrate how agriculture and forests respond to extreme events. The case started with little or no rainfall at all in May 1982, which caused drought (agricultural drought means precipitation of less than 100mm/month, and the requirement for wetland is 200mm/month).

As a result, growth rate decreased by more than 50% in Java and Bali, with negative growth rate in Sulawesi (dry season crop) and a delay in the planting season of 1982-1983. The farmers then diverted their land from paddy to maize production as maize requires less water than rice. Thus for the 1983 season, there was a 53% increase in maize production, and 2% increase in sugarcane production (as cane prefers high solar radiation which was plentiful in that growing season). The rice production returned to normal in 1984.

The drought also caused fires in the forest of Kalimantan (East) which usually receives more than 2,500mm of rain annually. When almost no rain was observed in February, March and April 1983, the tropical evergreen forests which were believed to be immune to drought were damaged by drought and fires which destroyed 3.5 million ha in East Kalimantan and another million in Sabah. The fires were caused mainly by accumulation of leaves on the forest floor. There was also evidence that selectively logged forests which left higher amounts of debris on the floor, suffered more damage than the natural forest. The lowering of the swamp also added dried swamp species to the fire (Glantz et al., 1987).

Table 10.3. Rainfall at selected stations in Indonesia (1982), in mm/month.

		Apr	May	Jun	Jul	Aug	Sept	Oct
West Java	Av.	264	159	83	59	30	43	109
	1982	310	90	20	2	1	0	55
Central Java	Av.	129	117	84	62	39	46	52
	1982	236	12	55	2	6	0	21
East Java	Av.	232	156	78	43	25	27	79
	1982	259	0	0	3	0	0	0
Bali	Av.	88	75	70	55	43	42	106
	1982	53	2	1	0	3	0	1
S. Sulawesi	Av.	154	95	65	32	14	11	45
	1982	109	77	6	0	0	0	0

The Climate Scenario

Scenarios for climate change are partly taken from the Hamburg Meeting (World Congress for Climate and Development, November 1988) by K. Hasslemann using General Circulation Models of Geophysical Fluid Dynamics Laboratory (GFDL), GISS and NCAR, which all used the assumption of doubling atmospheric CO_2. The predicted change, as compared to those presented by Barbier (1989) is shown in Table 10.4.

Based on GCMs' generated annual average there appear to be very small changes in climate parameters for any country within the region, with the exception of Thailand which happens to be closer to the temperate zone, and thus will be exposed to bigger changes. It must be noted that the GCMs' results are far from perfect and that the different models give widely different results. It is interesting to study the monthly data of GISS models (Panturat & Eddy, 1989) when shown that most locations within this region have different patterns of precipitation even though the annual rainfall may amount to the same. The changes are as follows:

1) heavier rainfall in the already wet months,
2) lower rainfall in the already dry months,
3) delayed rain for the rainy season.

Table 10.4. Regional scenarios for climate change

Parameters	Indonesia	Malaysia	Philippines	Singapore	Thailand
Temperature increase (°C)	0-2	0-2	0-2	0-2	0-6
Precipitation increase (mm/d)	0	0	1	0	1-4
Soil water difference (cm)	0	0	0	0	0 to -4
Summer Temp. increase (B)		Region in 0.9 to 0.7 x Global Increase			
Winter Temp. increase (B)		Region in 0.9 to 0.7 x Global Increase			
Precipitation (B)		Enhanced in region with heavy rainfall today			

(B) = Barbier (1989)

This scenario, in turn, will cause :

1) delay of growing season,
2) plenty of water in rainy season, which may cause floods and more erosion,
3) dry season crop in non-irrigated areas will probably fail due to drought stress,
4) tropical cyclone increases in number and intensity from ocean warming resulting in additional damage by storm runoff,
5) loss of vulnerable areas such as coastal and river regions and marginal land (infertile soil, slopes, and non-irrigated),
6) species to re-establish when climate change reverses and colonization of invading species which can tolerate the new climate.

Table 10.5 summarizes the effects of climate impacts in another way:

Table 10.5. Some comparisons of climate impacts on agricultural factors

Parameter	Light rain long period time	Heavy rain short period time	Increase Temp.
Water infiltration into soil	more	less	-
Water runoff	less	more	less
Erosion	less	more	-
Sedimentation in reservoirs	less	more	-
Nutrient washout	less	more	-
Soil moisture	more	less	less
Growth cycle	-	-	shorter

The effect on growth cycles is mainly dependent on the increased CO_2, since net primary productivity of plants can be increased with atmospheric CO_2 even under water limited condition. For small amounts of CO_2 increase, the net primary productivity increase can be calculated as follows:

$$NPP = (1 + B \times DELCO_2 / CO_2 (o)) NPP (o)$$

where B is the specific CO_2 fertilizing factor describing the response (NPP) of different plants to increases in atmospheric CO_2 (B has the value of 0.15 to 0.60). $DELCO_2$ is the increase in atmospheric CO_2, and $CO_2(o)$ is the present CO_2 condition.

It should be pointed out that there is no certain evidence that CO_2 fertilization will increase forest productivity, as photosynthesis models for leaves and tree seedlings cannot be scaled up to the stand level. Little is known about water uses for species-differentiated stomatal sensitivity to increased CO_2. Even if beneficial, it may not be so from the ecological viewpoint (conclusion of the European Workshop on Interrelated Bioclimatic and Land Use Change, 1987). However, doubling of CO_2 can be beneficial to the agriculture sector if moisture is available. For maize, sorghum and sugarcane, the increase in yield will be about 10%, and for wheat, rice and soya, 10-50%.

Effect of temperature increase in addition to the change in precipitation pattern in this region, will also cause moisture to escape from the soil which may reduce total runoff even though precipitation increases, so that on the average, the soil will be dryer than normal. Cloud cover may decrease as a result of less evaporation rate from the dried soil in summer months thus increasing the solar energy to the soil surface which further enhances soil drying.

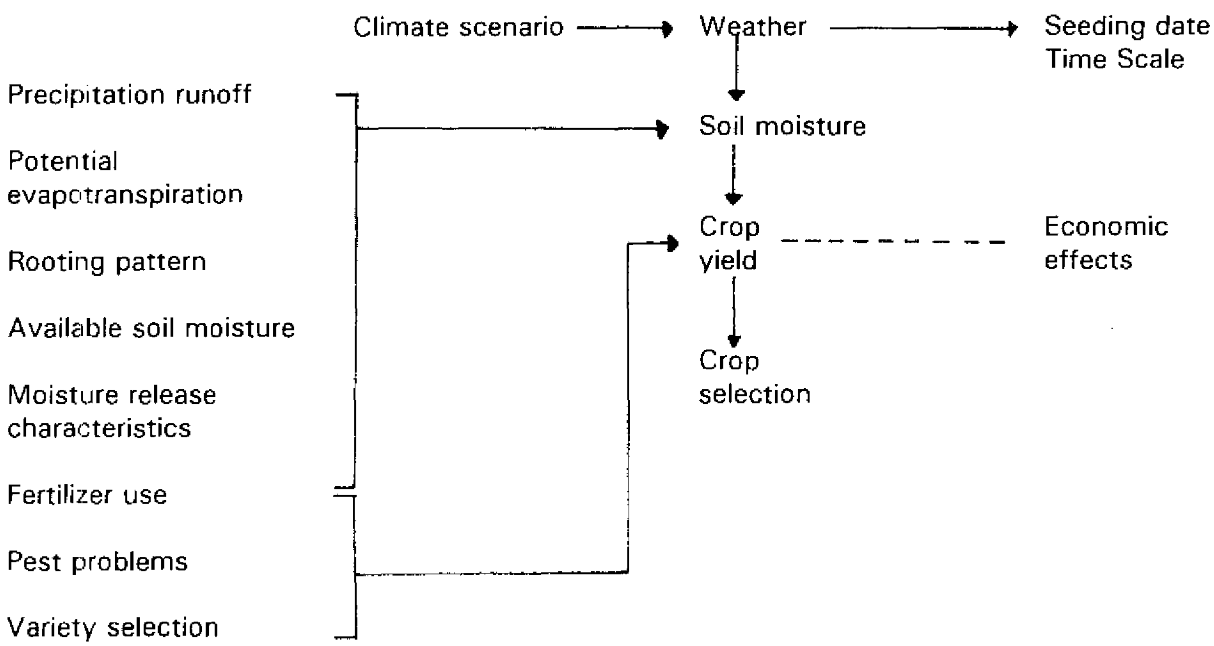
Drought caused by soil drying in the top 0.2m is serious since this layer contains nutrient supplies and supports root and microbial activities. Therefore, drying of this layer indicates yield loss. It is expected that a temperature increase of 1-4°C will increase potential evaporation by as much as 5-15%.

On the other hand, extreme weather can cause an increase in precipitation in certain places and times. Since increase in runoff of 15-30% can be caused by only 10% increase in precipitation, erosion will become a serious problem.

In summary, the effects caused by the climate scenario, will also see changes such as forests being changed into shrubby woodlands which can adapt better. Soil chemistry and pest ecology will change, making it very difficult to predict what will happen. The scenario indicates that the change in climate varies for even the same latitudes, and any study on impacts of climate change will have to be site specific for quantitative results.

Methodology for impact assessment

Crop yield depends on weather, radiation, CO_2, soil moisture, fertilizers, etc. Special models for quantifying yield have been developed such as the Versatile Soil Moisture Budget (VSMB) models used for Agriculture Canada for each Prairie crop reporting district (winter wheat, rye, grain and silage corn, sunflowers, tame hay, native pastures, etc) as follows (Arthur, 1987) :



The above model works on the five processes which determine the dynamics of vegetation at a site:

1. Germination and establishment
2. Growth and conception
3. Seed production (include dormancy and seed longevity)
4. Dispersal of seeds
5. Mortality (age-specific and age-dependent)

The Canadian study shows significant yield response to moisture. Increases in precipitation can offset slight increases (less than 1°C) in temperature-caused evapotranspiration.

Another case study by Panturat & Eddy (1989) makes use of the upland rice in Chiang Mai, Thailand, for the climate scenario of GISS ($2xCO_2$) for monthly data on maximum and minimum temperature and precipitation. The model used is Ceres-Rice version 1.10 which is a daily time step model that simulates grain yield and growth components of different varieties in any agroclimatic condition for one cropping season. The model represents the transformation of seeds, water and fertilizers into grain and straw through the use of land, energy (solar, chemical, and biological) and management practices, subject to environmental factors such as solar radiation, maximum and minimum air temperature, precipitation, daylength variation, soil properties and water conditions. The model has the flexibility of running with irrigation and nitrogen fertilizer. Also available is Ceres Maize and Soygro (soybean) models. In order to use such models, water models may have to be employed.

It can be estimated that while biomass accumulation results from increased CO_2, transpiration will also increase and the yield, on the whole, would increase. Soybean and maize will be crops which will benefit from climate change more than rice. Rainfed rice crops will be affected by precipitation pattern change, and irrigated areas may require additional water.

A CASE STUDY : THAILAND'S NORTHERN UPLAND

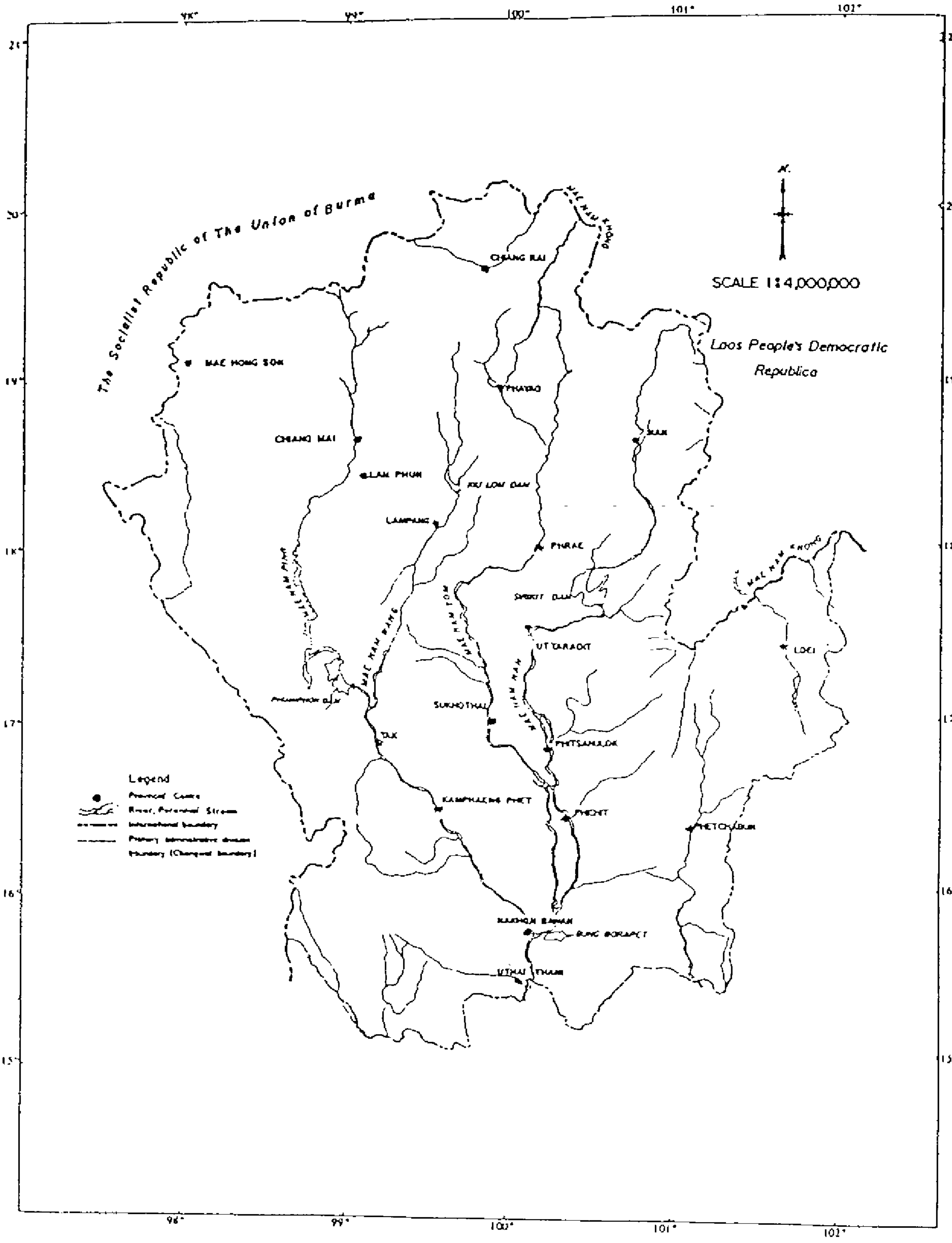
In order to assess the impact on agriculture and forestry, it is important to have all the required data in detail, since the impact is not so direct as mentioned before. In this study, Thailand's Northern Upland is used for a case study, as this area is typical of agricultural practices in the region (monocropping and multicropping, highly adaptable, and water-dependent). Moreover, this area is predicted to receive the most severe climate change impact based on the GCM models.

The profile of Thailand's northern area was provided by the Thai-Australia-World Bank Development Project which was published in 1985. Map of the area is shown in Fig. 10.1, and the conditions are as follows:

Soil

The lowland soils are finely textured, poorly/slowly permeable soils well suited for flood irrigation, and medium textured, moderate to well-drained soils suited to rainfed annual cropping. Thus the lower lying area is suitable for wetland rice. The elevated parts are used for upland crops such as tobacco, soybean, peanuts, vegetables and fruit trees. In the uplands, the soil is increasingly infertile with organic matter of less than 2% and acidic (pH 5.0-6.5) which is typical of forest soil in the tropics. Up the highlands, the slopes become the limiting factor for other uses than forestry. Runoff is moderate to high due to the high permeability of soil. Erosion occurs in 27-55% of the area, the degree varying from moderate to severe.

