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Vulnerability assessment of two major wetlands in the Asia-Pacific region to climate change and sea level rise

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Environment Australia
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supervising scientist

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Project description

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1 Introduction

The major wetlands of the Asia-Pacific region provide many values and benefits (*sensu* Finlayson 1996) to humans. Foremost amongst these are the supply of water, the production of food, and the amelioration of floods (Scott 1992). In addition, the wetlands are major conservation zones for plants, fish and migratory birds (Scott 1989, Scott & Poole 1992, Jaensch 1996, Gopal & Krishnamurthy 1993). In recent decades the pressure on these habitats has increased as human populations have expanded and sought more land for urban and agricultural usage and development. This has brought production activities into conflict with conservation and resulted in the loss of the habitats concerned. Further, these pressures and conflicts are manifest in wetlands of the coastal zones of many countries (Finlayson et al 1992, Khoa & Roth-Nelson 1994, Leatherman & Nicholls 1995, Hollis 1998).

In addition, wetlands in the coastal zone are vulnerable to flooding, siltation and erosion from global climate change and sea level rise (Leatherman & Nichols 1995, Watson et al 1996). In the worst cases, many of the essential features of the coastal wetlands that provide immense value and benefit to society (*sensu* Ramsar Wetlands Convention, Finlayson 1996) could be lost due to such change.

As an example of the rapidity and extent of potential loss due to climate change and sea level rise, an analysis of the wetlands in Kakadu National Park in northern Australia indicated that many of the existing high value coastal freshwater wetlands could be replaced by saline wetlands within 30 years (Bayliss et al 1997, Finlayson et al 1997, Eliot et al 1999). Given that the biodiversity resource of these wetlands has been afforded extensive value and protection by the Australian government (Finlayson 1990, Bayliss et al 1997, Johnston & Needham 1999, Johnston & Prendergast 1999) this level of habitat change (loss) could be seen as catastrophic.

Not only do the Kakadu wetlands provide a striking example of the potential loss or change that could occur, but they are linked with others across the Asia-Pacific region through the East Asian-Australasian Flyway (Anon 1996, Shorebird Working Group of Wetlands International–Asia Pacific 1999). Thus, the value and management of the Kakadu wetlands is not separable from the value and management of wetlands across much of eastern Asia.

2 Program

Given the importance of coastal wetland habitats in Asia-Pacific to both people and for biodiversity it was proposed to undertake vulnerability assessments of two major wetlands in the Asia-Pacific region, beginning with sites in the Philippines and China. Support for these assessments was provided by the Asia-Pacific Network for Global Change Research (APN; www.apn.gr.jp).

The sites chosen were the Yellow River Delta in China and Olango Island in the Philippines. These have recognisable value for both people and for biodiversity, with both sites being listed under the East-Asian Australasian Shorebird Reserve Network and Olango Island being listed as an internationally important wetland under the Ramsar Wetland Convention.

The assessments were undertaken in collaboration with relevant conservation management authorities. For the Yellow River Delta this included the State Oceanic Administration, while for Olango Island the Department of Environment and Natural Resources (DENR) was the major collaborating agency. The assessments were based on the model provided by the Kakadu study (Bayliss et al 1997) using a procedure presented by Kay and Waterman (1993) and Waterman (1995) and included the following steps:

- Collation of information on major land uses, conservation values and management threats and issues
- Analysis of the major values and benefits derived from the wetland
- Development of a bibliography
- Analysis of the vulnerability of the major wetland habitats to climate change and sea level rise
- Comparison of the relative threat imposed by climate change and sea level rise and identification of possible management responses
- Development of a research and monitoring strategy to provide further management guidance
- Identification of necessary training for local conservation personnel

3 Process

The project was coordinated by the Environmental Research Institute of the Supervising Scientist (***eriss***), a governmental research institute based in Jabiru, northern Australia. ***eriss*** conducts an international wetlands research and monitoring program which includes the above mentioned Kakadu vulnerability assessment (Bayliss et al 1997) and further coastal monitoring in the same region (Eliot et al 1999). It was joined by the Oceania (Canberra) and China (Beijing) offices of the international non-governmental organisation Wetlands International to develop collaborative processes with relevant national conservation agencies and choose the sites for the vulnerability assessment.

The project emphasised wetland sites that had been identified by governments as part of the *Asia–Pacific Migratory Waterbird Conservation Strategy: 1996–2000*. Specifically, sites along this Flyway are subject to an Action Plan for the Conservation of Migratory Shorebirds in Asia–Pacific (Shorebird Working Group of Wetlands International – Asia Pacific 1999). The Action Plan was launched with the support of Recommendation 6.4 from the 6th Meeting of the Conference of the Contracting Parties to the Ramsar Wetlands Convention (Ramsar Convention Bureau 1996; www.ramsar.org).

This APN project supported the migratory shorebird initiative by developing standard habitat assessment and data handling procedures to provide a basis for further assessments and training of local personnel to undertake these.

4 Workshops

A workshop was held in each country during the latter stages of the project to discuss the project or, specifically, the issue of climate change and sea level rise, the process of coastal vulnerability assessment and the actual assessment of the respective wetland site. The proceedings of the workshops have been summarised (Vulnerability assessment of major wetlands in the Asia-Pacific region 1999), while van Dam (1999) outlines the coastal vulnerability assessment framework used for the project. Where possible, comments from the workshops were addressed and incorporated into the final report.

5 Outcomes

The report from the site assessments will be forwarded to relevant national agencies and other interest groups. In this manner it is anticipated that national and local planning agencies will have access to the most recent information on the vulnerability of the wetlands to climate change and sea level rise. Further, this will be presented within a context of human usage and the maintenance of the biodiversity of the sites, as per the philosophies agreed under both the Convention on Wetlands of International Importance (www.ramsar.org) and the Convention on Biological Diversity (www.biodiv.org).