Figure 10.1 Map of main rivers in northern Thailand



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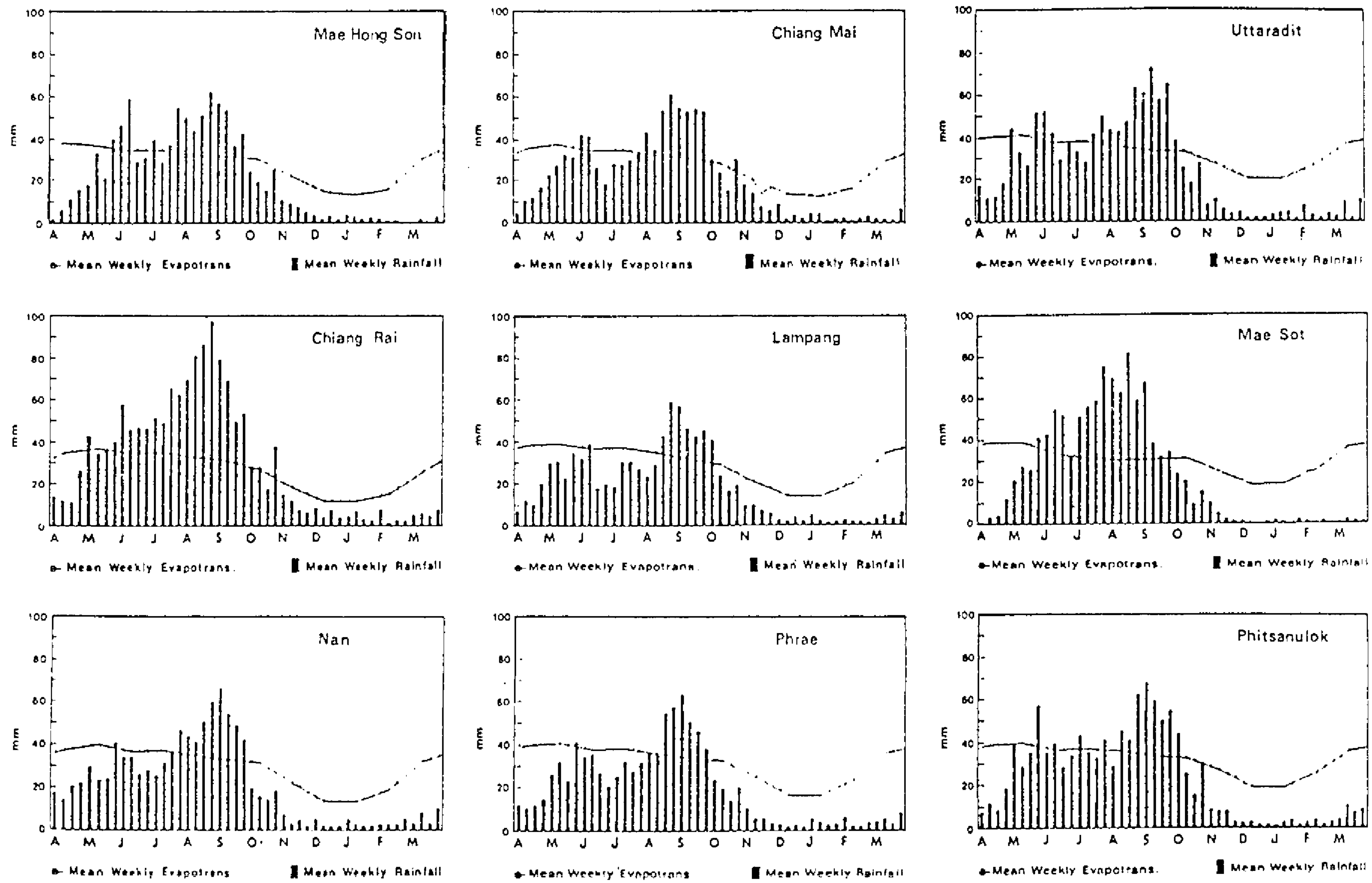


Figure 10.2 Mean monthly rainfall and potential evapotranspiration.

In any case, the soils have low fertility and inadequate in organic but sufficient in mineral content. Available soil moisture is low (about 50-100 mm/m^2) and is the major constraint to crop production when rain is inadequate, particularly in the growing season (June and July).

Mean monthly rainfall and potential evapotranspiration is shown in Fig. 10.2. It should be noted that there is a general tendency for drought to occur in July, which is the flowering time for rice and maize which are planted early in June. Thus, it is safest to plant in late July. The evapotranspiration calculated by the Department of Land Development as shown in Fig. 10.2 vs. precipitation shows the time when there is a surplus and a deficiency in moisture for plant growth. Even in the rainy season there is still a problem with water deficiency.

Agricultural Practice

Land is generally ploughed and planted in rows. Fertilizers are not widely used except for gypsum or ammonium sulphate. The area of main crop sown is shown in Table 10.6.

Table 10.6. Area of main crop sown (1982-83)

Crop	Area (million ha)	% total	Production yield (kg/rai)
Rice	2.15	54.0	346
Maize	0.94	23.6	280
Mungbean	0.39	9.8	96
Sorghum	0.11	2.8	121-206
Soybean	0.10	2.6	110-214
Sugarcane	0.09	2.3	650
Peanut	0.08	2.0	114-252
Cotton	0.06	1.6	90-201
Cassava	0.05	1.3	n.a.

Note: 1 ha = 6.25 rais

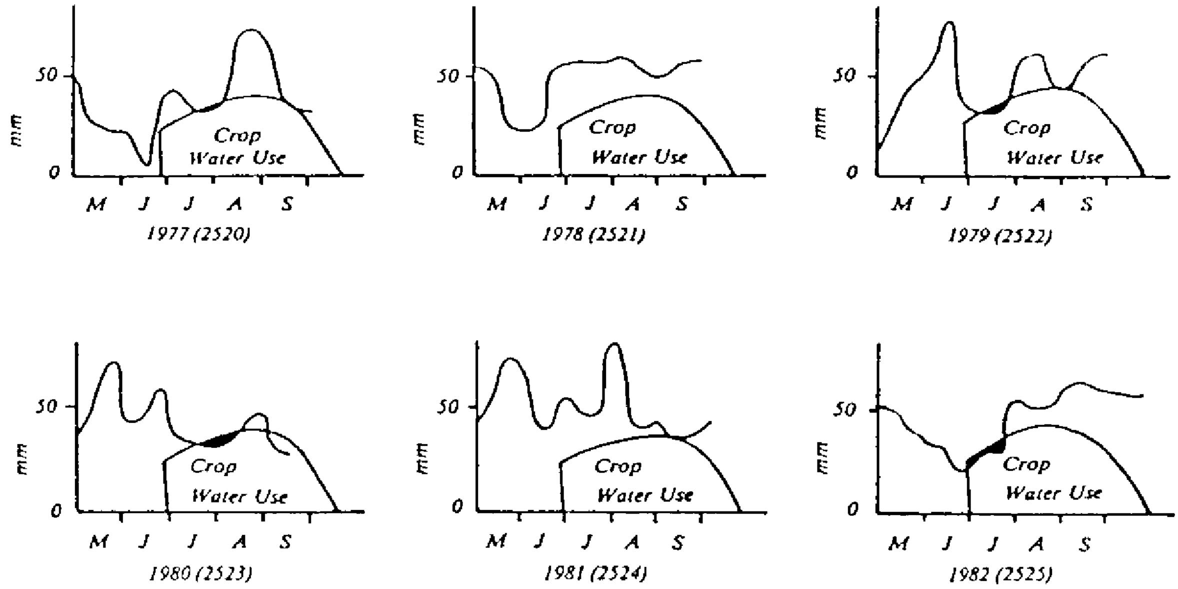
Climate Effects

Yield of rice has a strong relationship with rainfall, through a correlation coefficient (r) of 0.64-0.83 with July rainfall, and 0.61-0.69 with July and August rainfall, and only 0.24-0.62 with July, August and September rainfall (1972-83 data). As July is the "drought" month in the growing season, it produces the strongest impact on the yield. On record, the good years were 1973, 1977 and 1982, with bad years in 1979 and 1981.

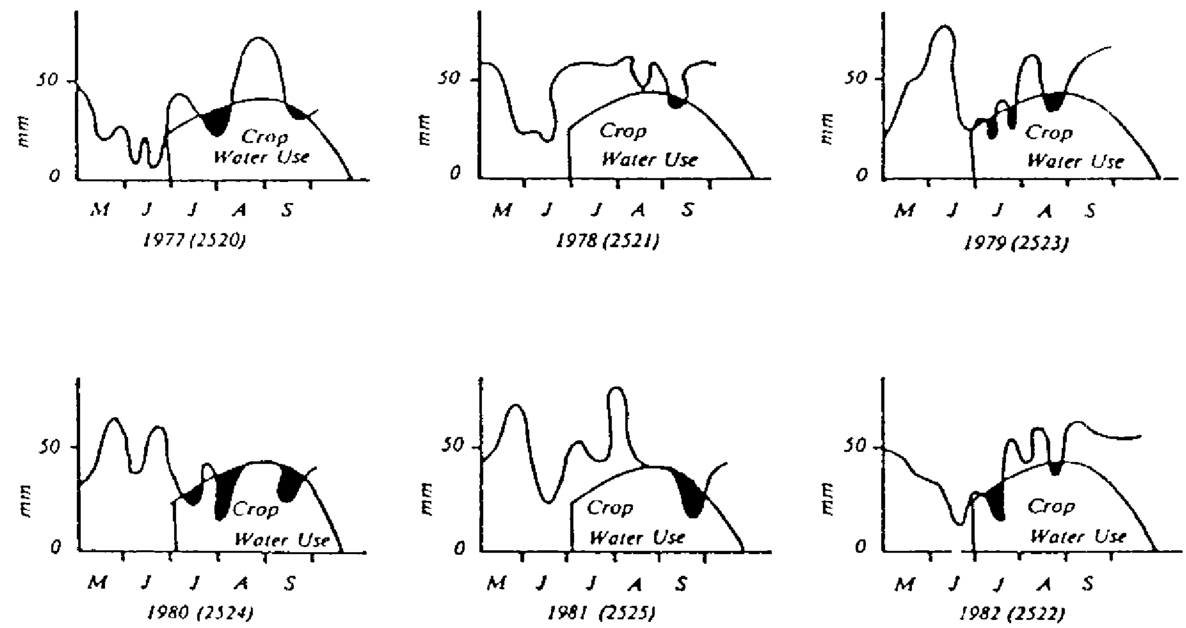
The trend for maize is not as clear, which indicates that maize is more resistant to drought. However peanuts show similar climate effects to those of rice.

Figure 10.3 Estimated total available moisture under (a) ponded and (b) drained conditions based on rainfall and wet season crop water use at Hang Chat over a six year period. Irrigation would be of benefit in the periods of moisture deficit indicated by shading.

(a) Ponded Conditions



(b) Drained Conditions



Under the present agricultural system for the case study area, maize is favoured in the areas of better soil and reliable rainfall, in alternation with blackbean and upland rice. On poorer soil, peanuts (pigeon pea) is favoured. On degraded land, maize, rice or cassava can be planted with some form of animal production as a measure of insurance in case of drought. The erosion problem is highest with peanut and mungbean, followed by soybean and rice.

Suggested system for agriculture to cope with climate change

As the GCM models do not predict large changes in the total, or pattern of precipitation, the major climate impacts will be caused by temperature increase with corresponding evapotranspiration. July will be the most critical period.

To retain enough water for the dry months, the method of bunding of rice lands and rice terrace in areas of marginal rainfall will be helpful, since in most areas of the case study, total rainfall is adequate for rice growing in ponded conditions.

As the area is not normally irrigated, strategic irrigation using small water storage (i.e. pond of 14 x 14m for each ha of land) will be beneficial. In Fig. 10.3, the benefits of ponding and strategic irrigation are shown and if both methods are used, good crops will result in almost every year, even in 1979 and 1981, which were considered to be bad years. However, the months of July and August produce severe water shortage condition for most years (except 1978). Thus, in the case of higher evapotranspiration due to increasing temperature, we can predict that the rice yield will be reduced due to water limitation even under ponding condition. However, if strategic irrigation is applied, it seems that the impact will be largely averted. Then rice will enjoy the benefit of CO_2 fertilization providing that water is available through July and August.

Discussion on the case study

The predicted impact of climate change on agriculture for Northern Thailand is that if strategic irrigation and ponded methods are both applied to ensure adequate water in July and August, then the area can benefit from the climate change, otherwise it will be severely impacted from drought. This conclusion may not be applicable to other areas of the Southeast Asia region but the method can be applied to an investigation of the problem.

The irrigation scheme to ensure water for agriculture in the dry months seems to be necessary to all areas in the region, since evapotranspiration will be the main cause of impact. Forests which rely on rain may be the most affected, unlike agriculture which can be irrigated, and if the forests are severely reduced then the question of irrigation will arise. This study thus does not recommend that governments allow forests to die out, but to study means of saving them. Changing crops to more weather-resistent species is not recommended as markets will be limited, and restricted by attitudes of farmers and consumers.

What should be done in the coming future

In climate change studies there is always mention of "waiting cost", that is, doing nothing until the situation arrives and then solving the problems as they arise. Agriculture and forestry, however, form the livelihood of the majority of the people in this region. From the study it is concluded that the effects will probably be adverse since non-irrigated areas will be affected, and most of the cropland is not being irrigated.

It is recommended that site-specific studies be conducted for important and representative crops and forests in the regions. Such studies are being performed under the UNEP Project "Socio-Economic Impacts and Policy Responses resulting from Climate Change"

These studies will in future answer the questions of what we should do to protect, and sometimes, gain from climate change. Crops can respond to fertilizers, better irrigation and soil drainage. Marginal lands will have to be changed for some other uses. Crop varieties can be introduced to adapt to the changes. The technology and the ability of the region's scientists are adequate for impact study and planning of mitigation measures.

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11. IMPLICATIONS OF FUTURE SEA LEVEL RISE ON COASTAL AREA UTILIZATION AND MANAGEMENT IN SOUTHEAST ASIA[2]

J.N. Paw & T.E. Chua

International Center for Living Aquatic Resources Management,
MC P.O. Box 1501,
Makati, Metro Manila, Philippines

INTRODUCTION

Carbon dioxide levels in the atmosphere have steadily increased as a result of burning of fossil fuels. In addition, atmospheric concentration of trace gases like nitrous oxide, methane and chlorofluorocarbons have also increased due to emissions from domestic, agricultural and industrial activities. These gases, known as greenhouse gases, trap infrared or thermal radiation leading to the warming of earth's surface, called the greenhouse effect (Ramanathan, 1988, Baes et al., 1981; Hansen et al., 1983; Jaeger, 1988; Titus et al., 1984). Projected temperature rises range from 0.06°C to 0.8°C per decade, beginning 1985 (Jaeger, 1988). However, warming will not be uniform due to various non-linear interactions of the atmosphere, oceans and landmass which could alter general oceanic and atmospheric circulation (Rodgers-Miller & Bardach, 1989; Ramanathan, 1988).

In the humid tropical region (latitudes 0°-30°), projected temperature rise will be about 0.3° to 5.0°C of global average by the middle of the next century. Hydrologic regime of evaporation and precipitation may rise as greenhouse gases concentration increases. Thus, rainfall could increase by 5 to 20% and possibly with more drought (Jaeger, 1988; Kerr, 1988). With global warming, present sea level will rise due to ocean thermal expansion and the increase in glacial melting (Jaeger, 1988; Barnett, 1983; Hoffman, 1983; Thomas et al., 1983). Although climate change modelling with respect to greenhouse effect has variable results on the regional level, this report will follow the climate change scenario adopted by the United Nations Environmental Programme (UNEP) for the East Asian Seas Region. This scenario assumes a rise in global temperature of 1.5°C and a corresponding sea level rise of 20cm by the year 2025. While this report will focus on the possible impact of sea level rise on the coastal area, effects associated with overall climate changes will be covered where necessary.

Impact of sea level rise on the coastal zone

Climatic change and accelerated sea level rise in the next century due to global warming may have significant impact on the coastal zone, especially on coastal resources, ecosystems and the myriad socioeconomic activities therein. Reviews on the possible impact of sea level rise have been given by Bardach (1988), Jaeger (1988), Converse (1987), Sorensen et al. (1984) and Titus et al., (1984). Some of the physical impact of sea level rise have been discussed by Sieh & Lee (1989). The impacts of sea level rise are:

1. Coastal erosion

Erosion could alter shoreline configuration as well as causing shore retreat and narrowing or loss of beaches.

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[2] ICLARM Contribution No. 542.

2. Inundation

Low-lying coastal areas and wetlands could be vulnerable to inundation at high sea level rise, especially if high tide coincides with storm surges and heavy rainfall. Extensive damage and flooding could occur if protective structures against these phenomena are inadequate or absent.

3. Saltwater intrusion

Higher sea level of is likely to increase saltwater intrusion in insular and coastal (continental) freshwater aquifers. With the projected increased storm frequency and drought, salt intrusion along tidally influenced rivers could extend further inland than present range.

Implications of future sea level rise on the coastal areas of Southeast Asia

The Southeast Asian region covers an area of 26.1 million km^2 that extends from 15°S to 26°N latitude and from 93°E to 149°W longitude (Morgan & Fryer, 1985). Table 11.1 shows the land area and coastlines of Southeast Asian countries. The region is highly populated with some 70% living on the coast. In addition, its coastal resources are vast and varied and support a wide range of diverse economic activities.

Impact on coastal utilization

The coastal resources in the region are heavily utilized. Solar salt-making, mangrove exploitation and fishing are some of the important socioeconomic activities that could be affected by sea level rise. These three activities are prevalent in most ASEAN countries with the exception of Singapore, and to a lesser extent Brunei Darussalam.

Table 11.1. Areal extent and coastlines of selected Southeast Asian countries.

COUNTRY	Areal Extent (km^2)	Coastline (km)
Brunei Darussalam	5,699	161
Indonesia	1,491,564	80,791
Malaysia	329,735	4,675
Philippines	300,000	17,460
Singapore	620	132
Thailand	514,000	2,960

Sources: Haeruman, 1988; World Bank, 1988; Pitman, 1985; Samson, 1985; Knox and Miyabara, 1984; SEAFDEC, 1987)

Salt-making through solar evaporation of seawater is an important small-scale industry in many coastal areas in the region (Bardach, 1988). Salt production is seasonal, mainly during the dry season. It is done in shallow coastal ponds with depths of not more than 5cm. The rise in sea level could erode and flood salt ponds that are sited very close to the seashore unless some protected structures like high peripheral dykes are built. Otherwise it may be necessary to relocate such ponds elsewhere or entirely abandon them. Although production is seasonal, changes in precipitation due to climate change may shorten it for some areas while longer production periods could be experienced during drought.

Mangrove resources exploitation is a traditional economic activity in the region (Paw & Chua, 1988; Bardach 1988). The rise in sea level will most likely result in a retreat of mangrove vegetation further inland. However, it may disappear if such retreat is not possible due to natural or artificial barriers. Hence coastal communities that are dependent on this resource could be affected. It may be necessary for these communities to seek alternative sources of livelihood to augment income. However, in managed areas or reserves, such conditions may not be severe.

Another traditional coastal activity is fishing. The majority of those engaged in this activity are subsistence fishermen (Samson, 1985; Torell, 1984). At present, fish catch has shown some decline and many fishing grounds are heavily exploited (Pauly & Chua, 1988). Sea level rise impact could affect fish habitats like mangroves and estuaries including coral reefs, and may lead to changes in species composition and distribution of important fish and crustaceans (Bigford, 1989). Fish landing areas and other stationary fishing structures could be damaged, especially during storm surges. Moreover, climate changes could alter the productivity of coastal waters (Bardach, 1988) and diminish catches in some areas and compound the socioeconomic problems that already occur in these areas (e.g. poverty, conflict between commercial and subsistence fishermen, etc.).

Coastal tourism and recreation

Many countries in the region have numerous scenic coastal sites like beaches, coral reefs and islands which are increasingly attracting both local and international tourists. Coastal tourism has become an important industry providing substantial foreign exchange earnings. In Thailand, tourism contributed about 3.4% of the country's gross domestic product (GDP) in 1986 (Dobias, 1989) while for Singapore, GDP from 1980 to 1983 was 6% (Chia et al., 1988). Well-known tourist resorts in the region are Bali, Indonesia; Johore and Sabah, Malaysia; Puerto Galera, Boracay and El Nido, Philippines; and Pattaya, Phuket and Ko Samui, Thailand. Singapore is also a major tourist venue known largely for its recreational facilities like golf clubs, swimming pools, botanical garden, water sport complexes and museums. Singapore has very few beaches catering for tourists due to a competing demand for space for shipping, port and marine-related industries. Notable tourist island in Singapore is Sentosa. Apart from recreational facilities, Sentosa's other attractions include the World Insectarium (one of the largest collections of insects in the Asian region) and Coralarium (houses rare and live corals and other marine lifeforms) (Chia et al., 1988).

As mentioned earlier, sea level rise could erode beaches and affect beach resort structures, particularly if these are inappropriately constructed or where no protective structures are built. At present, many of the region's prime beach resorts have been established without adequate planning, resulting in highly eroded beaches and poor delivery of basic services (e.g. La Union, Philippines and Pattaya, Thailand). Possible beach control systems have been discussed by Sorenson et al. (1984). The impact of sea level rise on the coastal geomorphology of the ASEAN countries has been examined in detail by Wong (1990).

With the projected sea level rise of 20cm, it is unlikely that major coastal resorts will be severely affected unless local subsidence occurs. However, it is possible that some basic services could be affected, since some of these are currently poorly instituted. These services include potable water, particularly in islands where it is derived from aquifers or rain, waste disposal systems (leaching or wash out of solid wastes or clogging/overflow of drainage system due to possible backflow during high tide and storm surges), and transportation systems (damage to coastal roads and wharves).

Coastal aquaculture

Coastal aquaculture, particularly shrimp culture, contributes substantially to the foreign exchange earnings of many countries in the region. The predominant culture system is pond culture, which is typically sited in reclaimed mangrove areas. Penaeid shrimp and milkfish are major species being cultured. Marine netcage systems for seabass and groupers, and raft or stakes for mollusc culture are also employed. Some molluscs like blood cockles are generally cultured on mudflats as in Thailand and Malaysia, while seaweed like Eucheuma is cultured in reef flats in the Philippines (Chua et al., 1989). A summary of the aquaculture systems employed in the region is shown in Table 11.2.

Table 11.2. Coastal aquaculture systems in the Southeast Asian region (adapted from Chua & Paw, 1987).

	Culture system						
	Pond	Cage	Pen	Raft	Longline	Pole/ Stake	On-Bottom
Brunei Darussalam	4	4	-	-	-	4	-
Indonesia	1	1	-	4	-	4	3
Malaysia	2	2	-	-	-	-	2
Philippines	1	2	2	2	3	2	3
Singapore	3	2	-	3	-	-	-
Thailand	1	2	-	3	-	-	2

Legend: 1 - Predominant system
2 - Moderate scale
3 - Small scale
4 - Experimental or pilot scale

Brackishwater ponds are typically sited along the coast with an elevation of not more than 2m above mean sea level for ease of water exchange. The projected 20cm sea level rise would possibly have minimal impact on such ponds but may be significant if high tide coincides with a storm surge. Such condition could cause erosion of dykes or inundation if the dykes and water structures are inadequately built. Possible wash-out including loss of stock may also occur. Aquaculture areas where such ponds are located include Citarum Delta, Indonesia; Pampanga-Bulacan, Pangasinan and Capiz, Philippines; Chao Phraya delta and Ban Don Bay, Thailand. A sea level rise of 1m along the Chao Phraya delta could inundate or submerge ponds sited in it unless protective structures are built which may entail considerable costs (Fig. 11.1). Otherwise, these ponds will have to be abandoned. On the other hand, coastal agricultural lands which may be affected by sea level rise could be converted into brackishwater ponds instead of being abandoned.

Aquaculture structures sited in coastal waters like net cages, raft and mollusc stakes could be damaged if high tides coincide with storm surges. The latter may have to be sited closer on shore if sea level rises. However, this will depend on several factors like suitability of site and presence of spat. It is projected that climatic change will affect the distribution of species and possibly laval settlement (Chua & Paw, 1989). Culture areas (mudflats) for blood cockles could be inundated or eroded as sea level rises. Thus some of these areas will have to be abandoned or culture activities sited elsewhere.

Modelling to determine sea level rise and climate change impact on aquaculture areas in the region is needed to establish which areas would be vulnerable to such impact. In view of this uncertainty, the impact of sea level rise and climate change on aquaculture can only be generalized in most cases. Fig. 11.2 summarizes the possible implications of sea level and climate changes on aquaculture.

Coastal settlement and industrial development

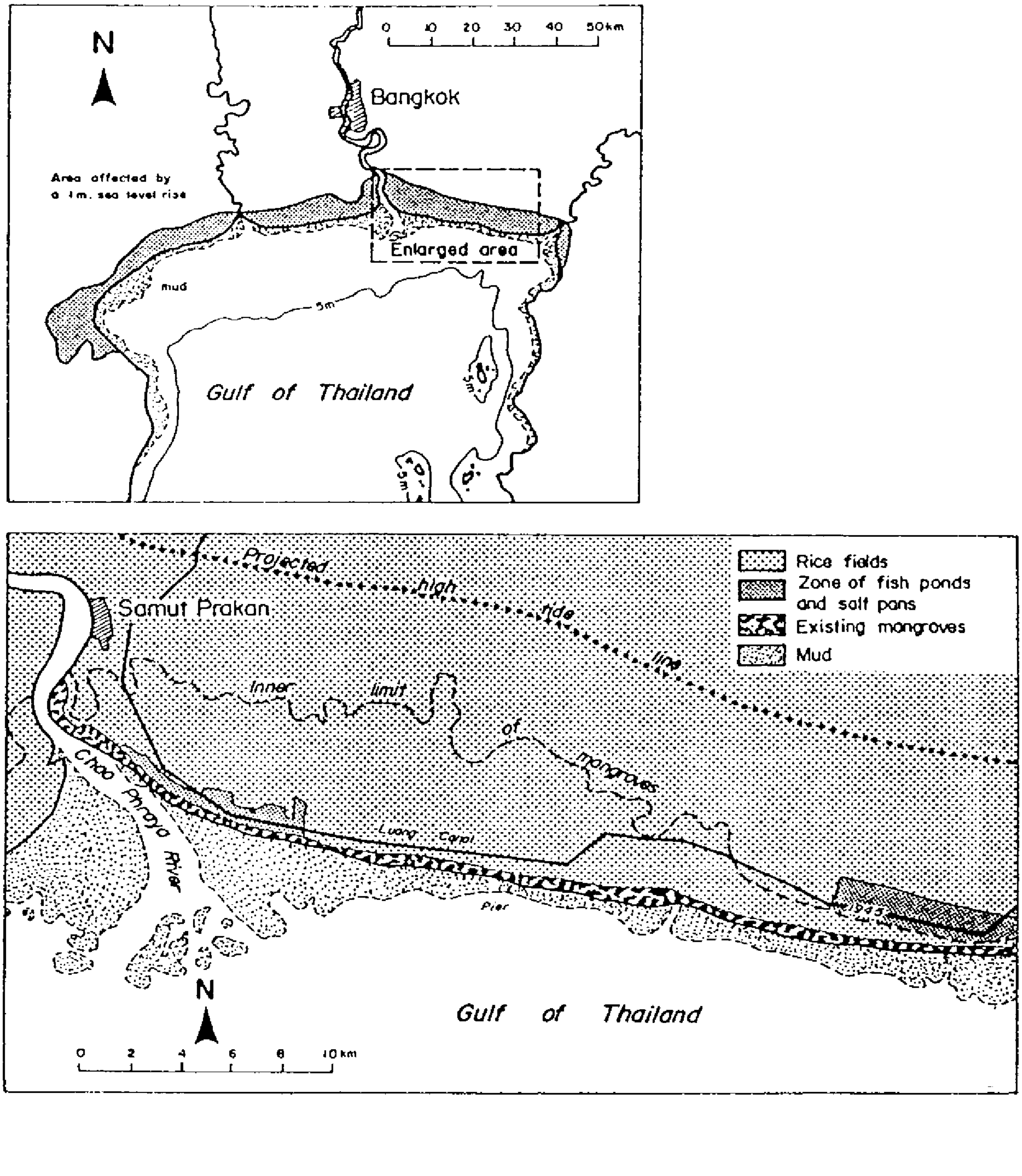
Major cultural, commercial and industrial activities are generally concentrated in urban centres in the region (ESCAP Secretariat, 1986; NEDA, 1987; Cheong & Sieh, 1985). Rural areas are typically underdeveloped although many governments in the region have plans to site industrial development in these areas. Coastal urban centres like Bangkok, Jakarta, Manila and Surabaya (Indonesia) are densely populated ($>$10,000 persons/mi^2) as compared to rural areas ($<$1,000 persons/mi^2) (Almanac, 1989). This is because of the perceived socioeconomic opportunities that are available in such centres. With the burgeoning populations in these coastal cities, basic services like water and waste management systems have become inadequate and inefficiently managed, if not acute including housing facilities (ESCAP, 1982). Flooding is common during heavy rains, particularly in low-lying areas due to inadequate drainage and pumping systems, and obstruction of waterways by solid wastes and proliferation of illegal shanties. This situation is compounded when high tide coincides with storm surge which create backflow along river systems that are generally used as drainage. Urban centres that frequently experience flooding are Bangkok, Jakarta and Manila, see Figs. 11.3, 11.4 and 11.5 (ESCAP, 1982; DPWH, 1988; Phanapavudhikul, 1987).

Singapore, being a city state and highly maritime, has a relatively efficient and adequate water and waste management system despite high population density ($>$32,000 persons/mi^2) (Chia et al., 1988; Almanac, 1989). It has excellent port facilities and extensive industries like petroleum and petrochemicals, ship-building, ship repairing, oil rig construction and manufacturing. Some of these industries are located on offshore islands as well as on the main island of Singapore (Chia et al., 1988).

Similarly, industrial and commercial activities are very extensive if not concentrated in major coastal cities like Bangkok, Jakarta, Manila and Penang Island (ESCAP, 1982; Phanapavudhikul, 1987). In contrast with Singapore, industrial waste management is inadequate and inefficient in these cities, creating pollution problems. Most of the wastes (particularly liquid wastes) are discharged into waterways which eventually go to the sea. Treatment of wastes is relatively uncommon, although in Malaysia, palm oil mill and rubber effluents are treated prior to discharge into rivers or the sea (Ong et al., 1987). Most of these industries are typically sited along river banks except for marine related industries.

The impact of a projected 20cm sea level rise by year 2025 on these coastal cities may be minimal except those low-lying areas which have no adequate protective structures (e.g. seawalls and revetments). However, backflows during heavy rainfall coinciding with high tide or storm surge could flood these cities and may even inundate low-lying areas for considerably longer period than is now presently being experienced. In coastal rural areas, on the other hand, sea level rise impact could erode the seashore, inundate low-lying areas and render freshwater aquifers salty. Water villages, especially those located in estuarine areas like Kampong Ayer in Brunei Darussalam could be vulnerable to such impacts and may have to install necessary protective structures (e.g. dams or pump lift drainage) in order to minimize economic loss and human lives.

Figure 11.1 The Chao Phraya delta showing the shoreline at 1m projected sea level rise (modified after Bird, 1988).



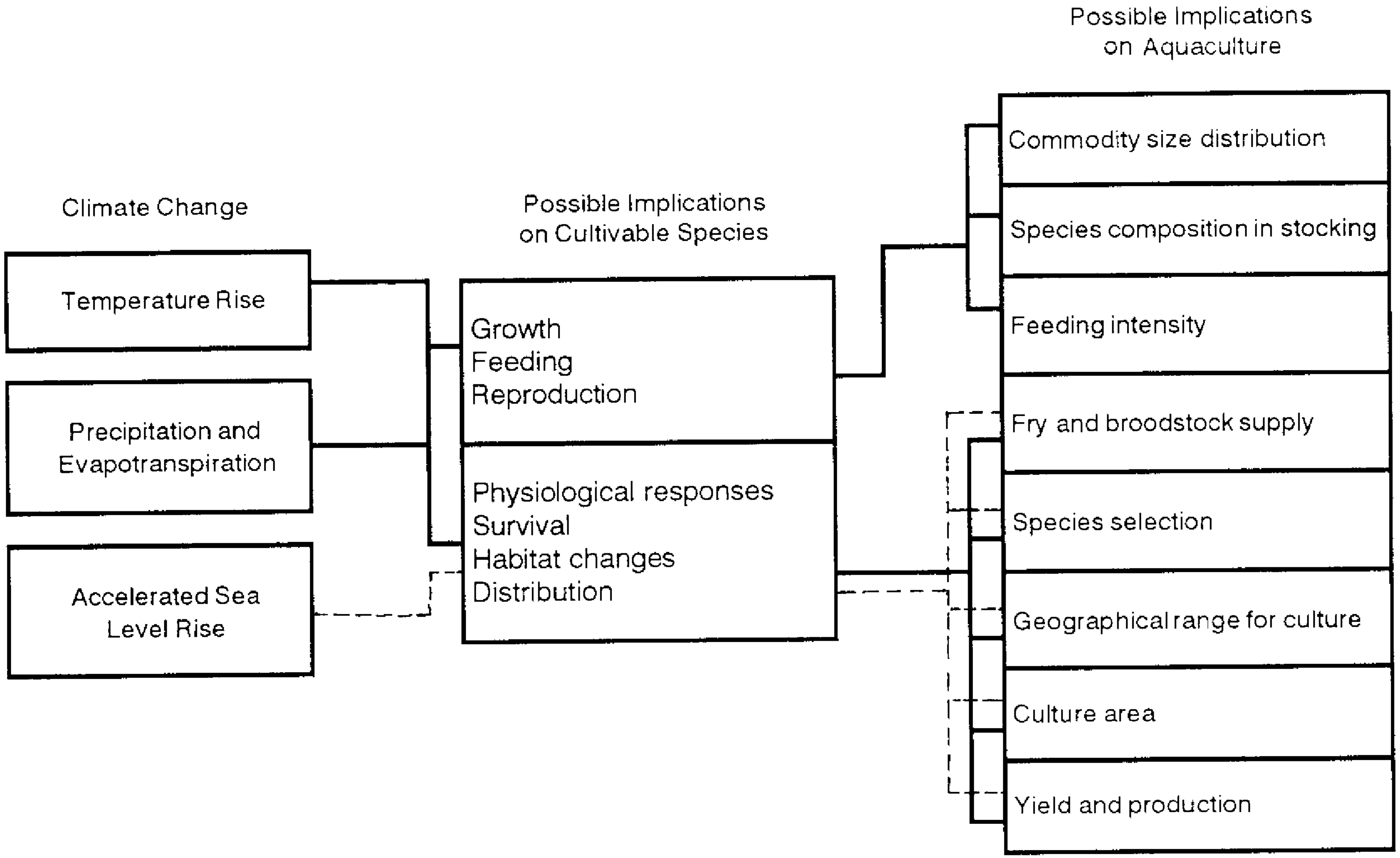


Figure 11.2 Summary of the implication of climate change and sea level rise on aquaculture species and systems (adapted from Chua Paw, 1989).