It also anticipates that the assessments will be useful as inputs to various global research programs, such as those conducted through the auspices of the International Geosphere-Biosphere Programme (eg Land-Use and Land-Cover Programme (LUCC), Land-Oceans Interactions in the Coastal Zone (LOICZ), and Global Change and Terrestrial Ecosystems (GCTE); www.igbp.kva.se) and also important for science policy links under other international environmental treaties (eg Framework Convention on Climate Change; www.unfcc.de). It will also specifically address management and research issues of direct relevance to the *Asia-Pacific Migratory Waterbird Conservation Strategy*. The latter is important as the initial program for this strategy does not extend greatly beyond the identification of sites of importance for migratory waterbirds and the development of a newtork of contacts (Shorebird Working Group of Wetlands International–Asia Pacific 1999).

The assessment processes will provide input to the development of common methodologies for vulnerability assessment being developed under the Intergovernmental Panel on Climate Change (IPCC; Waterman 1996). As such they will also be considered in future updates of the IPCC Scientific-Technical Analyses of the impacts, adaptations and mitigation of climate change (Watson et al 1996).

The collaborative processes that underpin the project will ensure that local capability is enhanced and training provided, standard data management practices are agreed, communication between research institutions is developed and links made to science policy. This will assist the APN and others in the region who are increasingly showing interest in coastal zone vulnerability which includes wetland processes as a major component. The outcomes can be used as a basis for further coastal zone management and an extension of the assessment methodology to other sites along the migratory bird flyway.

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Vulnerability assessment of the Yellow River Delta to predicted climate change and sea level rise

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Executive summary

The Asia-Pacific Network for Global Change Research (APN) funded a study assessing the vulnerability of the Yellow River Delta (YRD), in China, to predicted climate change and sea level rise. The study was coordinated by the Environmental Research Institute of the Supervising Scientist (***eriss***), in Australia, and Wetlands International–China Program, with the major local collaborator being the State Oceanic Administration of China.

The study's major objectives were to raise awareness of the issue of climate change and sea level rise in the Asia-Pacific region, to provide advice and training to national and local agencies on procedures for Vulnerability Assessment, and specifically, to obtain a preliminary understanding of the potential impacts of climate change and sea level rise on the biological, physical and socio-economic attributes of the YRD.

The YRD was chosen as a study site primarily because it has been nominated for the East Asian–Australasian Shorebird Reserve Network. Due to its importance as a habitat for migratory and resident shorebirds, a 1500 km^2 Nature Reserve has been established along the eastern coast of the delta.

The assessment included the following steps:

- Description of the YRD, including its physical, biological and socio-economic attributes;
- Identification of natural and anthropogenic 'forcing factors', including predicted climate change and sea level rise, and their impacts;
- Assessment of the vulnerability to existing forcing factors;
- Assessment of the vulnerability to climate change and sea level rise;
- Documentation of current responses to coastal hazards;
- Recommendations for future monitoring and management strategies;
- Identification of information gaps and research priorities.

Information was obtained from existing literature, including a number of quantitative estimates of impacts of climate change on specific attributes of the YRD.

The YRD represents the meeting point of the Yellow River with the Bohai Sea, in eastern China. The delta covers approximately 6000 km^2, although historically it has been in a

dynamic state due to the high sediment load and frequently changing course of the Yellow River. More recently, the river course has been stabilised, allowing substantial development to occur. The YRD is now a highly urbanised and industrialised region, with a population of 1.64 million and major industries including oil extraction and crop and cattle farming. Subsequent demands on water resources, both from within and upstream of the YRD have greatly reduced the flow of the Yellow River in the last decade. The Nature Reserve was established in recognition of the YRD's importance as a site for migratory and non-migratory shorebirds, however, it is under great pressure from urbanisation, farming, and oil and natural gas extraction.

The major physical attributes of the YRD include the river and underground water, the low topographical relief of the delta, the geomorphic units of the terrestrial delta, the subaqueous delta and the tidal flats, the sediment load of the Yellow River and subsequent sedimentation, and the natural resources of oil, gas and water. The major biological attributes include terrestrial and aquatic plants and animals, particularly the birdlife, which includes 152 species of protected birds. Over 500 000 shorebirds are estimated to utilise the wetlands of the YRD during their northward migration. The major socio-economic attributes include the population of over 1.64 million, and the primary industries of oil and natural gas extraction and crop and cattle farming.

The predicted climate change scenario for the YRD was based on regional climate change scenarios for temperate Asia or China specifically, by the IPCC and other investigators. The scenario used for this study included the following estimates:

- A rise in relative sea level of 48 cm by 2050 (specific for the recent YRD);
- A rise in mean air temperature of 1.4°C by 2050 and 3°C by 2100 (for China/East Asia);
- A rise in annual precipitation of 2–4.5% by 2050 (for East China).

The major natural forcing factors acting on the YRD (excluding climate change) are sedimentation, the Asian monsoon, El Niño, and flooding and storm surge. Major impacts associated with these include erosion and expansion of the coastal wetlands, damage to infrastructure, crops and livestock, and loss of human life. Major anthropogenic forcing factors include the large population and associated types of land use, oil and natural gas development, and water and air pollution. The major impacts include a reduction in freshwater supply, a reduction in surface and ground water quality, degradation of the Nature Reserve and the subsequent loss of wetland habitat and biodiversity.

The YRD is already extremely vulnerable to existing forcing factors. Although river flows have decreased in the last decade, the YRD is still highly vulnerable to flooding from both upstream sources and from storm surges. The high utilisation of water resources, while aiding in the development of industry and agriculture and enhancing the standard of living, will eventually result in major ecological consequences, such as salinisation, loss of wetland habitat and desertification. Without proper management, urban, industrial and agricultural activities will further pollute the already poor quality waters within the YRD.