Figure 11.3 Flood prone areas of Metro Manila, Philippines during 1987 (DPWH 1988, JICA 1989)

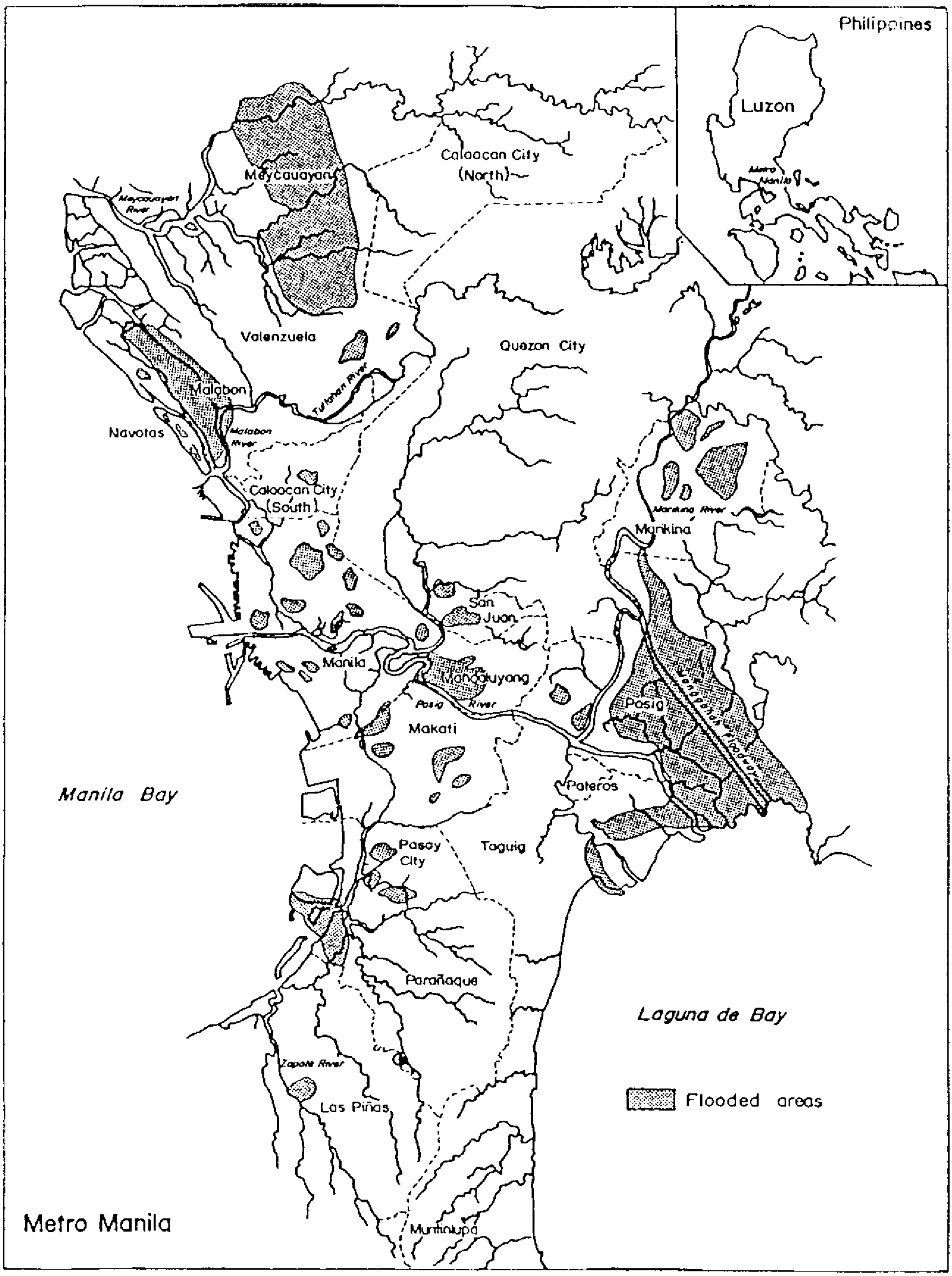
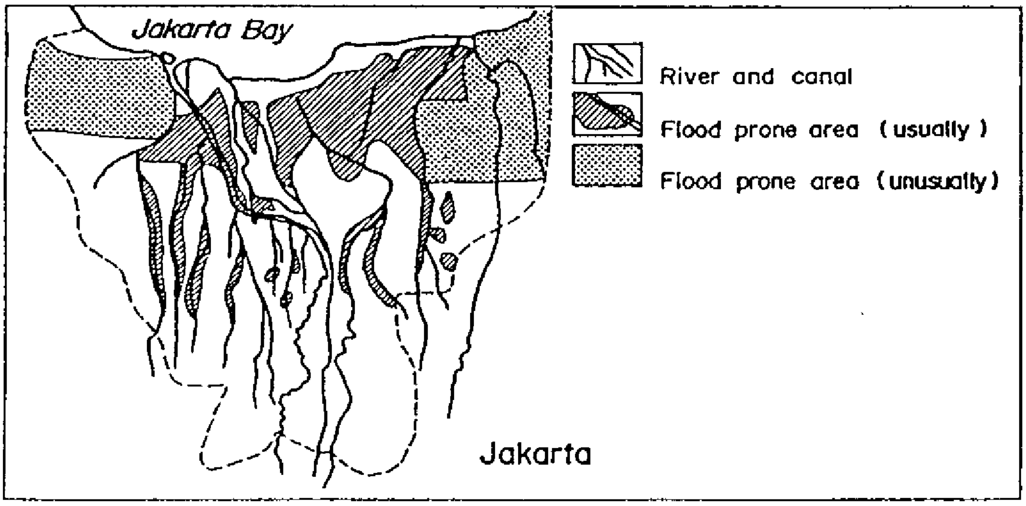


Figure 11.4 Flood prone areas of Jakarta, Indonesia (ESCAP, 1982).

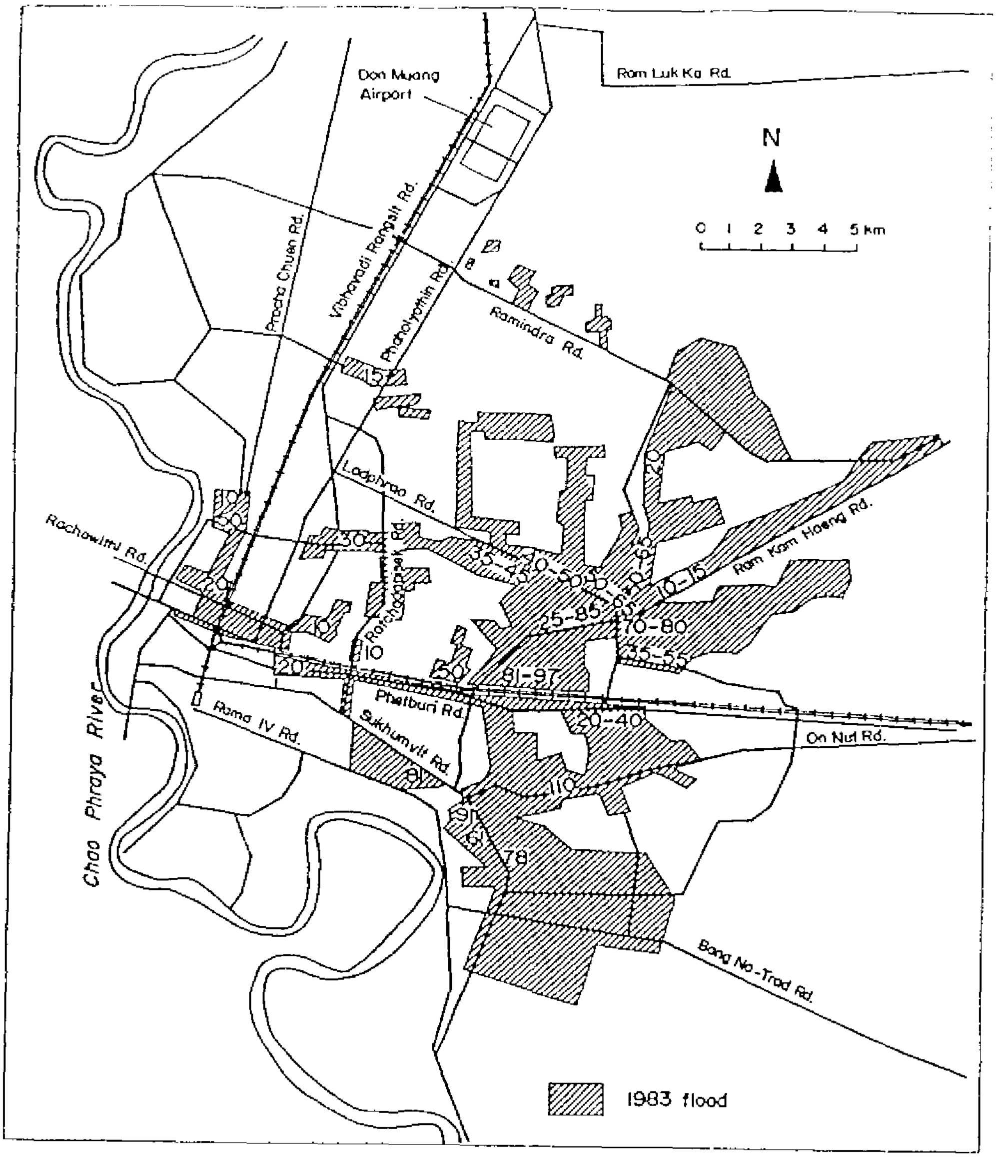


Industries (e.g. refineries and oil depots) sited along the coasts may need necessary structural adjustments and reinforcement in order to cushion increased hydraulic loading brought about by sea level rise as well as the impact of climate changes like changes in rainfall pattern and storm frequency. These adjustments should also be extended to port and harbour facilities in order that these facilities remain useful (Bardach, 1988; Vellinga, 1988).

In urban and industrial centres, serious socioeconomic dislocation could occur if basic services like water supply, energy supply (electricity) and waste disposal system are disrupted. Bad weather conditions, especially during severe storms often cause such disruptions resulting in some loss of life and property. It is not difficult to imagine a bigger magnitude of damage with respect to the greenhouse effect. Water supply for drinking, irrigation and other uses must be managed properly to meet the needs of population and socioeconomic activities. In the case of Bangkok, heavy groundwater extraction has caused subsidence and salt intrusion (Nutalaya et al., 1988). Shortage of water supply, especially for densely populated areas is due to poor planning and management. Moreover, present water supply systems are generally designed without consideration of the flexible absorptive capacity of such systems with respect to climate changes (not necessarily associated with greenhouse effect) and increasing population pressure (Riebsame, 1988).

Waste management in the region is an important issue that must be addressed with respect to sea level rise and climate changes. Presently, wastes from industrial, agricultural and domestic sources are causing serious problems in the region ranging from obstructed waterways, flooding, environmental degradation and diseases (Ong et al., 1987; Chia et al., 1988; Phanapavudhikul, 1987)). Flooding and submergence of waste dumping sites could leach out hazardous substances like heavy metals, toxic chemicals and pathogenic organisms contaminating soil and water causing potential health risks (Flynn et al., 1984). Sea level rise and climate changes associated with the greenhouse effect could exacerbate such conditions.

Figure 11.5 Flooded areas of Bangkok in 1983 indicating the flood depth (cm) (adapted from ESCAP, 1986)



CONCLUSION

The coastal resources of Southeast Asia are rich and varied and support a wide range of diverse economic activities. Population pressures and rapid economic development have contributed to the heavy exploitation of these resources including pollution, habitat degradation and resource use conflicts due to sectoral lack of coordination and poor planning. Although these issues are beginning to be addressed, management strategies being developed focus on sustainable development of these resources and generally assumes climatic stability.

Climate changes associated with greenhouse effect and the consequent sea level rise could compound existing coastal resource management problems. It is expected that extensive land-use changes will be necessary in order to adjust and compensate for the impact of sea level rise and climate changes by the next century. This would include zoning, particularly of high risk areas (e.g. flood prone areas; dump sites; erosion prone areas). Thus, it is imperative that current coastal resources management strategies being formulated must include climate risk factors to cushion the impact of climate change associated with greenhouse effect. Similarly, national development plans should be amended to include such factors. Understandably, this greenhouse effect phenomenon is not familiar to many policy-makers in the region and as yet no concrete observational data are available to seriously convince them. Hence, uncertainties regarding regional projections of climate change and sea level rise must be resolved in order that policy-makers in the region could integrate these into national development plans.

RECOMMENDATIONS

The following recommendations are made :

1. Concerted research efforts are needed to measure the greenhouse gases and determine their impact on climate and sea level rise through modelling. Regional climatic change modelling, especially for Southeast Asia, is needed.

2. Research and monitoring of sea level changes should be established which will take into account local variations in the region.

3. Inventory and mapping of coastal types using remote sensing and geographic information system. There is also a need to determine precisely which areas will be vulnerable to impacts associated with climatic change and sea level rise as well as developing scenarios that will show the possible extent of impact in these areas.

4. Research and monitoring of the socioeconomic activities in coastal areas.

5. Research on the coastal geomorphology of the region.

6. Identification and zoning of the high/low risk areas to sea level rise. Where this is available, coastal development should be controlled or stopped in high risk areas to minimize economic loss and harm to human life.

7. Waste management and waste drainage systems in the region have to be improved with appropriate consideration to proper dumping sites and freedom from obstruction. High risk zones which are susceptible to flooding and inundation should not be used as dumping grounds.

8. Water management systems in the region should also be improved. Groundwater pumping should be stopped where land subsidence is already creating grave problems to the community. Climate risk factors should be included in water management planning to provide a flexible absorptive capacity in water management facilities, particularly in urban areas.

9. Preventive mechanisms against flooding, erosion and impact of climatic change should be formulated and evaluated with respect to the capacity of the countries within the region to implement them.

10. Compensatory mechanisms and regulatory responses to the loss of coastal properties associated with sea level rise should be formulated. Current natural hazard management regulations should be evaluated to incorporate future sea level rise impacts.

The countries in the region may not have the capabilities to conduct the first two recommendations as these will involve funds and technical knowhow, not to mention appropriate facilities. Developed countries are in a better position to do these. However, joint research efforts between the countries in the region and the developed countries are feasible to address these issues particularly in relation to the local and regional impact of climatic change and sea level rise.

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12. IMPLICATION OF CLIMATIC CHANGES ON HUMAN SETTLEMENTS

H. Uktolseya

Ministry of State for Population and the Environment[1]
Jl. Merdeka Barat No. 15
Jakarta Pusat, Indonesia

INTRODUCTION

The Indonesian archipelago is situated between the Asian and the Australian continents, and between the Pacific and the Indian oceans, and consists of about 17,508 islands with more than 81,000 km of coastline. With a high and even temperature throughout the year and high humidity, the geographical position also explains the monsoonal nature of the climate. Rainfall in Indonesia and the adjacent areas is regarded as the most important feature of the climatic and weather conditions; due to its impact on agriculture and on other economic activities such as construction, transportation, and tourism as well as other social aspects.

Besides rain, excessive droughts are the foremost concern of the people in Indonesia. Severe droughts were experienced during 1961, 1963, 1965, 1967, 1972, 1976-1977, 1982-1983, and during the five-year and other cyclical patterns which cause severe damage and other socioeconomic impacts in the country.

Surface temperatures of the seas in and around Indonesia are the highest in the world and this spot of high surface temperature moves west to east and back again from this areas towards South America, giving rise to the "El-Nino and Southern Oscillation" phenomenon or ENSO.

The weather of the Indonesia archipelago is closely related to the Southern Oscillation. The 1982-1983 drought was the worse drought in a decade which had an impact on rice production. Rice production in Indonesia has increased consistently since the early 1970s. As a result of a series of measures aimed at improving production factors such as irrigation, new seed varieties, fertilizers and pesticides, credit availability and marketing, Indonesia has progressed from being the largest importer of rice at the end of 1970s to being self-sufficient in this basic commodity. The impact of the 1982-83 drought on rice production in Indonesia can be summarized as follows :

- the overall effect was not a decrease in production, but a drastic reduction in the growth rate (which remained positive);
- the drought effects were concentrated in the eastern part of the archipelago;
- the drought affected the dry-season crop of 1982 and delayed the planting of the 1982-1983 wet-season crop;
- production of secondary crops that were much affected in 1982 rebounded in 1983. Crop substitution mitigated the impact of the drought;
- at the National level, the main consequence of the drought was that it postponed the realization of self-sufficiency objectives until 1984, and the 1982-1983 production represents a major setback in this respect;

[1] Present : Ministry of State for the Environment

- despite the intensity of the drought, the rice production system in Indonesia appears to have shown good resilience inasmuch as no province returned to the pre-1980 production levels and, by 1984, the situation appeared to have returned to normal. Current views that intensive agriculture systems are becoming increasingly susceptible to climatic variations may have to be revised in light of these observations.

Drought and the forest fires of Kalimantan were felt as the most dramatic and disastrous effects of the 1982-83 dry weather in Indonesia. The drought in East Kalimantan was so pronounced in 1982 and early 1983 that it led to serious damage to the tropical evergreen forest, which was hitherto believed to be protected from climatic events. The drought and fire damaged an estimated 3.5 million hectares in East Kalimantan alone, with such a magnitude that it prompted the IUCN to call it one of the worst environmental disasters of the last century. The loss in revenue for the Indonesian Forestry sector has been estimated at more than US$6 billion (in terms of damaged logs and reduced growth), together with many other socioeconomic impacts. The fires appeared to have been triggered by agricultural practices, which include burning as a land clearing procedure. Site and soil factors influenced the impact of climate and have, to a large extent, determined the susceptibility of vegetation to drought and fire.

Consequently, it could be concluded that the two very different ecosystems in Indonesia showed contrasting responses to the 1982-1983 drought. Both have been affected but to varying degrees. Through various measures, the intensively managed wetland rice production system was somewhat protected from disastrous consequences that had affected it in previous dry years (e.g. 1972, 1976). No decrease in production was recorded at the national level, and the temporary reduction in the production growth rate was quickly reversed, thereby reducing possible long-term consequences of the drought. However, the tropical forest of Kalimantan suffered one of its worst disasters in recorded history, due to a combination of an unusually prolonged drought and the outbreak of fires exacerbated by land-use practices.

HUMAN SETTLEMENTS IN THE REGION

At the "International Seminar on Human Settlements Development in Urban Areas" held in Jakarta during October 1989, the Executive Director of the United Nations Centre for Human Settlements (Habitat) stated that :

"In most developing countries cities are growing at a rate higher than the total population growth rate. What is particularly dramatic about this phenomenon is the speed at which it is taking place. A 6% annual urban growth rate doubles a city's population in 12 years, which gives an indication of the challenge facing urban policy makers and administrators, who already face tremendous backlogs in shelter, services and infrastructure for the existing population as well as for commercial, service and industrial establishments and enterprises".

Urbanization in Asia is proceeding at an unprecedented pace. Asia's urban population is growing at an average annual rate of around 3%. It doubled in the period 1960 to 1980 from 359 million to 688 million, and as the average rate of growth of the urban population is not expected to change significantly between 1980 and the year 2000, this implies a further doubling of the urban population to 1.2 billion by the end of this century. The bulk of this urban population growth is taking place in the developing countries of this region (Table 12.1). Changes in the distribution of urban and rural populations between 1980 and 1988 in Indonesia are shown in Table 12.2.

Table 12.1 Population structure and distribution in the East Asian Seas region.

Country	Total Population (x 1,000)	Men	Women	Urban	Rural	%Urban
Brunei Darussalam	224	n.a.	n.a.	n.a.	n.a.	n.a.
Indonesia	166464	82900	835640	42170	124294	25.3
Malaysia	15448	7780	7669	5905	5943	38.2
Singapore	2559	1303	1255	2559	0	100.0
Philippines	55120	27675	27446	21844	33276	39.6
Thailand	1604	25888	25715	10211	41393	19.8

note : n.a. = not available

Table 12.2 Urban and rural population distribution in Indonesia between 1980 and 1988 (from population census statistics).

	Urban (x 1000)		Rural (x 1000)		% Urban Population of Total Population	
Island	1980	1988	1980	1988	1980	1988
Sumatra	54814	78110	225145	279781	19.58	21.82
Java	229264	320497	682906	735105	25.13	30.36
Kalimantan	14413	20108	52756	63953	21.46	23.97
Sulawesi	16542	20637	87463	102528	15.90	16.76
Other Islands	13425	19361	91036	112087	12.85	14.73
Indonesia	328458	458713	1139307	1293454	22.34	26.18

Indonesia

The Kampung (=village) Improvement Program (KIP) implemented as an urban housing programme consists of developing the physical environment within the manpower capacity, income and productivity of the village population. This community development is aimed at raising communal consciousness so that self reliance and self help among the village community can be promoted. Usually in large cities the problem of village livelihood is too acute and the Government placed physical environment improvement as the top priority 20 years ago, especially in Jakarta and Surabaya, where the KIP, which involves very large numbers of people as well as area, has been successful for the relatively small investment per capita. Table 12.3 summarises the results so far.

Today about 6 million live in those kampung areas at a population density of 570 /ha and a growth rate varying from 3.66 - 4.62 per year between 1981 and 1988. The fast population growth has an impact on urban land which is in limited supply, resulting in increasing land price. The result is very apparent, especially in cities which do not have economic potential value - for instance areas prone to floods, neglected land, or urban open spaces which become weak spots for poor migrants to settle in.

Table 12.3. Results of the Kampung (= village) Improvement Programme

	Total Kampung Improved	Area in ha	Population affected
First Five Year Plan (1969-1874)	89	2400	1,200,000
Second FYP (1974-1979)	242	5806	1,918,000
Third FYP (1979-1984)	210	27275.5	641,900
Total	541	10953.5	3,809,000
Population density			348/ha

Malaysia

Malaysia's Housing Policy and Strategies are basically geared towards meeting the objectives of ensuring access to adequate and decent shelter to all its citizens particularly the low-income group. In implementing this policy both the quantitative and qualitative aspects of housing development are taken into account in order to ensure that the national housing programmes effectively contribute not only towards the provision of physical shelter as a basic social need but also towards improving and enhancing the quality of life of the people through the creation and development of decent and viable human settlements.

Planning and design considerations in Malaysia are accompanied by the basic infrastructural facilities and social amenities to safeguard the health and convenience of the inhabitants besides fulfilling their basic socio-cultural needs.

Legal measures adopted by the Malaysian Government ensure the adequate and decent provisions of shelter and the minimum standards required for a sound living environment.

The provision of shelter and a healthy living environment has and shall always remain an important facet of nation building in Malaysia as evidenced in each of the five year National Development Plan of Malaysia and the various policies and strategies laid out to ensure their successful implementation.

Singapore

Singapore had its housing problems in the post-war period for almost two decades. In 1960, the government took a firm stand and committed itself to tackle the problem squarely. For this a new authority, the Housing and Development Board (HDB) was set up and given powers to expedite the building of low-cost housing and solve the acute housing shortage problem. A totally new form of public housing development for Singapore was also adopted: high-rise, high-density housing, i.e. flats in multi-storey blocks.

This turned out to be a breakthrough. The HDB not only got the housing problem soon under control, it then went on to build homes for the middle income people. It brought about tremendous changes in housing stock. There was a large increase in good quality housing whilst at the same time the number of substandard ones continued to decline. Thus, for example, the housing stock grew by 50% between the census years 1970 and 1980, from 300,000 dwelling units to more than 460,000 units, mainly due to new public housing flats.

Of the 100,000 attap and zinc-roofed houses (many of the squatter dwellings belong to this category) existing in 1970, some 50,000 units had been demolished by 1980. In their place the stock of public flats rose rapidly from 120,000 units in 1970 to 340,000 units in 1980 to a further 620,000 units in early 1988.

In short, Singapore's experience in dealing with the shelter problem has been an uninterrupted process. It dealt first with the more severe aspects of the problem, that of bad housing and environmental conditions. It then moved on to provide housing for the next group needing adequate accommodation, the middle-income group. Then it went on to develop still better housing and subsequently aspires to bring good quality in living to all the public housing estates and new towns.

IMPLICATIONS ON HUMAN SETTLEMENTS

In Indonesia, human settlements and their development are coordinated by the State Minister for Human Settlements, but due to the "Sustainable Development" principle and environment considerations, an integrated management and development approach should be maintained within the related agencies involved to achieve the improvements in this context.

The Environmental Quality guidelines issued by the State Ministry for Population and the Environment will be used as guidance to provide the required consistency in urban and rural development for human settlements; these are based on the following considerations:

1. human settlement and newly planned urban areas should match the quality of houses to be built to improve both the environmental quality as well as the quality of the living space;

2. buildings and newly planned areas, should avoid or minimize the use of productive agricultural areas or agricultural areas already equipped with technical irrigation systems;

3. the interdependency of the human settlements and the surroundings should follow the urban rural system in order to stabilize the environmental function itself, like the water system, air system, soil system and climatic regime;

4. the newly planned human settlements will be built to be self-sufficient to avoid irregularities of traffic and other community behaviour;

5. to fulfill the need for more homes, urban renewal should be developed to improve the environmental quality of the human settlement, based on Spatial Planning procedures;

6. the role of community participation should be fully supported to avoid individual benefit, as according to the Basic Provisions for Agrarial purpose, while concentrating on Social Prosperity;

7. the development of human settlements and new planned areas should not disturb the original socio-cultural set-up of an existing location, such as: local architectural buildings, environmental aesthetics, landscaping and different styles of human settlements, in order to attract tourism.

A great deal of human settlement in Indonesia is situated on the coastal zone and low-lying areas near rivers and estuaries, and coastal zone management principles need to be incorporated with spatial planning requirements in these provincial areas. The predicted global sea level rise will cause major problems in coastal regions around the world, but the problems will be particularly severe in low-lying areas of the Indonesian archipelago and will affect human settlements situated in these areas.

It is necessary to begin planning now for the expected environmental change. Since the actual activities related to the impact of global climatic change are still in the initial stage, the data and information compilation system for such a purpose is still far from adequate, and therefore the following is required:

a. More information on patterns and rates of natural and human changes on the coasts of Indonesia at the present time; on changes in the levels of land-sea interactions;

b. Land use required for coastal regions in Indonesia, accompanied by assessments of the economic returns from such activities as shrimp farming and salt manufacture, as well as fishing;

c. Detailed surveys are required for each type of coastline (beaches and beach ridges, steep and cliffed coasts, estuaries and lagoons, deltas and coastal plains, mangrove coasts and former mangrove coasts) to estimate the effects of a sea level rise that is at first gradual, attaining 12 to 18 cm by the year 2030 and then accelerating to reach 1 m by the year 2090;

d. On the basis of land-use planning requirements, estimates are needed of the economic losses that will result from the predicted submergence and erosion by the sea, the number of people disadvantaged and displaced, and the impacts these socioeconomic changes will have on the immediate hinterland and other areas of Thailand where resettlement may occur, e.g. the losses in Aceh provincial area in September 1989 due to flooding from upland has been estimated at more than Rp. 2 billion (in terms of direct loss); maintenance costs against coastal erosion as in Bali and Padang (west Sumatra) of around Rp. 0.2 billion per year since 1980;

e. Also on the basis of land-use planning requirements, an attempt should be made to predict possible alternative land uses for areas behind submerged and eroded coastal regions;

f. Assessments are required of the preferred type and extent of sea wall construction to prevent coastal submergence and erosion, and the likely cost of such engineering works;

g. More data is needed on the techniques of moving intertidal and near-shore mud deposits onshore, or to sites off eroding coastlines, as a means of preventing erosion and submergence, and of maintaining coastal land areas by artificially raising them,

h. Assessments should be made of the possibilities and problems of retaining more freshwater inland as a means of promoting aquaculture, and of diminishing river flooding and sea level rise;

i. Existing policies of land and resource use in coastal areas (e.g. the management of mangrove forests) should be reviewed in terms of the predicted 1 m sea level rise during the coming century.

CONCLUSION

Although the activities on the "Implications of Climatic Changes on Human Settlements" programme is at an initial stage in Indonesia, together with other related programmes, it is obviously understood that responses in the country have to be widely developed by the people and related agencies within the Government, especially for human settlements, in order to face the threat of climate change impacts.

13. THE EFFECTS OF A PREDICTED SEA LEVEL RISE ON THE COASTS OF SOUTHEAST ASIA: SOCIO-ECONOMIC AND POLICY IMPLICATIONS

E.C.F. Bird & G.J. Missen

Department of Geography
University of Melbourne
Parkville 3052, Australia

PHYSICAL AND ECOLOGICAL EFFECTS OF A SEA LEVEL RISE

General Effects (Fig. 13.1)

A global sea level rise of 20 centimetres by the year 2025 will lead to marine submergence of low-lying sectors and extensive coastline erosion (Titus, 1986; Bird, 1988d). Such a rise will enable the highest tides to reach levels of at least 20cm above their present limits, allowing for a possible slight increase in tide range as near-shore waters deepen. On most coastlines the high tide line will move landward to well beyond the present 20cm contour because of the initiation or intensification of erosion. The extent of erosion will depend on how the near-shore sea floor is modified by erosion or accretion as the coastline migrates landward, and associated changes in the wave energy regime. The low tide line will also move landward, at least part of the existing intertidal area becoming permanently submerged.

The geomorphological and ecological changes that accompany a sea level rise may already be seen on coasts undergoing land subsidence (Milliman, 1989). Within the East Asian Seas region these probably include parts of the coast at the head of the Bight of Bangkok, some sectors of the west Malaysian coast, parts of the north coasts of Java and Sumatra, and some areas in Irian Jaya.

In seeking assessments of the nature and extent of such changes, it is useful to recognize three broad categories of coastline: steep and cliffed coasts, sandy beach-fringed coasts, and wetland coasts, most of which have extensive mangrove areas. Table 13.1 indicates their relative extent in each of the three countries so far examined. Coral ecosystems are treated as a separate category.

Table 13.1 Three broad catagories of coastline in Indonesia, Malaysia and Thailand

	Sandy beach coast	Steep and cliffed coast	Wetland coast
Thailand	56%	10%	34%
Malaysia	39%	14%	47%
Indonesia	32%	15%	52%

Notes: These are the preliminary estimates. The Malaysian figures apply so far only to Peninsular Malaysia. Substantial parts of the wetland coast have been converted into mariculture areas or reclaimed for agriculture and urban development.

Figure 13.1 Models of the effects of sea level rise (MSL_1 to MSL_2) on a variety of coastal types encountered in Southeast Asia.

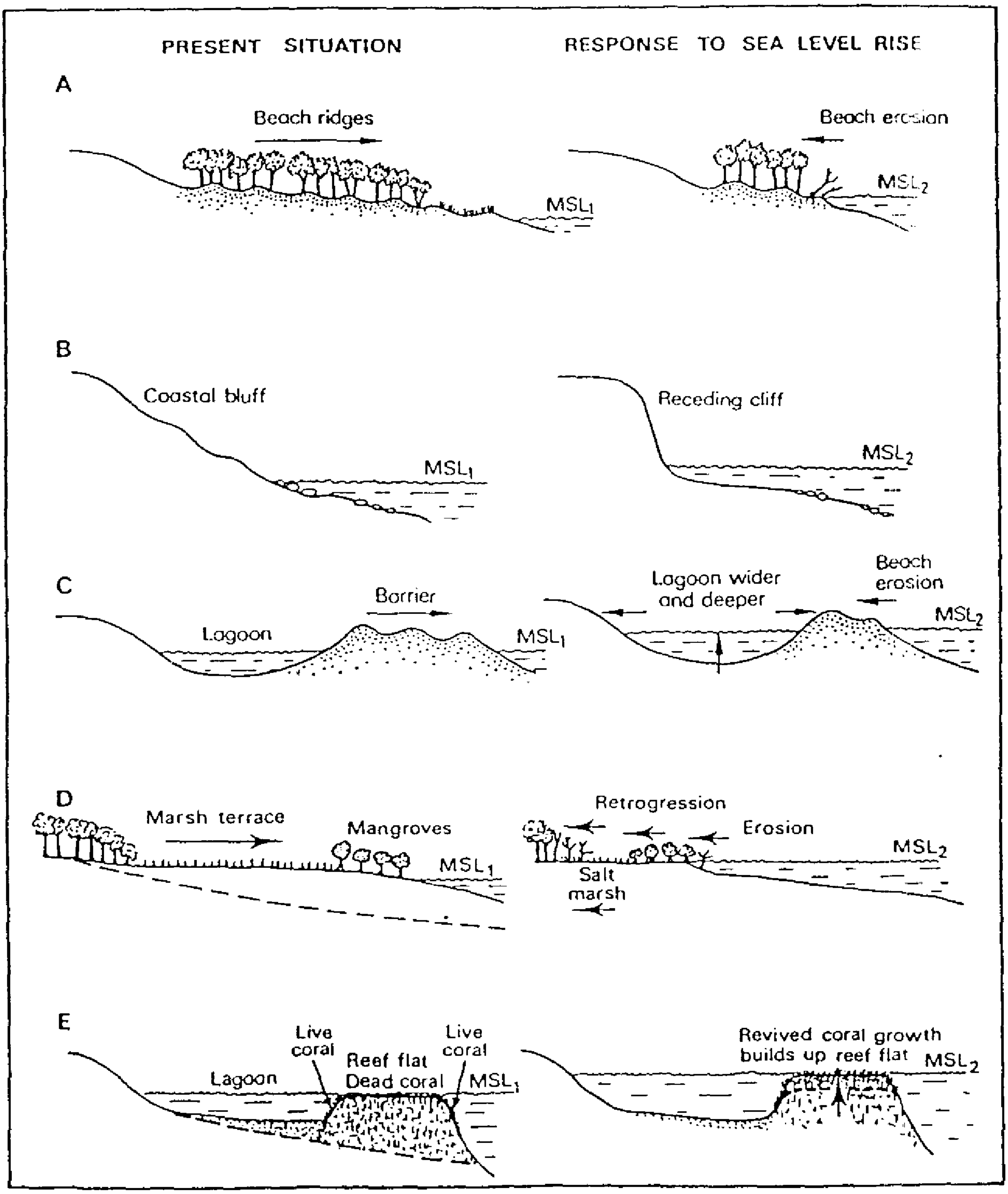
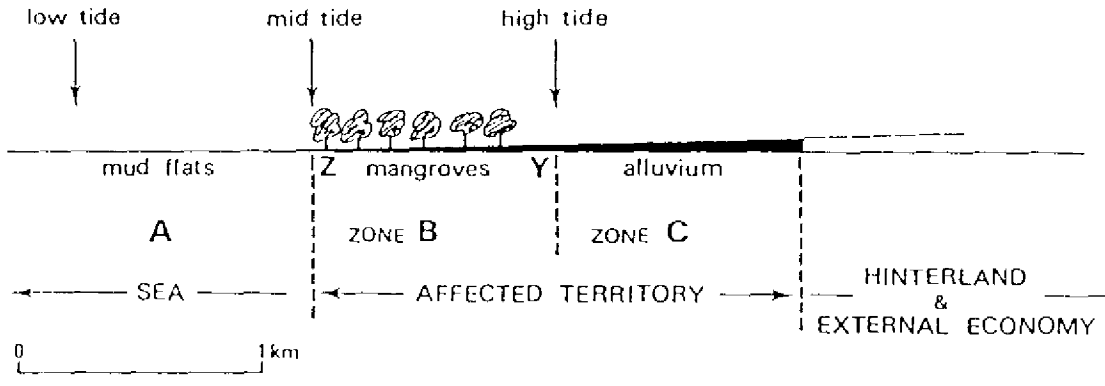


Figure 13.2 Generalized model of the coastal wetland



Sandy Beach Coasts (Fig. 13.1A)

Sandy beaches occur extensively in Southeast Asia. Some consist of sand washed in from the sea floor, which has locally been cemented to form beach rock; others have been supplied by rivers, especially those that drain relatively high catchments; and others are derived from the erosion of nearby cliffs. Many beaches are backed by low parallel sandy beach ridges, usually planted with coconut palms, and in places are backed by lagoons and swamps. This terrain, known as permatang in Malaysia, represents intermittent progradation by accretion of sand carried alongshore and in from the sea floor. Sometimes the beach ridges are surmounted by coastal dunes.

In recent decades there has been erosion on many of these sandy beaches, often as a consequence of diminishing sand supply from rivers or the sea floor. In Thailand and Malaysia, some beach ridge areas have been mined for detrital tin deposits.