The YRD is also vulnerable to predicted climate change and sea level rise. Increased moisture stress, insect pests and plant diseases resulting from climate warming are expected to have unfavourable effects on agricultural production. Salt marshes and other coastal wetlands are thought to be particularly vulnerable to permanent inundation and erosion as a result of sea level rise and increased storm surge. This would have flow-on effects to tourism, freshwater supplies, fisheries and biodiversity. Sea level rise will result in a number of other impacts including a reduction in the protective capacity of the dyke systems. Assuming a 1 m sea level rise and 2–3 m storm surge, approximately 40% of the YRD could be inundated. Saltwater intrusion will also be a major issue, further reducing already limited freshwater resources. The above impacts will have major consequences for both the socio-economic and biological attributes of the YRD.

A series of dyke systems have been in place in the YRD for many years to protect against floods both from upstream and from storm surges. Some of these have been upgraded whilst others require attention. Many of these flood control dykes will serve as protective barriers to sea level rise and increased storm surge, although the extent to which they can protect the adjacent land is uncertain. Other control measures are in place to prevent or minimise floods resulting from ice jam in the river. Freshwater shortages are being addressed by increasing the capacity of existing reservoirs or proposing the construction of new reservoirs.

The study identified a number of management strategies or countermeasures for protecting the YRD from both existing forcing factors and predicted climate change and sea level rise including:

- Integration of information from programs monitoring sea level rise, coastal zone ecology and sensitivity, and socio-economic and cultural indicators;
- Stabilisation of the course and mouth of the Yellow River;
- Consideration of flood risk in urban and industrial planning;
- Protection and management of coastal wetlands and the Nature Reserve;
- Control of urban and industrial pollution;
- Establishment of reservoirs for water storage and conservation;
- Increasing community awareness about environmental protection.

In addition, recommendations regarding the management of the Nature Reserve include:

- Development of an appropriate administrative and management system;
- Drafting and implementation of appropriate environmental protection laws;
- Increasing scientific research to provide a basis for management;
- Enhancing community awareness of ecology and environmental protection.

The YRD currently faces a range of serious ecological and socio-economic problems, most of which are related to water supply, be it in shortage, excess (flooding) or of poor quality. These issues highlight the need to consider both economic development and environmental protection when planning the future sustainable development of the YRD. In addition, it is now imperative that the issue of climate change and sea level rise are incorporated in any such plans. This study highlights the vulnerability of the YRD to predicted climate change and sea level rise, particularly in terms of exacerbating the region's current water supply and quality problems. The proposed management strategies provide the first step in effectively addressing the issue of climate change and sea level rise.

1 Introduction

The major wetlands of the Asia-Pacific region provide many economical and ecological values and benefits to humans. Foremost amongst these are the supply of water, the production of food and the amelioration of floods. In addition, the wetlands are major conservation zones for plants, fish and migrating birds. In recent decades the pressure on these habitats has increased as human populations have expanded and sought more land for urban and agricultural usage. These pressures have brought production activities into conflict with conservation, and in places have even resulted in the loss of the habitats concerned (IPCC 1991,Watson et al 1996).

Coastal and delta wetlands are expected to be highly susceptible to changes in climate and sea level (Watson et al 1996). Climatic changes, sea level rise and storm surges could result in the erosion of shores and associated habitat, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays, changes in sediment and nutrient transport, a change in the pattern of chemical and microbiological contamination in coastal areas, and increased coastal flooding. Some coastal ecosystems are particularly at risk, including saltwater marshes, mangroves, coastal lagoons and river deltas (Watson et al 1996). Consequently, many of the essential features of the coastal wetlands that provide values and benefits to society could be lost. The Yellow River Delta (YRD) in China is an example of a vulnerable coastal wetland.

1.1 Project background

This report documents a component of an Asia-Pacific Network for Global Change Research (APN) project coordinated by the Environmental Research Institute of the Supervising Scientist (***eriss***), an Australian government research institute based in Jabiru, northern Australia, and Wetlands International (Oceania and China Offices). The project aimed to assess the vulnerability of two major wetlands in the Asia-Pacific region to climate change and sea level rise. The YRD was chosen as one of the wetland sites to be studied, for reasons outlined below, with the major aspects of the assessment and report writing being jointly undertaken by the Oceanic Management Department (in Beijing) and First Institute of Oceanography (in Qingdao), State Oceanic Administration of China and the Wetlands International–China Office (in Beijing).

The project supports the East Asian-Australasian Flyway initiative by developing standard habitat assessment and data handling procedures that provide the basis for further assessments and training of local personnel to undertake these tasks. It emphasises global change issues, especially those associated with climate change and sea level rise, and provides information that can contribute to global and national research programs and scientific policies.

1.2 The study area

The Yellow River flows across the arid inland regions of China into the Bohai Sea through the Yellow River Delta (YRD). As the Yellow River has changed its course frequently, there are several definitions of the YRD boundary, and the delta continues to expand due to extremely high loads of silt carried by the river. The ancient YRD comprised a large plain formed over the period 1128–1855, during which the river changed its course four times. Since 1855, with ten further changes of its course, the river shifted northward, leading to the formation of the present YRD (Cheng 1987, Cheng & Xue 1997). Dongying, today the principal municipality of the YRD, did not exist until 50 years ago. Geographically speaking, the YRD covers an area larger than the Dongying Municipality. The study area for the project includes the coastal wetlands in the delta plain, the tidal flats and the subaqueous delta system.

The key economic resource of the YRD is an oil field, administered by the Shengli Oil Administrative Bureau. Because of the frequent changes of the river's course, the YRD remained an underdeveloped rural area before the discovery of the Shengli Oil Field in the

1960s. Even today, the government is hesitant to locate projects, except for oil production, in this region. River 'harnessing' is the precondition for further development of the YRD. The government has approved an engineering project for strengthening the embankment along the Qingshuigou channel, and the first stage of that project is underway. At present, the wetland of the YRD is still in a natural state. Thus, it is important that further development and conservation of the wetland region be strictly managed and monitored.