The predicted sea level rise will initiate erosion on beaches that are at present stable or slowly prograding, and accelerate erosion already taking place. In general, submergence will result initially in the deepening of near-shore water, permitting larger waves to break upon the shore, thus increasing erosion. Beaches may disappear from sectors where they are narrow, and backed by high ground or mangrove swamps, but they will persist as erosion cuts back through beach ridge plains, where a 20cm rise is likely to cause recession of 20 to 40m beyond the limits of submergence (Bird, 1985). This will be reduced in areas where a sand supply, whether from cliff erosion, discharging rivers, or the sea floor is maintained at a sufficient level to compensate for the effects of submergence, but the indications are that these would be very restricted in Southeast Asia. If sea level continues to rise, beach erosion will of course become more extensive, and more rapid.

There has been extensive development of beach resorts for tourists in Southeast Asia. In many places, hotel and other tourist facilities have been built on low sandy beach ridges, and will be threatened as these are cut back by erosion as sea level rises.

Steep and Cliffed Coasts (Fig. 13.1B)

Steep coasts in Southeast Asia are generally slopes mantled with weathered materia held in place by a scrub and forest cover, rather than actively-receding cliffs. Occasionally there is slumping of the weathered mantle, especially after the slope floor has been undercut by storm waves. A rising sea level will increase wave attack at the base of these bluffs, causing increased slumping, while existing cliffs will retreat more rapidly.

Where there are buildings, roads, and other structures close to the crests of cliffs and steep coastal slopes, increased undercutting and slumping of the weathered mantle may result in structural damage. For example, hotels have been built on top of headlands bordered by steep coastal bluffs near Pattaya, in Thailand, and a rising sea level is likely to lead to demands for expensive engineering works to protect these sites.

Active cliffing is seen on the more exposed shores of promontories and islands, washed by ocean swell and waves generated by the south-west monsoon, as on the Andaman Sea coast of Thailand and the south-west coast of Sumatra. Where the cliffs are eroding very slowly, cut into resistant rock, such as the limestones of the Phuket region, a rising sea level will have little effect, but softer formations such as volcanic ash cliffs in southern Java will be cut back more rapidly, and land losses will ensue.

Wetland Coasts

There are large areas of swampy lowland on the coasts of Southeast Asia, especially on the deltas of large rivers which have delivered vast amounts of silt and clay to prograde the coast. Swampy lowlands also fringe estuaries and coastal lagoons. Associated with these lowlands are extensive mangrove swamps, backed by marshes and areas of freshwater forest.

Sedimentation from rivers is still prograding deltaic areas and infilling coastal lagoons, and this will continue if runoff from river catchments is maintained, or increased, during the expected global warming. A sea level rise will curb the growth of deltas, and if the rate of submergence is greater than the rate of fluvial deposition, delta shorelines will be cut back.

The larger rivers in Southeast Asia have high water and sediment yields to the sea, and only their lower reaches are estuarine. A rising sea level will result in submergence and widening of the mouths of these rivers, and the increased penetration by salt water, which may also invade underground aquifers. Coastal lagoons will be enlarged and deepened by a sea level rise, with erosion of fringing swamp areas (Fig. 13.1C). The Songkhla Lagoon in southeast Thailand, for example, will be enlarged by a 20cm sea level rise, which will also increase salinity and lead to ecological changes, with freshwater plant and animal communities being replaced by brackish ecosystems.

Mangroves grow luxuriantly on the low-lying coasts of Southeast Asia. There are more than 30 species, often zoned in distinctive ecological communities, forming forests up to 40 metres high intersected by branching tidal channels. In Thailand, about 98,000 people live in or near the mangroves, mostly at the landward edge, but there are also fishing villages within the mangrove area (Kunstadter et al., 1986). They are an ecologically rich environment, important as a breeding area for fish and shrimp; they sustain important fisheries; they protect the shore from erosion and trap drifting sediment; and they are used for the production of charcoal, firewood, poles, timber and fishing gear. In general the mangroves are backed by low-lying estuarine and alluvial land, with freshwater swamp, or areas reclaimed for agriculture, especially rice farming. Some areas of mangrove have been cleared to dredge out placer deposits of tin which occur beneath the mangrove mud, but the most extensive clearance has been made for the establishment of salt pans and aquaculture (shrimp and fish ponds). In Thailand, the mangrove area declined 45% between 1961 and 1987 (Aksornkoae, 1988), and a similar reduction has occurred in Malaysia and Indonesia.

Mangroves occupy the intertidal zone, and a 20cm sea level rise is likely to modify them (Fig. 13.1D). They will be maintained, or even prograded, in areas where the rate of substrate accretion equals or exceeds the rate of sea level rise, but in many areas there will be increased submergence. This will cause a die-back, and erosion of the seaward margins, and there will be a tendency for mangrove communities to migrate landwards as the sea rises, displacing fresh water swamps or forests in the hinterland.

In areas where the hinterland has been reclaimed for agriculture (usually rice farming), or converted to salt pans or aquaculture, embankments have been built at the inner margin of the mangroves. If these areas are maintained, the retreating mangrove fringe will become narrower, and may in places disappear altogether. Where the mangrove area has been converted to aquaculture, a sea level rise will threaten to breach the enclosing banks, submerging and eroding much of the area now occupied by fish or shrimp ponds. Use of the intertidal zone for coastal aquaculture permits the gravitational inflow and outflow of sea water, and if the ponds are maintained, the enclosing walls and the floor areas will have to be raised 20cm by the year 2025. Alternatively, pumping systems may have to be introduced.

In addition to these direct effects, marine submergence of coastal areas in Southeast Asia will raise the near-coast water table so that low-lying parts of coastal plains will become permanent swamps or lakes. The rising ground water could be accompanied by the upward movement of saline material, resulting in salt damage in rice paddies and farmland soils.

Coral Ecosystems

Coral reefs occur extensively within the East Asian regional seas, and as fringing reefs on many headlands and islands. Some of these reefs have been damaged by the use of dynamite to harvest fish, by the cutting of boat channels, and by pollution, including the in-washing of muddy sediment generated by nearby tin-dredging. Collecting of shells and corals has also impoverished many reefs, and several Marine National Parks have been set up to protect coral ecosystems.

Most coral reefs have been built up to about low tide level, and the reef flats are mostly dead coral. A slowly rising sea level may stimulate the revival of coral growth on reef flats, so that they maintain their level relative to the sea (Fig. 13.1E) (Neumann & Macintyre, 1985; Hopley & Kinsey, 1988). Some of the less vigorous coral reefs may fail to revive in this way, and others will become permanently submerged as sea level accelerates. Fringing reefs are less likely to survive than outlying reefs because of increasing turbidity and nutrient supply (both detrimental to coral growth) as larger waves erode the beaches and the land behind them.

Low islands (cays) on reefs will survive as long as the sea level rise is slow enough for corals to grow upward and maintain the surrounding protective reef. They may even be enlarged by accretion of coralline material derived from the growing reef. However, the freshwater lenses within low islands, upon which natural vegetation and crops depend, and which are important water resources for local people, will shrink and become more saline as sea level rises. The ensuing ecological changes will be adverse for human occupation and agriculture.

SOCIO-ECONOMIC AND POLICY IMPLICATIONS

One possible response to the effects of a sea level rise on the coasts of Southeast Asia is to maintain the present coastline by constructing sea walls (the "Dutch solution"), and either reclaim the areas that become below sea level, or manage their ecosystems by instituting pumping systems to maintain present water levels. The costs of this solution can be massive. In the Netherlands it has been estimated that the raising of coastal defenses to counter a sea level rise of 20cm along about 250km of coastline will cost about US$1 billion (Goemans, 1986). The equivalent figure for Thailand would be about $4 billion, for Malaysia about $3.5 billion, and for Indonesia about $7 billion.

Another possible response is to abandon eroding and submerging coastal areas, retreating to higher ground. This implies the evacuation of people from coastal settlements and the loss of productive land. This too can be very costly.

The social implications of a sea level rise may therefore be thought of as the net social costs which lie between preventing the sea invading the coastline (controls) on the one hand, and allowing the sea to invade on the other. Policies may then be based on these comparative costs and benefits. The question then becomes: how are these comparative costs to be determined? What we offer here is a guideline to answering this question.

Such comparative costing is at the heart of orthodox economics, which seeks the efficient allocation of resources through understanding opportunity costs of different production options. This is the fundamental purpose of land use studies undertaken currently along Southeast Asian coastlines. Even without the sea level rise, we might ask: is it socially and economically desirable to replace the production of complex mangrove systems with a narrow and allegedly more productive fish or shrimp pond system (Singh, 1987); and, if so, is a capital-intensive pond better than a technically less advanced pond? How does one weigh the gains of a proposed tourist industry against the social costs of paddy farmers being displaced by the tourist facilities?

These sorts of least cost/most gain questions become more difficult under conditions assuming sea level rise. This is not simply because of the problem of costing a relatively long evolutionary process which has a high degree of uncertainty. It will also be difficult because invasion by the sea **and** controls to prevent that invasion, will, in different ways, alter coastal ecosystems which, in turn, will change the picture of opportunity costs and social claims in coastal zones.

Comparing zonal ecologies and the productive uses to which they might be put under sea level rise therefore is a central concept for any empirical study concerned with informing policy. There are two aims to these studies: first, understanding the present claims to different ecosystems and the relative values produced from these land uses, and, secondly, predicting how these claims and relative values would alter under the new ecologies brought by sea level rise. If this sounds obvious, it is worth noting that there is still considerable debate over the first step, about how best to use **current** coastal resources (Gong & Ong, 1987).

A possible guide to research projects which might inform policy is illustrated here with reference to one coastal type only, though a common one in Southeast Asia -- the coastal wetland. In due course, we will develop guidelines for other coastal types.

A PHYSICAL MODEL OF COASTAL WETLANDS

A generalized model of the wetland is shown in Fig. 13.2. At present, it consists of the sea (A) which at low tide becomes mud flats; an intertidal zone (B) of about one kilometre between mid-tide and high tide, which is mostly occupied by mangroves; and a zone of alluvium (C) which extends about a kilometre beyond the high-tide mark and part of which is occasionally subjected to excess high tides. The inland boundary of C is usually two to three metres above the mid-tide mark. We call B and C the **affected territory**. Beyond C is a drier hinterland which is part of the **external economy** (with its national and international links)

These zones will change with sea invasion or with controls (in this case, walls). Left to invade, the sea will occupy B, and B will occupy C. A wall placed on either the landward margin (Y) or the seaward margin (Z) of B will mean the reduction in or the disappearance of the mangrove ecosystem. A wall system at Y to protect C would have a variable affect on C depending on the technology of the wall: a simple bund might keep out the sea but not prevent a worsening of C's drainage and salt conditions as the sea rises beyond the bund; a wall in combination with pumps might mean no deterioration in drainage or salt conditions despite the rising sea - indeed, drainage might be improved. In short, for given physical conditions, the variable zonal effects will depend on the presence, location, and technology of control systems.

Upon this territory, we now place different combinations of resource uses (actual and potential). These uses might be thought of as social claims competing for the higher priced land that would occur with sea level rise or its control. In that competition, people and fixed capital (buildings, irrigation works, roads) might become displaced from the affected territory (**displacement costs**) or replaced from one zone to another within the territory (**replacement costs**). What then are the implications of each combination? By way of illustration, three scenarios are considered:

1. Mangrove ecosystem and sea fisherfolk

The population is housed on either side of the mid-tide mark: some people dwell within the mangrove zone. Most production comes from the sea; the mangrove ecosystem contributes directly to some production (fish, shrimp, wood) and indirectly to production by being, along with other mangrove areas, a breeding ground for fish and shrimp species. C is unoccupied.

Cost-policy implications

Walls would destroy the mangroves by replacing the regular tidal inundations, to which they are adjusted, by permanent waterlogging, which would drown them, or by permanently dry conditions, which they cannot tolerate. If production from the mangrove system is to be maintained, sea invasion should be allowed with both mangroves and houses retreating landward. Accordingly, houses designed for relocation would lower replacement costs.[1] This

[1] One of the important implications of sea levels rise in many developing countries is the need for coastal people to move house (and other buildings). If we think of these buildings as solid fixtures -- bricks and mortar -- we will be tempted to adopt strategies which seek out high land where these buildings will be safe. This might not be the right approach in many cases. Some zonal ecologies and land uses might be suited to a landward retreat of buildings as the sea rises. The replacement costs of this retreat can be lowered by buildings designed for movement. Modern architects do not think this way (nor do their customers); traditional architects in Southeast Asia often did. Old Malay houses that were jointed rather than nailed, for example, were designed for movement. Movable buildings in association with more costly

scenario depends on an important assumption: the predicted **future value** of C which presently has no value. If this value is high, a seaward wall (at Y or Z) involving the loss of the mangroves and the displacement of the fishing population might become warranted.

2. Shrimp ponds competing at B (Fig. 13.3)

Assume that a policy option is to upgrade production of zone B by installing shrimp ponds in the near future. This policy is based on the currently lucrative shrimp export market and advances in pond technology. Let us assume, too, that three aquaculture systems are considered: an extensive system (S1) which depends on tides to supply the shrimp larvae; a semi-extensive system (S2) and an intensive system (S3), both of which do not depend on tides for larval stock.

Cost-policy implications

Under no sea level rise, S2 is the preferred option according to Hirasawa (1988): it has lower variable costs than S3 and lower fixed costs than S1 and, accordingly, is able to withstand reductions in export market prices as world shrimp supply, as is expected, increases. Is this costing altered under sea level rise assumptions? Possibly not. Being tidal, S1 would have to retreat landward; given the relatively high fixed costs of this system, its replacement costs might be high compared to the construction of a wall at Z, behind which S2 can operate. The preference for S2 would be strengthened if C had high value (currently or potentially), for the wall at Z would preserve C as well as allow ponds. On the other hand, if C (now or potentially) had low value, S1 may be the preferred option especially if risk costs are taken into account. In this case, the high replacement costs of S1 (associated with its landward retreat if the sea rises) is discounted by the (high) uncertainty of that rise occurring as predicted. In short, the type of pond system will depend on the value of what lies behind the ponds in C.

3. Sea fishing (in 1 above) or extensive aquaculture (S1 in 2 above) competing with paddy farming in C (Fig. 13.4)

Farmers are housed on their paddy farm at C. The seaward margin of this zone plus some of B is occupied by people engaged in tidal aquaculture or fishing at sea.

Cost-policy implications

This combination, which is very common in Southeast Asia, can no longer exist in the affected territory: walls protect C but destroy B, no wall means B retreats into C. A choice between these competing claims would depend on a comparison of the losses (production and capital losses plus displacement costs) between the farm sector (if the sea invaded) and the fishing sector (if walls protecting farmers destroyed fishing). These comparisons are, however, complicated by the question of future values. Consider this example. In current terms, C's rice production value, its irrigation and other fixed capital values, and its population are all larger than those in B. This suggests that C should be protected by a wall, at Y or Z. Consider now different accounts of this scenario, each of which considers the future in different ways.

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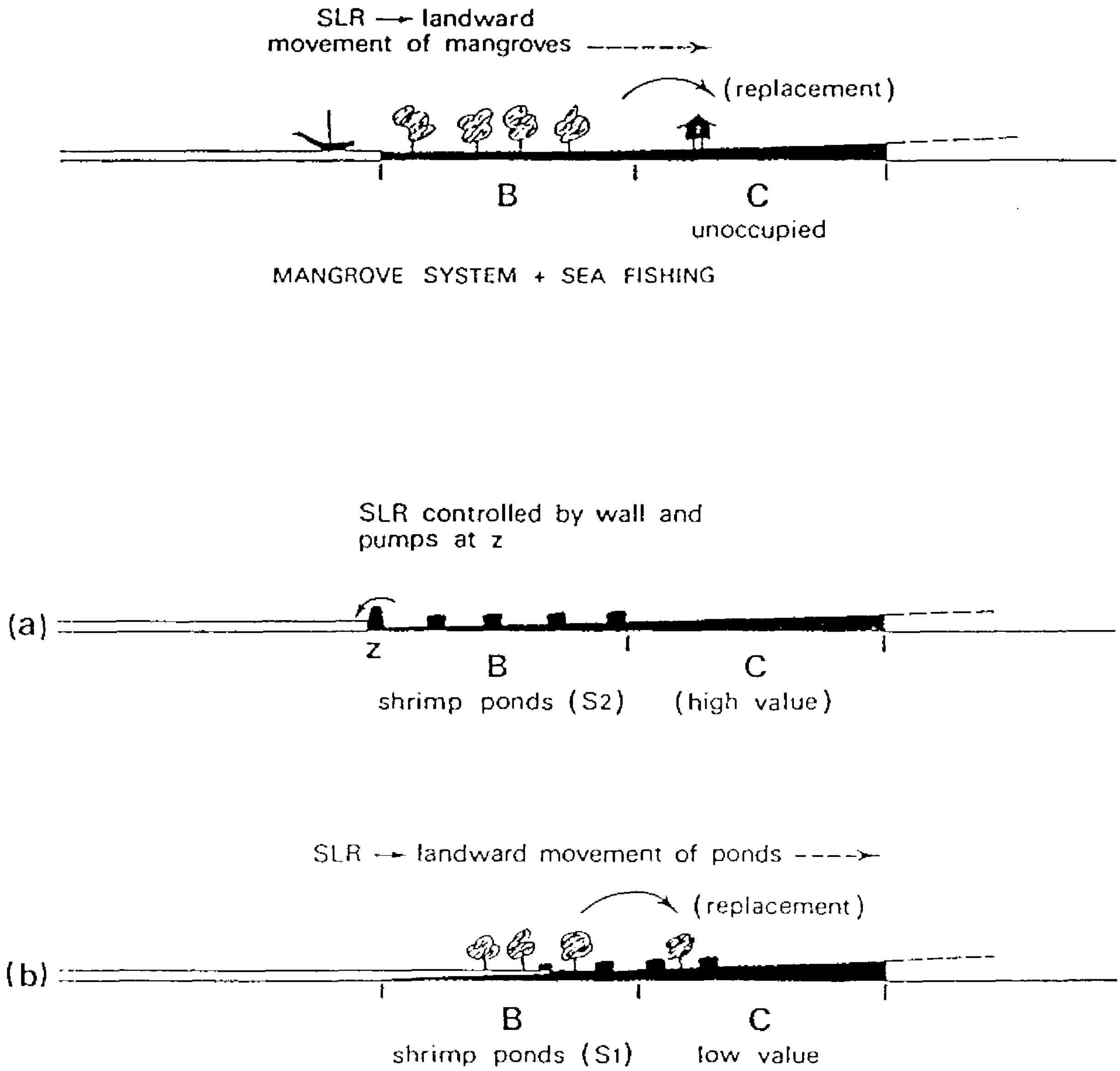
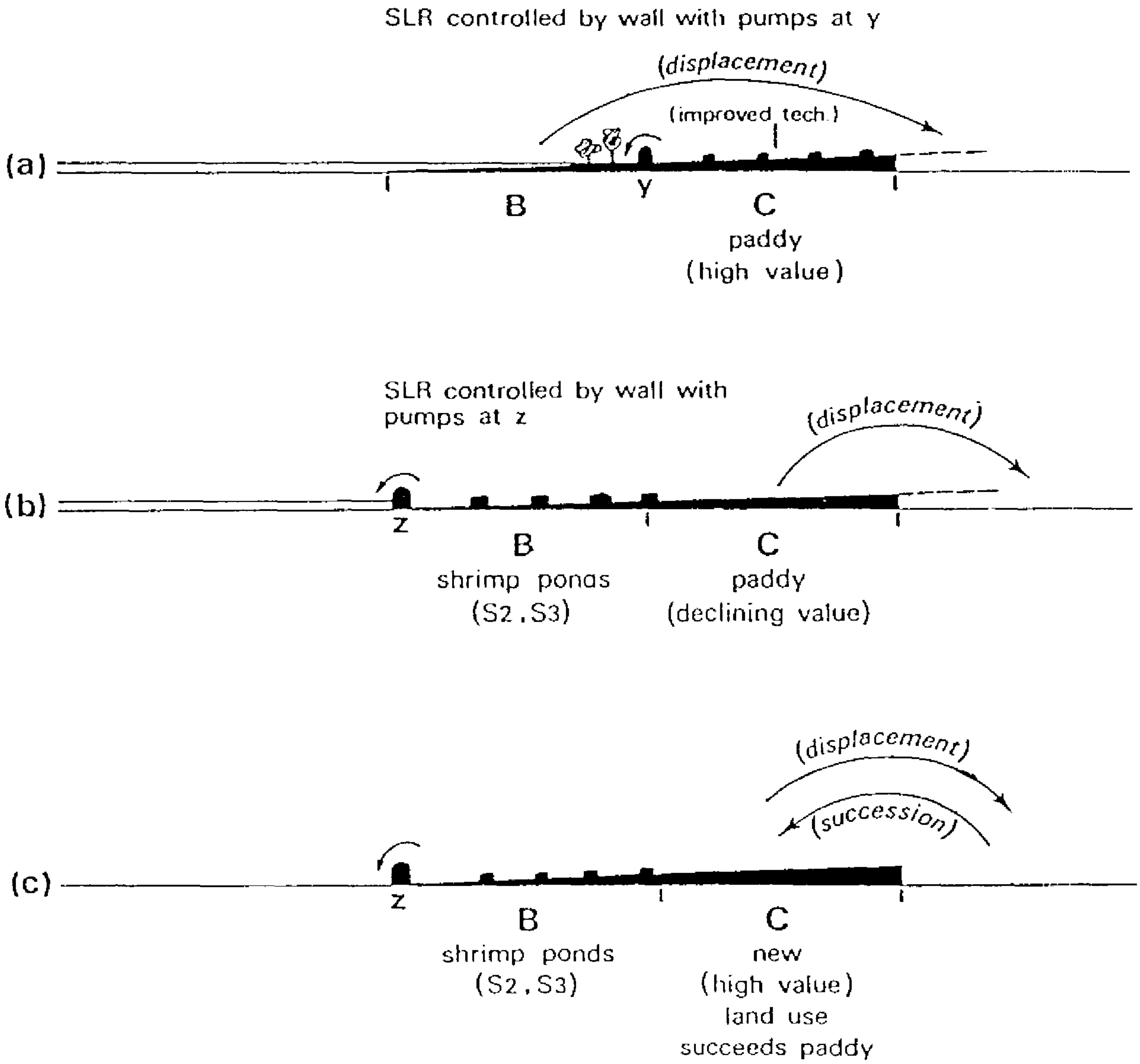
fixed structures may be a useful way of planning future land uses which accommodate both large and small businesses, rich and poor groups: a planned tourist hotel, for example, would need to be located on high ground, but wooden movable facilities geared to different customers may be quite viable on lower ground. These ideas imply, however, new notions of property rights.

Figure 13.3 Shrimp ponds competing at the inter-tidal zone



To this scenario is added the deliberate policy to expand C's rice productivity by upgrading irrigation technology. This technology is to be incorporated into a wall involving pumping, to be built at Y. In this case, the potential for expanding current rice production **confirms** policy based on current values (Scenario 3a). Suppose, however, that national economic trends point to a different future. It is observed that, beyond the coast, paddy lands in areas rather like those of C are being abandoned as farmers migrate to the urban labour market; and that the market for shrimp, even taking into account an expected lower world price, appears promising and has foreign exchange and local processing benefits. A wall at Z, with shrimp ponds behind it, now becomes a policy option. In this case, the perceived potential for expanding production involves **changing** zonal production and technology **works against** a policy based on current values. The original valuation of B is upgraded by the promise embodied in shrimp pond technology, and that of C is discounted by an amount proportional to the lost production plus the unused capital plus the population displacement that would have occurred anyway in C (assuming national trends in similar rice areas would apply in C) (Scenario 3b).[2]

Figure 13.4 Sea fishing (in scenario 1) or extensive aquaculture (in scenario 2) competing with paddy farming in zone of alluvium



[2] This question of the potential for increasing paddy production, that is of valuing paddy land more highly in the future than present valuations, might be important, for example, in Thailand. There, the low proportion of paddy land that is irrigated plus the fact that for Asian countries as a whole, paddy yields correlate positively with proportions of paddy land irrigated (Grigg, 1985), suggest the value of paddy land in Thailand is undervalued in current terms.

However, as we have seen in Scenario 2, the capital outlay of a walled pond system in B may only be warranted if it is associated with high valued land in C. Under an assumption of declines in paddy, a higher valued land use should occupy C to justify ponds in B (Scenario 3c).

Enough is said by way of illustration. We could add other social claims to the physical model of coastal wetlands -- urban, manufacturing, or tourist claims, for example; we could alter the zonal ecologies of our wetland model; we could consider other coastal types. These would complicate something that is already complex. They would not, however, change what we have been trying to demonstrate: that an objective assessment of policy options under a sea level rise will rest upon an understanding of the social claims (actual or potential) to different zones of territory that will be affected by the rise, and upon the comparative net social costs involved.

VARIABLES

It is clear that to determine the relative costs and benefits of zonal land uses under sea level rise involves manipulating a number of variables. For any given set of zonal ecologies in an affected territory (including the ecological changes which will occur with sea invasion or controls), the net social costs will be a function of the following:

- the value of present production from each zone that will be lost or increased;
- the value of future production for each zone which will be foreclosed through land lost or through ecological change;
- the contribution each zone makes to the external economy (externalities) through systems of exchange;
- the extent to which these values have to be discounted by the fact that changes would have occurred anyway, without sea level rise;
- the cost of controls (sea walls, pumping systems);
- the cost of moving assets and population from one zone to another (replacement costs);
- the cost of moving people and infrastructure out of the affected territory and absorbing them in other parts of the economy (displacement costs, including social welfare and compensation);
- the structural trends and plans in the external economy and their effects on future land valuations.

SOME QUALIFICATIONS

This outline, we stress, is a guide. Its cost approach may suggest that precise economic equations can usefully be used. This impression needs to be qualified on a number of accounts.

First, there is a high risk of error in estimating the rate and height of a rising sea level. Uncertainty will produce policies which are essentially conservative (incrementalist and procrastinalist) (Broadus, 1988), which involve diversity (risk spreading), and which avoid heavy fixed commitments and outlays.

Second, valuing one use against another is difficult enough in full exchange economies where comparability might be based on price; it is a more difficult task when one has to compare a zone which will be withdrawn from the exchange system (eg. mangrove conservation) with a zone the value of which is solely determined by its market price; and comparisons are a far harder task in Southeast Asia where production is sometimes for exchange and often for subsistence.

Third, sea level rise will involve basic issues of justice which cannot, and should not, be qualified by what things cost. The voice of a poor family whose land might be lost to the sea will be unheard in the market place beside the clamourings of a large corporation whose business is under threat. It is as much the role of the policy-maker to accommodate the small voice in their plans as it is to allocate scarce resources on economic principles; lawyers as well as economists should have their ear.

INITIAL EMPIRICAL NEEDS

If it is assumed that what we have outlined here constitutes a useful framework for developing objective policy options for a sea level rise, what are the immediate empirical needs? Briefly, given sea level rise assumptions, they are as follows:

Definition of the affected territory along coastlines

The inland boundary of this territory is not defined simply by high tide, but by the physical changes that will operate to landward (erosion, drainage, salination).

Definition of the land use zones within this territory

These will form the basis of social claims.

Macro-estimates of current and future populations and production values within these zones

For each zone, there will normally be more than one production estimate. These should include the degree to which production contributes to the external economy as distinct from local household subsistence.

Defining coastal types (including the physical dynamics that will operate)

This has largely been done, but the distribution and extent of each type, and its existing status in terms of utilization and development, have still to be assessed geographically.

These exercises will allow more detailed work to be organized on a national basis. Priorities for research could be established by knowing where social costs are likely to be most heavy. Detailed physical and social accounting studies could then be done in these areas. In addition, a broad view is needed to formulate national policies which will involve diversity of response; which will allow the sea to be controlled in some places and to invade in others, and take account of the various adjustments that we have discussed.

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14. IMPLICATIONS OF PROJECTED SEA LEVEL RISE : A CASE STUDY OF BANGKOK METROPOLITAN AREA, THAILAND

J.N. Paw

International Centre for Living Coastal Resources Management
MC P.O. Box 1501, Makati
Metro Manila, Philippines

INTRODUCTION

This case study assesses the implications of projected sea level rise of 20cm by the year 2025 on the Bangkok Metropolitan Area including nearby coastal areas. Bangkok, the capital of Thailand, has a population of over 5 million. The Bangkok Metropolitan Area comprises an area of about 1,569km^2 in the southern part of the Chao Phraya Basin known as the Lower Central Plain. The Chao Phraya River meanders through the center of Bangkok. Details on the historical development of Bangkok are described in a report prepared by the ESCAP Secretariat (1986).

Physical Environment of Bangkok and Adjacent Coastal Areas

The topography of the Lower Central Plain is generally flat and consists of alluvial and marine deposits. The elevation of the plain ranges from 20m above mean sea level at Chai Nat in the north to less than 2m within the vicinity of Bangkok. It has an approximate area of 40,250km^2 and has been accreting at about 4-5m/yr (Somboon, 1988; Pitman, 1985; Ten Cate, 1984). Four rivers drain into this plain: the Mae Khong, Tha Chin, Chao Phraya and Bang Pakong.

The Lower Central Plain, also known as the Chao Phraya delta is divided into several landform features (Fig. 14.1). The two zones most affected by the sea are the inter-tidal zone and the brackish swamp zone. The inter-tidal zone extends 130km from Samut Songkhram in the west to Bang Pakong in the east, and varies in width from 2 to 15km. Average elevation is 1m above mean sea level. Mangroves and nipa abound. Further inland is a swamp zone about 10-25km in width and about 1-2m above mean sea level, much of which is currently used for agriculture (Thiramongkol & Somboon, 1988).

Bangkok metropolis is situated in an area called Bangkok plain which is within the Lower Central Plain. Much of the metropolis is underlain by the Bangkok clay formation, which has very low permeability and is highly compressible (Fig. 14.2). Large-scale extraction of ground water for domestic and industrial uses has resulted in land subsidence, attributed to consolidation within the soft clay. A large subsidence bowl has formed in the area where there was arge-scale ground water extraction (ESCAP Secretariat, 1986).

Land subsidence and flooding

Land subsidence in the Bangkok region between 1933 and 1988 ranged from less than 20cm to more than 160cm within an area of about 4,550km^2 (Fig. 14.3). This was closely correlated with the degree of groundwater extraction (Nutalaya et al., 1988). As a result, some areas of the city are already below mean sea level (Fig. 14.4), but subsidence of some areas, especially in the inner part of the city stopped after groundwater extraction was prohibited by the government, which made available a piped water supply.

Figure 14.1 The geomorphology of the Lower Central Plain showing the location of Bangkok. (after Thiramongkol, 1984)

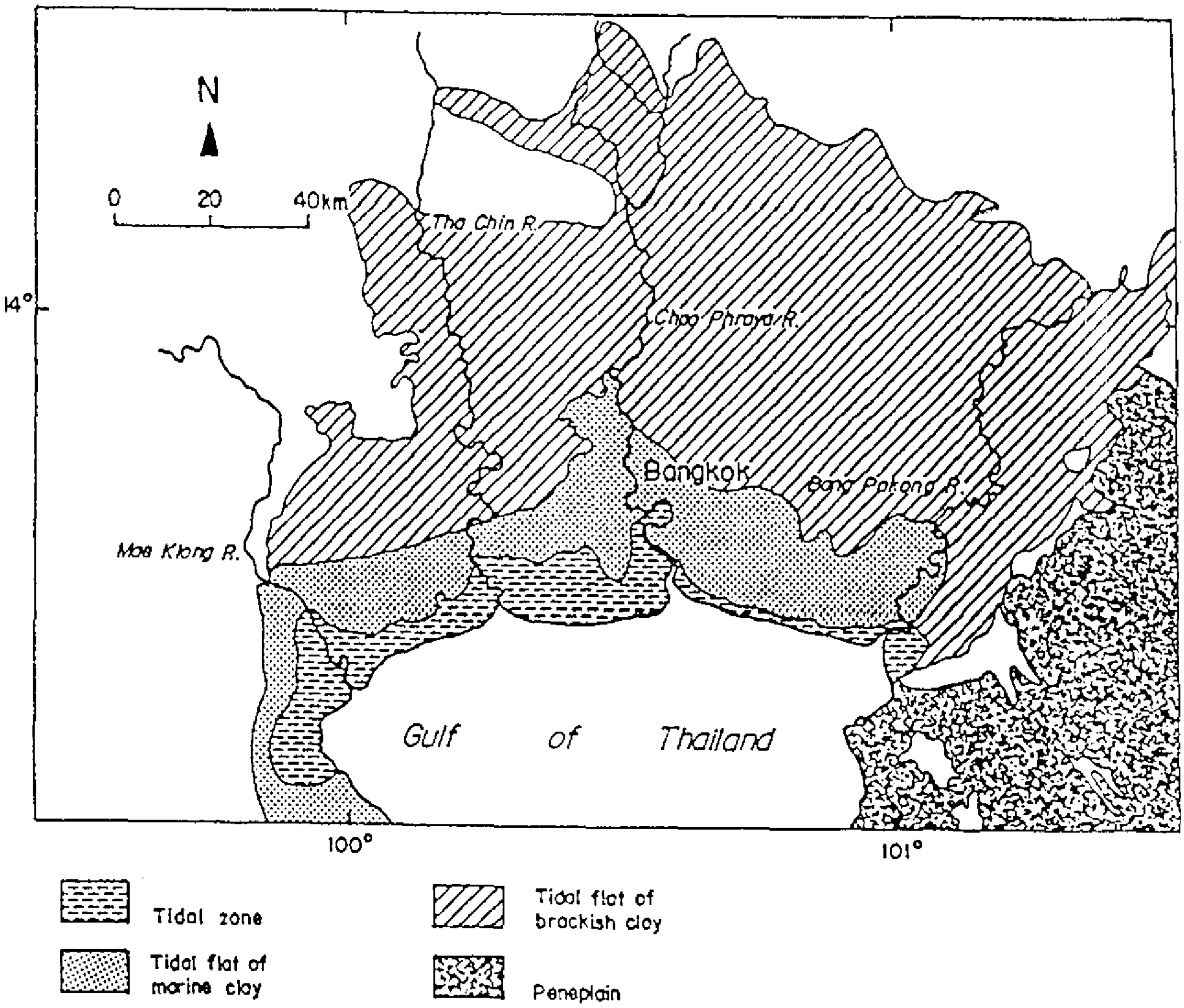


Figure 14.2 Cross-section of the Chao Phraya River showing the deposition of sedimentary materials (adapted from Thiramongkol, 1984).