1.3 Approach of the assessment

This report assesses the vulnerability of the natural and social systems of the YRD to climate change and sea level rise. Vulnerability is defined as the extent to which a natural or social system is susceptible to sustaining damage from climate change and sea level rise (Watson et al 1996). Vulnerability is a function of the sensitivity of a system to changes in climate and the ability of the system to adapt to changes in climate. Under this framework, a highly vulnerable system would be one that is highly sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and one for which the ability to adapt is severely constrained.

Because available vulnerability studies have not employed a common set of climate scenarios and methods, and because of uncertainties regarding the sensitivities and adaptability of natural and social systems, the assessment of regional vulnerabilities is necessarily qualitative. However, this report provides substantial information on what is currently known about the vulnerability of the YRD to climate change.

The IPCC developed a Common Methodology (IPCC 1991) for vulnerability assessment which was tested in China (Wang & Zhao 1995) and by a wide range of other nations, including Australia (IPCC 1994). The approach being developed in China seeks to accommodate regional and local differences in coastal regimes by way of physical, biological and geographic conditions, as well as social and cultural variations, within and across the governmental jurisdictions. The present approach seeks to build upon policy frameworks and the strength of coastal management processes and procedures in terms of the institutional and administrative arrangements of Dongying Municipality and Shandong Province.

The approach developed will be used to address the vulnerability of coastal areas to both natural and human (anthropogenic) induced changes. Consideration of both natural and anthropogenic changes is essential if the impacts of long term, climate induced change are to be identified, planned for, and managed. By addressing both natural and anthropogenic changes, the vulnerability assessment has immediate utility, as it will assist in putting the natural variability of coastal systems (climatic, oceanographic, geomorphic, hydrologic, ecological) and the resilience of the system into planning and management frameworks. Thus, this will allow responses to be developed and implemented in ways that are endorsed politically and understood by the broader community. This will be achieved by utilising available information, initiating studies to fill the information deficiencies, and using appropriate tools for spatial information management and decision support systems. Additionally, it will build on and develop innovative approaches for governmental and community involvement in the coastal zone of China and nature reserve management of the YRD.

In a number of instances, quantitative estimates of impacts of climate change are cited in the report. Such estimates are dependent upon the specific assumptions employed regarding future changes in climate, as well as upon the particular methods applied in the analyses. To interpret these estimates, it is important to bear in mind that uncertainties regarding the character, magnitude and rates of future climate change remain.

A technical workshop was also undertaken as an integral part of the assessment. The workshop was conducted in Beijing, in January 1999, with participants representing a range of organisations, including relevant national and local government agencies, the Yellow River Delta Nature Reserve, and the collaborating organisations. The primary objectives of the workshop were to increase awareness of local and national decision-makers of the potential impact of climate change and sea level rise, disseminate information on the vulnerability assessment process and the overall findings of the YRD study, and to obtain constructive feedback and advice on the study and its findings (Vulnerability assessment of major wetlands in the Asia-Pacific region 1999).

1.4 Aims and objectives

The aim of the project was to develop an approach to link the research, planning and environmental management requirements for the coastal areas of the YRD that could be affected by climatic change and sea level rise. The approach is intended to facilitate ongoing assessment of the vulnerability of the YRD to the effects of short-term changes in climate and other environmental factors that occur within planning horizons of approximately 100 years.

The project objectives were:

- To establish common standards to enable governments (national, province, local, community council) to respond to the impacts of natural and anthropogenic changes in the YRD and the coastal zone of China;
- To develop a scenario for climate change, including assessments of sea level rise, variation in tides, wind storm surges and flooding, based on published research;
- To assess the current vulnerability of the natural and social resources of the YRD to existing coastal hazards;
- To assess the future vulnerability of the natural and social resources of the YRD to climate change and sea level rise;
- To recommend future management responses to the predicted environmental changes.

2 Description of the YRD

2.1 Introduction to the Yellow River and the YRD

2.1.1 The Yellow River

The Yellow River is considered to have the highest sediment content in the world (Milliman & Meade 1983). In recent years the Yellow River has carried about 1 billion tons of sediment annually to its delta and to the coast.

The Yellow River rises in Qinghai Province and flows across the arid inland regions of China (Qinghai and Gansu Provinces, Ningxia Hui Autonomous Region and Shaanxi, Shanxi, Henan and Shandong Provinces) through the YRD and into the Bohai Sea. The total length is about 5460 km (figure 1; Cheng & Xue 1997). The lower reaches of the river have often shifted over the last 6000 years. In the North China plain, flood waters from the river have caused heavy losses for people (Xue 1993).

Presently, the Chinese government is managing to harness the Yellow River and to use its water and sediments. Generally, three hazardous areas occur in the Yellow River basin (Cheng & Xue 1997). The first is the Loess Plateau, where large volumes of sediment are eroded and carried into the river.

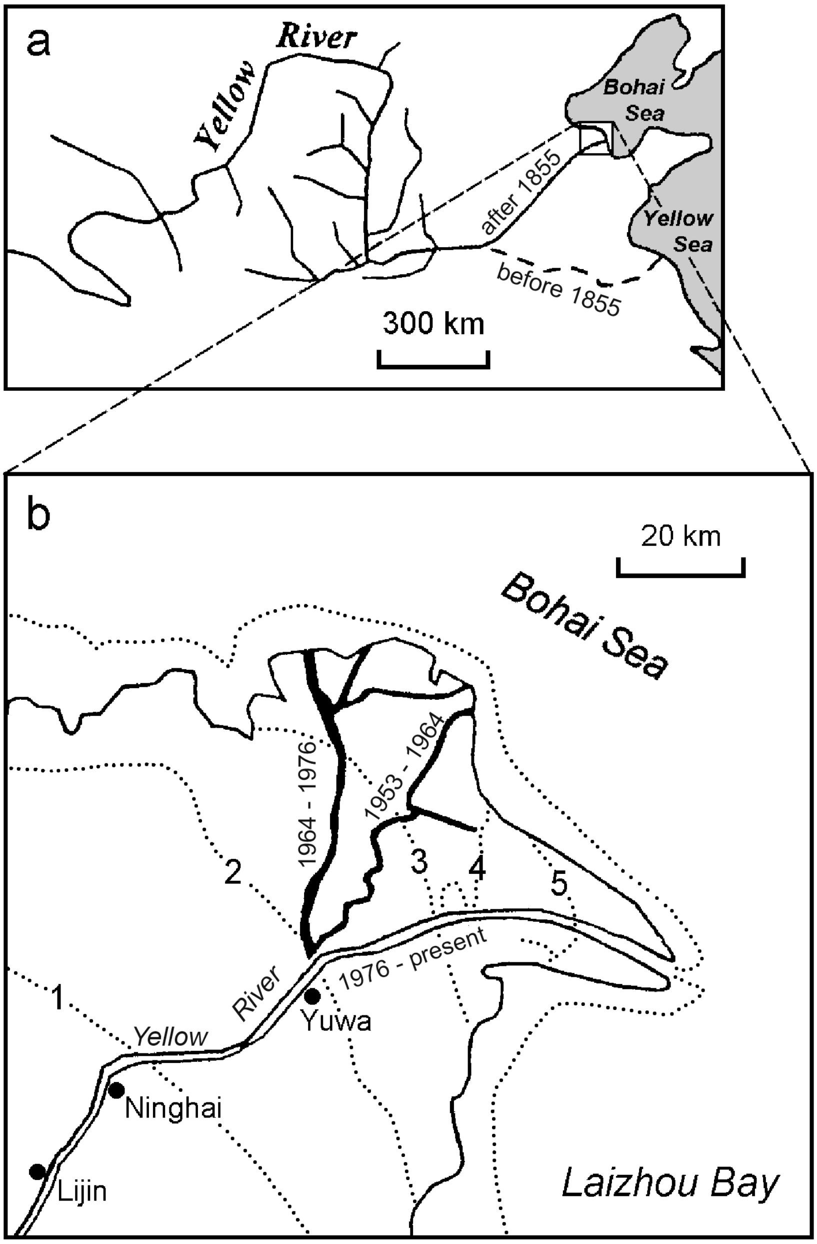

Figure 1 Map of the Yellow River: (a) the Yellow River basin; (b) the modern Yellow River delta and the historical changes of the coastal line; 1. Coastline of 6000 years BP; 2. Coastline of 1855; 3. Coastline of 1934; 4. Coastline of 1976; 5. Coastline of 1980.

The second is represented by the unstable lower reaches of the river where the channel bed is higher than the flood plain because of sediment deposition. The third is the delta plain where shifting of the distributary courses and the reduced water resources results in a range of environmental problems.

2.1.2 The Yellow River Delta (YRD)

The Yellow River Delta (YRD) is located in the north-east of Shandong Province (118°03′E to 119°20′ E and 37°20′N to 38°20′N), facing the Bohai Sea in the north and bordering Laizhou Bay in the east. Much of the YRD area is under the jurisidiction of the Dongying Municipality, Shangdong Province. Although the YRD covers an area larger than Dongying Municipality in terms of geography, the study area for the project is the modern YRD, within

Dongying Municipality, comprising an area of about 6000 km^2 and a population of 1.64 million (at the end of 1995). In the present report, the term YRD and Dongying Municipality are used interchangeably.

2.1.3 YRD evolution since 1976

The embankments of the Yellow River were broken at Tongwaxiang, Henan Province, in 1855. At that time, the Yellow River abandoned its former river course to the Yellow Sea through the north Jiangsu Plain. The flood water from the Yellow River entered the channel of the Daqing River to the Bohai Bay through north-east Lijin County, Shandong Province, where it created a new delta. During the period 1855–1995, the silt carried by the river flow created 5400 km^2 of new land (Chen et al 1997). The rate of sedimentation has caused the lower discharge channel to shift every 8–10 y (Cheng 1987, Cheng & Xue 1997, Yang & Wang 1993). The most recent major shift occurred in 1976 (figure 2). The evolution of the Qingshuigou channel (ie the current Yellow River channel), the new river course that resulted from this shift, is illustrated by a series of Landsat images (Remote Sensing TM Images: 1 Dec 1976, 21 Nov 1981, 3 Dec 1988, 26 Jan 1991, 2 April 1992, 15 Sept 1994, 4 Oct 1995, 20 Sept 1996 – 1/200 000 or 1/500 000; Liu et al 1987, Fan & Guo 1992).

Since 1976, the northern Diaokou River channel no longer received any sediment and the sub-delta of this river channel became unstable. This resulted in net erosion, and in a regression of the coastline (figure 3). Between 1976 and 1989, the coastline at the mouth of the Diaokou River channel moved about 4 km landwards due to erosion with an average scouring thickness of over 10 cm y^{-1} (Li et al 1992).

Just before the flood season in 1996, a new channel was artificially constructed in the downstream section of the Qingshuigou channel. This new channel diverts the river runoff from the former east-protruding river mouth to a new river mouth extending north-eastwards. This work was carried out mainly for economical reasons. The new river channel will create a new sub-delta in the position of the offshore oil field of the Shengli Oil Field, which is situated presently in shallow sea. This new sub-delta will play a very important role in the development of the offshore oil field, because it will make it possible to avoid expensive offshore infrastructure for its exploitation.

2.2 Physical attributes

2.2.1 Geology

The YRD lies in a fault-depression basin of Cenozoic Era on the North China Platform of Sino-Korea ancient land. It lies to the west of the Tancheng-Lujian fault zone, to the east of the Jiyang depression, and to the south of the Bohai Depression (Gao & Li 1989).

The YRD was formed on a metamorphic basement with a complete, deposit stratigraphic sequence and a total depth of over 10 km.