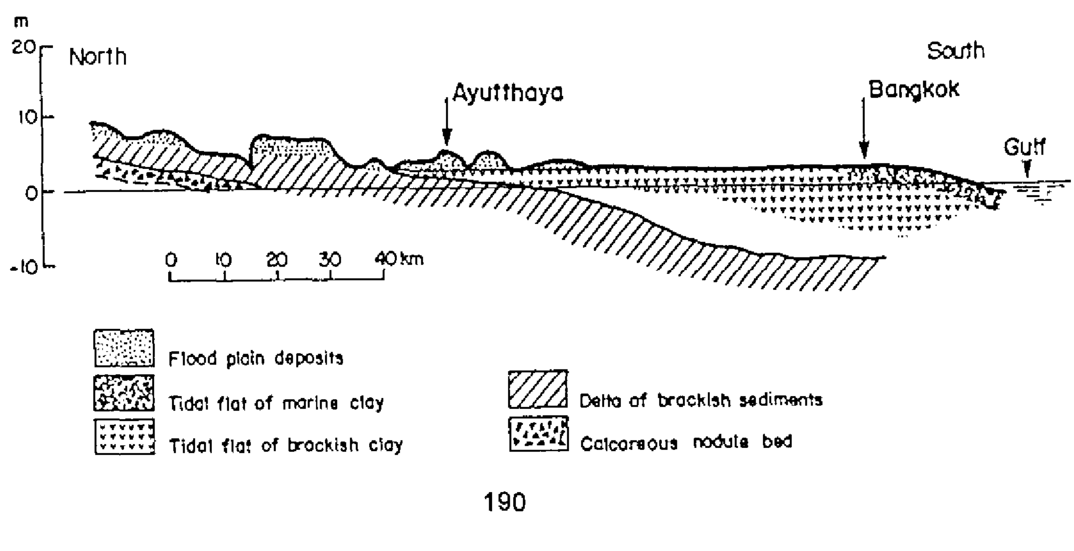


Figure 14.3 Topography of Bangkok and area of land subsidence (adapted from ESCAP Secretariat, 1986).

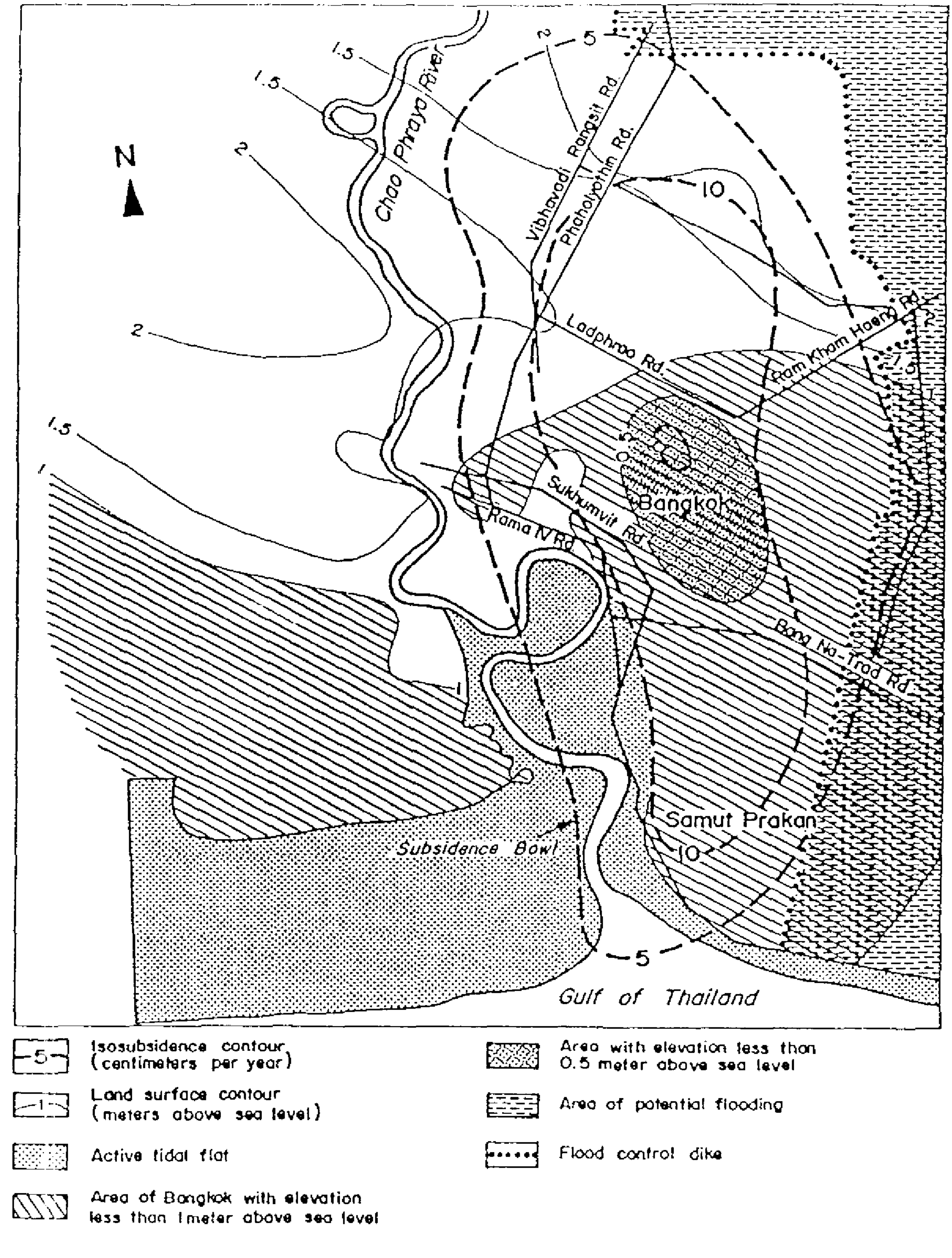


Figure 14.4 Ground elevations of some parts of Bangkok (adapted from ESCAP Secretariat, 1986).

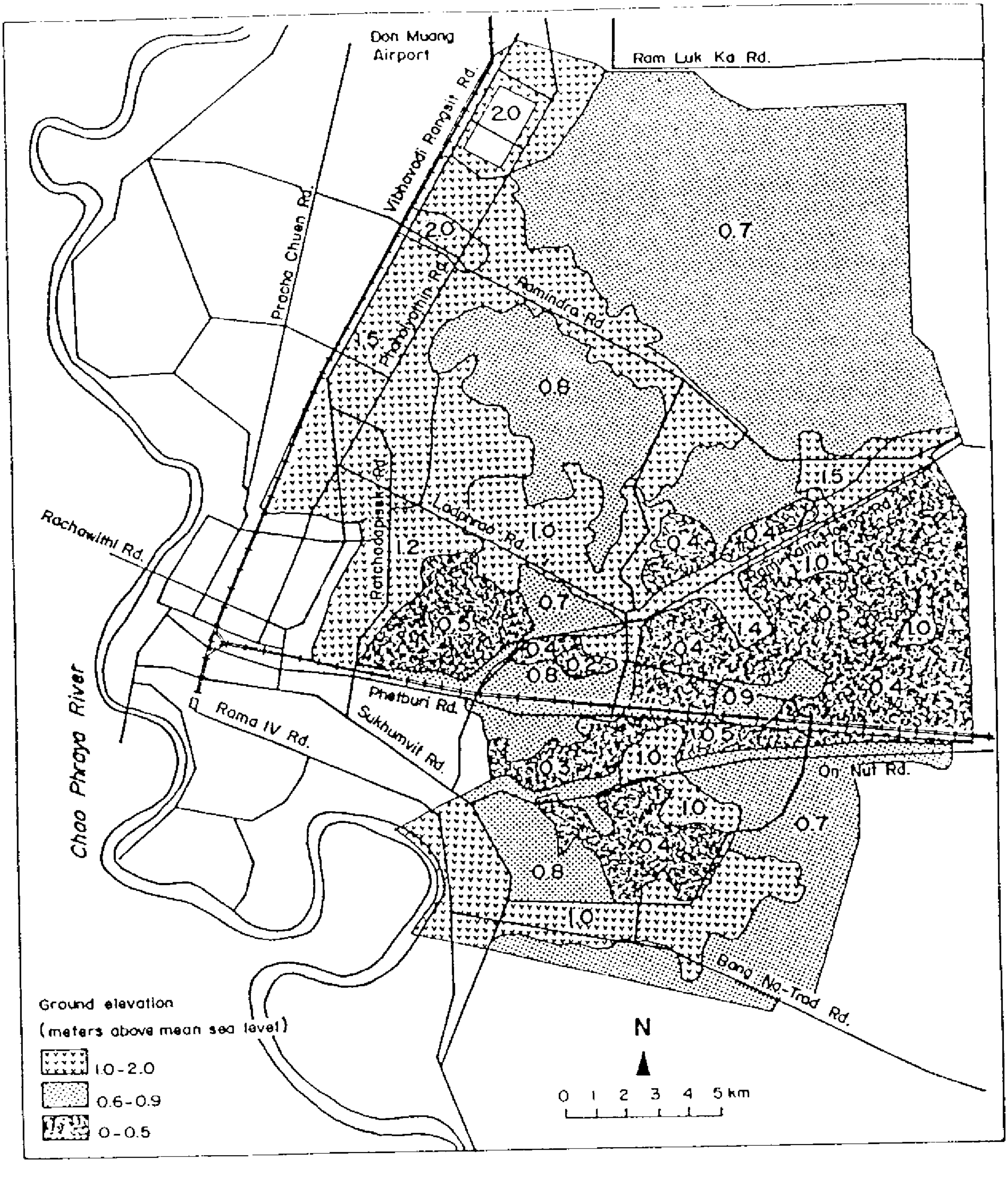
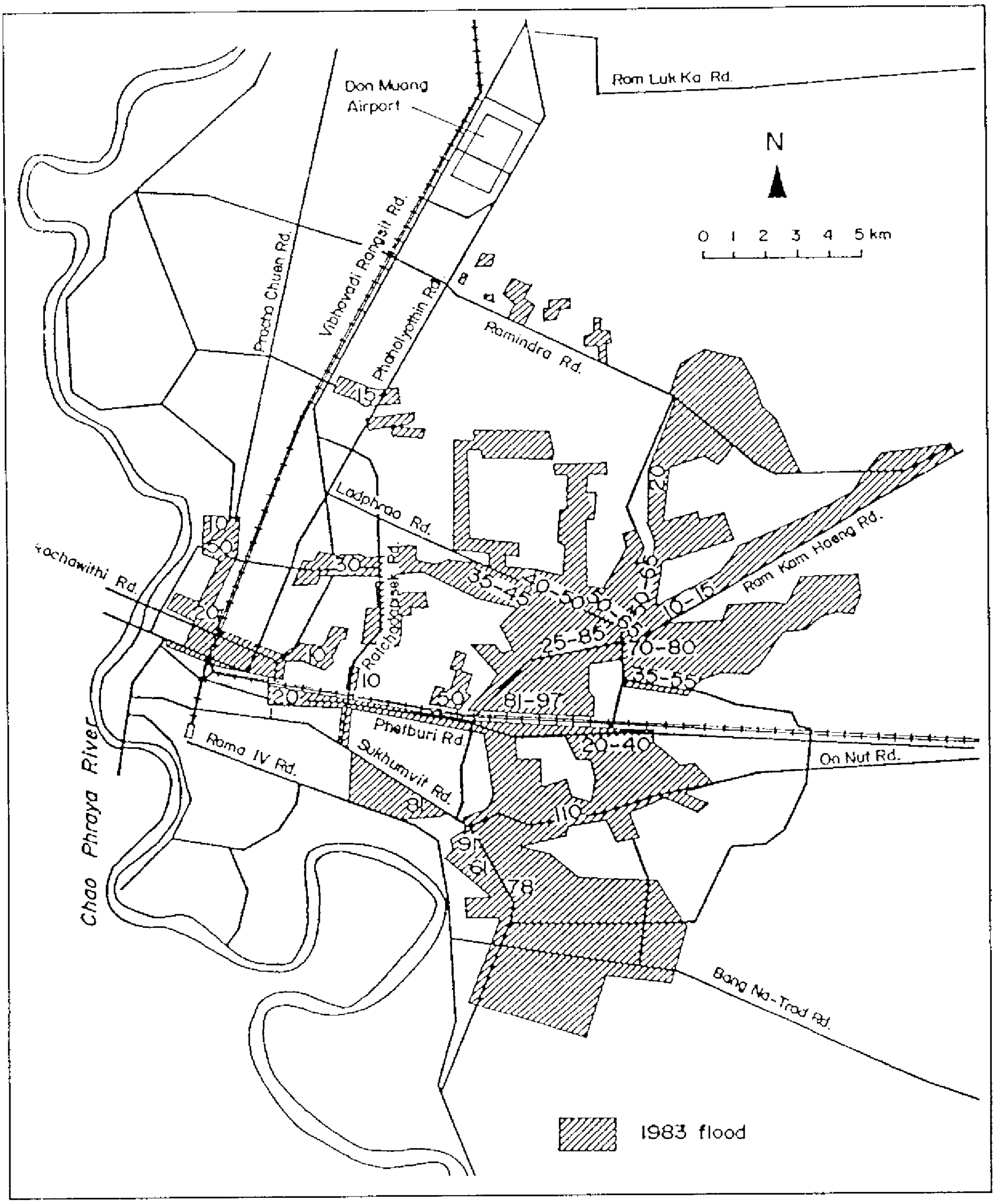


Figure 14.5 Flooded areas of Bangkok in 1983 indicating the flood depth (cm) (adapted from ESCAP Secretariat, 1986).



The topography of the Bangkok region is extremely low and flat with elevations of 0 to 1.5m above mean sea level. Flooding is a recurring event during rainy seasons, and is exacerbated by backflows from Chao Phraya River during seasonally high tides. A 60mm rainfall, for instance, causes extensive flooding and it then takes 6 to 24 hours for the flood waters to subside (Ten Cate, 1984; Nutalaya et al., 1988). Fig. 14.5 shows the areas flooded during 1983. Fortunately, protective structures have since been emplaced to prevent direct tidal flooding of low-lying areas.

Implications of Sea Level Rise

According to Barnett (1983) and Peltier (1988), the global relative sea level rise over the past 100 years ranged from 10 to 15cm (1.0 to 1.5mm/yr). It has been predicted that the greenhouse effect will lead to a worldwide sea level rise during the coming century, attaining 20cm by the year 2025.

Existing tidal fluctuations do not have much impact on the coastal areas and Bangkok in terms of flooding, but severe back-flows of the Chao Phraya River will inundate low-lying areas of the city when high tide coincides with high fluvial flow during rainy seasons, as was the case in 1983. A high tide level up to 1.35m is generally experienced during October to December (Nutalaya et al., 1988), but only low-lying coastal areas are flooded while Bangkok is seldom affected.

It is anticipated that groundwater extraction will continue until the next century because some parts of the metropolis will not be effectively serviced by piped water. However, it is expected that groundwater extraction will be reduced, especially in areas that currently have a high rate of subsidence. If groundwater extraction were halted, subsidence will still continue because of clay compression under the load of buildings and other constructions (ESCAP Secretariat, 1986).

From Table 14.1, it can be seen that a high tide of 1.35m may increase by 0.27 to 0.38m if continuing subsidence and a sea level rise results in submergence by 20 cm. Such a scenario would increase the possibility of severe flooding in low-lying areas due to increase in high tide level augmented backflow along the Chao Phraya River. In areas where the land is already below sea level (Fig. 14.4), flooding will become more frequent, and will take longer to drain with the existing pumping system. Apart from sea level rise, the global greenhouse effect may also lead to an increase in rainfall, and perhaps phases of severe drought. Although this remains to be quantified, especially for the East Asian Seas region, increased rainfall is likely to increase fluvial discharge, and so exacerbate river flooding in low-lying areas. However, a sea level rise of 20cm will only result in flooding in Bangkok if high tides coincide with heavy rainfall and high river discharge. Another impact of sea level rise would be saltwater intrusion into aquifers. Some wells in the city are already salty (ESCAP Secretariat, 1986), and with a sea level rise, saltwater intrusion into aquifers would increase, especially where groundwater extraction is high.

On the low-lying coastal areas, particularly below 2m elevation, high tides could cause flooding (Fig. 14.3). However, permanent inundation is unlikely if the Chao Phraya delta as a whole continues to aggrade at 4 to 5m/yr. Such a high sedimentation rate would maintain the land surface even if sea level rises 20cm by the year 2025.

Table 14.1. Projected sea level rise scenarios for Bangkok and adjacent coastal areas

Present High Tide Level:		1.35m
Land Subsidence (base year: 1989)		
Baseline:		0.0m
Low (2mm yr^{-1})		0.072m
High (5mm yr^{-1})		0.180m
Predicted mean sea-level rise (Year 2025):		0.20m
Predicted mean sea-level rise (Relative):		0.054m
Scenarios	Year 2025 (m)	Increment (m)
Baseline	1,404	0.054
Low	1,622	0.072
High	1,730	0.380

Notes:

1. Such high tide level is generally experienced during October to December (Nutalaya et al. 1988).
2. Subsidence rates of 2mm/yr and 5mm/yr are taken from AIT (1981) as cited by Ten Cate (1984).
3. Global mean sea level rise (relative) ranged from 1.0 to 1.5mm/yr according to Barnett (1983) and Peltier (1988).
4. Baseline scenario assumes a relative sea level rise of 1.5mm/yr (see note 3 above) and that subsidence has virtually stopped, or can be considered negligible.

CONCLUSION

A predicted global sea level rise of 20cm by year 2025 will have a marginal impact on the Bangkok Metropolis and adjacent coastal areas even if it is accompanied by land subsidence of up to 5mm/yr (an additional 18cm). Unless existing flood control systems are improved or expanded, severe flooding could occur when river back-flow due to higher high tides coincides with heavy rainfall. Along the coastal areas, permanent inundation may be at least partly offset by aggradation resulting from sediment deposition from the Chao Phraya River. Saltwater intrusion into aquifers will probably occur in areas where groundwater extraction remains high.

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