The surface of the YRD is formed from sediments deposited during the Holocene Epoch. There are two primary types: the Yellow River alluvium and marine deposits. Yellow River alluvium is the main alluvium in the YRD, and can be divided into four sub-types: river bed-back swamp alluvium, inter-river depression-flood alluvium, natural levee alluvium, and alluvial fan sediment. Most of the marine hydrodynamic factors are acting on the sand and mud from the river. Based on its characteristics and position, the marine alluvium may be divided into two types: the tidal flat sediment and the nearshore sediment.

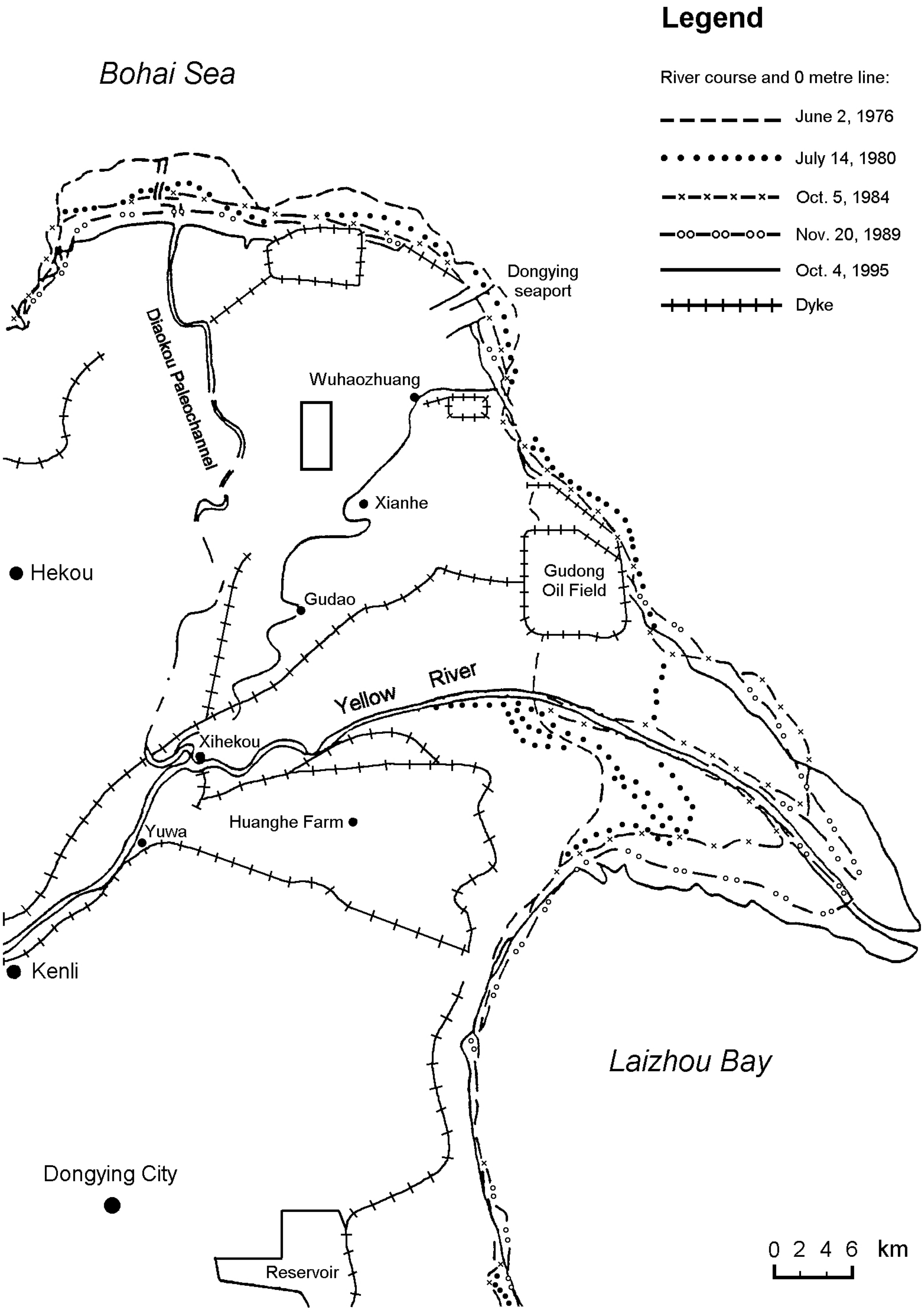

Figure 2 Map of the dynamic evolution of the Yellow River mouth (the river courses and 0-m lines from 1976 to 1989 are drawn according to the *Atlas of Remote Sensing Dynamical Analyses on the tidal flats along the Yellow River Delta*)

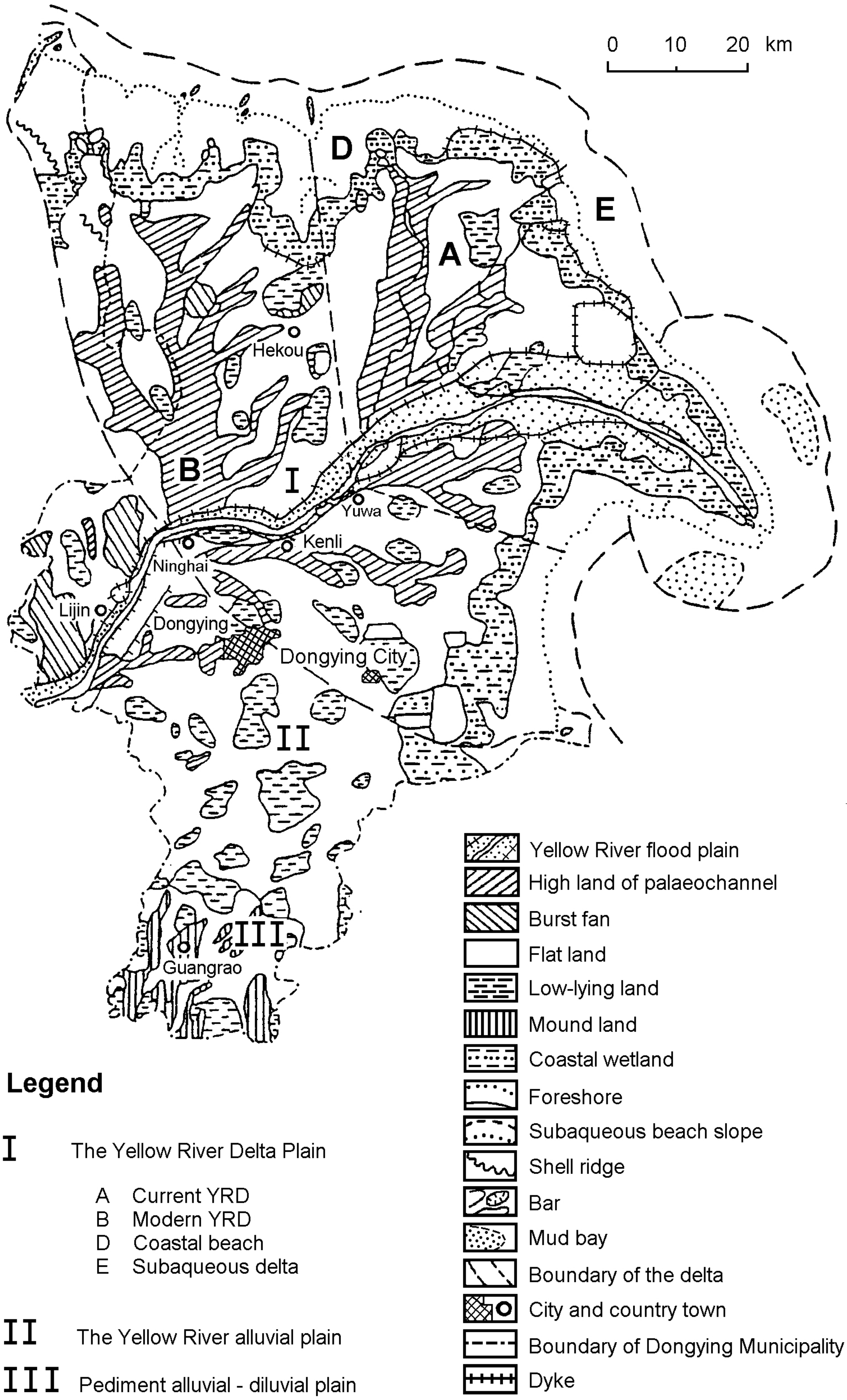

Figure 3 Terrestrial geomorphic map of the YRD region

2.2.2 Climate

Monsoon climate

The YRD has a monsoon climate of the warm-temperature zone with four distinct seasons. It is dry and windy in the spring, hot and rainy in the summer, cool and clear in the autumn, and cold, dry with some snow in the winter. In addition, there are distinct inland climate characteristics.

The average annual temperature across the region is 12.2–12.6°C. The highest average temperature is 25.9–26.2°C in July and the lowest -3.3–3.9°C in January. The highest temperature recorded is over 36.2°C and the lowest is -10.3°C. The frost-free period lasts 210 days per year. Average annual precipitation is about 600 mm, with 68%, 18%, 3% and 11% of this falling in summer, autumn, winter and spring, respectively. Average annual evaporation is 1900–2400 mm. The average annual relative humidity is 68%, the mean aridity is 1.6, and the continental index is 62.3, which indicate a semi-humid climate. The average wind velocity is 3.7 m s^{-1}. Prevailing wind directions are northwest by northward in winter and spring, and southeast by southward in summer and autumn (Science and Technical Committee of Shandong Province 1991, Yang & Wang 1993, Zhao & Song 1995).

The distinct economic advantage of the climate in the YRD is that precipitation is mostly concentrated in the growing season. The major disadvantage of the climate is its instability with variable precipitation, strong winds in winter and spring and abrupt change of annual temperature.

Major meteorological disasters

The major extreme meteorological events that occur in the YRD are as follows.

Drought and flood

Drought and flood are the main meteorological disasters for agriculture. There have been five severe droughts and three destructive floods since 1959.

Strong windstorm

The annual mean duration of strong wind (wind scale 8–17 m s^{-1}) is 15.4 days. The maximum is 30 days. The maximum wind velocity is 30.7 m s^{-1}. Strong wind is very destructive to agriculture, fishery, transportation and communications. The prevailing wind is from the north-east.

Hail

Hail occurs approximately once a year. The maximum is 5 times in one year. It mainly occurs from April to September and lasts 5–10 minutes in each occurrence. Hail diameter is 15–25 mm.

Rainstorm

Rainstorm is an extreme rain event with precipitation exceeding 50 mm. It is a main cause of flood disaster in the YRD.

Storm surge

Storm surge in the YRD mainly results from strong north-east winds, resulting in the collision between the surge tide of Bohai Bay and the high tide of Laizhou Bay. Spring and autumn are the windy seasons. High surge occurs if strong southeast winds are succeeded by strong northwest winds. Storm surges often occur during the flood season of the Yellow River. As a result of the flat topography at the mouth area, a 3 m storm surge can intrude inland up to 10 km. Storm surges often bring disasters to the delta (Yang & Wang 1993).

2.2.3 Hydrology

River hydrology and groundwater

The Yellow River exhibits four periods in its flow regime. The first, from the end of March to June, has a low discharge and constant water flow. However, due to increasing water consumption along the Yellow River, especially from the rapid development of water diversion works for irrigation, the flow is now frequently disrupted. This has occurred in 18 of the years between 1972–1992, and in the 1990s it has happened earlier and lasted longer. This is the key period for irrigation, so the disruption often has serious consequences. The second period, from July to October, is the main flood season, during which there is much more precipitation in the middle and lower reaches of the river, and a large discharge with a high flood peak. The third period is from October to the middle of December, during which the lower reaches of the river are controlled by atmospheric high pressure systems. Thus, the weather is clear, and the river discharge is steady. The fourth period is from the end of December to March, known as the ice-bound season. Although discharge at this time is not great, the water level rises rapidly due to poor drainage caused by ice blocking the river channel and forming an ice dam. Consequently, 'ice floods' happen regularly in the lower reaches, causing danger to life and properties.

Based on observations from 1950–95 at Lijin hydrological station near the mouth of the Yellow River, the mean annual discharge of the river is 41.9×10^9 m^3. The annual water discharge fluctuates greatly, with a maximum of 79.31×10^9 m^3 and a minimum of 9.15×10^9 m^3, representing almost a factor of nine difference. The average rate of discharge in this region is 1330 m^3 s^{-1}. The maximum at flood peak is 10 400 m^3 s^{-1} and the minimum is zero (Science and Technical Committee of Shandong Province 1991, Yang & Wang 1993). The Yellow River is the second largest river in China, and has the highest sediment-content of all rivers in the world. The average annual sediment load is 1.049×10^9 t with a maximum of 2.1×10^9 t (1958) and a minimum of 0.242×10^9 t (1960). The average sediment concentration is 25.53 kg m^3, with a maximum sediment concentration of 222 kg m^3. In recent years, with the increase in water diversion structures the river discharge and sediment load have decreased abruptly. The average discharge and sediment load from 1986–92 were 17.6×10^9 m^3 and 0.411×10^9 tons, accounting for 42% and 39% of the long-term average, respectively.

The Yellow River has a pH of 8.0–8.3, general hardness of 2.16–5.56 mg L^{-1} and a salinity of 0.2–0.6g L^{-1}. It is the major source of water consumption for people, animal and production (Wang et al 1997b).

Located near the sea beach areas, the groundwater of YRD is categorised as loose rock pore water, and includes both saline water and slightly saline water. Because of its high salinity, it is not particularly suitable for primary production. The saline water is comprised predominantly of NaCl and $NaSO_4$, while the slightly saline water is predominantly NaCl based.

Marine hydrology

The tide of the subaqueous YRD is controlled by an amphidromic point of M_2 tide (38 09ºN, 119 04ºE). The mean high water interval is 10–11 hours in the Yellow River mouth. The average spring tidal range is 1.3–1.78 m near the river mouth where the tide type is irregular semi-diurnal. The neap tidal range is 0.46–0.78 m (Zang et al 1996, Yang & Wang 1993).

A stationary tidal wave system dominates the tidal current field with the greatest current at the mid-tidal level in the subaqueous delta. Many observations have indicated that the ellipticity of the tidal current is less than 0.1, the principle axis has parabathic and diabathic components, and the tidal current flows generally along the isobaths on the delta front. The flood current moves to the south and the ebb current to the mouth. The tidal current curves were measured inside the river mouth with no river discharge; ebb current in excess of 1.75 m s^{-1} causes erosion.

Since 1976, the subaqueous delta of the Yellow River has rapidly expanded into Laizhou Bay, with the 2-m isobath prograding seawards at a mean rate of 1.29 km y^{-1}. During this expansion, a protruding mouth spit formed. The tidal current at the front of the delta has been strengthened by the effect of topography from the advancing delta front (Li et al 1992). The maximum spring tidal current velocity increased from 0.9 m s^{-1} in 1976 to 1.58 m s^{-1} in 1991. A strong tidal current can widen the distance of river-driven suspended silt dispersal and erode the subaqueous delta of the Yellow River in the dry season.

2.2.4 Topography and geomorphology

Topography

The topography of the YRD is low and smooth. The elevation of the southwestern part of the YRD reaches 11 m above sea level and the north-eastern part less than 1 m. The slope is about 1/7000. Table 1 shows the relationship between surface area and elevation (Liu & Drost 1997).

Table 1 Relationship between surface area and elevation in the YRD (from Liu & Drost 1997)

Elevation (m)	Surface (ha.)	% of total area	Elevation (m)	Surface (ha.)	% of total area
0~1.0	73 355	9.5	6.0–7.0	73 000	9.5
1.0–2.0	126 801	16.4	7.0–8.0	64 682	8.4
2.0–3.0	101 140	13.1	8.0–10.0	57 355	7.4
3.0–4.0	90 383	11.7	10.0–12.0	15 266	1.9
0–4.0	391 679	50.8	12.0–17.0	16 733	2.1
4.0–5.0	77 494	10.0			
5.0–6.0	75 390	9.8	**Total area**	**771 599**	**100**

The elevation of the YRD reflects a sedimentation history of shifting river channels. Each of the river channels has created its own individual alluvial fan, forcing the water into a new channel through nearby low-lying back swamps. This process results in a pattern of partly overlying, partly adjacent fans. Each fan is highest in its central and upstream parts, and is marked along its central axis by the remnants of the river channel; usually a narrow, meandering creek. Back swamps between existing fans were filled with sediments from newer fans. Some back swamps, however, have not been completely covered by new fans.

While the sedimentation process proceeded in a seaward direction, such back-swamps became isolated depressions, surrounded by higher territory. The summer rains tend to cause inundation in such depressions, as these depressions have no natural outlet for water. Examples of such isolated depressions are present between the 1926–29 and 1934–76 fans, and between the 1953–64 and 1964–76 fans.

Geomorphology

The modern YRD refers to the fan formed since the Yellow River breached at Tongwaxiang of Henan Province in 1855, and flowed into the Bohai Sea through the Daqing River mouth in the south, covering an area about 9000 km^2. It can be divided into a terrestrial delta (about 6000 km^2) and a subaqueous delta (about 3000 km^2), with intervening tidal flats (Gao & Li 1989, Zang et al 1996, Li et al 1992, Xu et al 1997, Yang & Wang 1993).

Terrestrial delta

The terrestrial delta is shown in figure 3. The annual average amount of sediment discharge of the Yellow River is about 1.05×10^9 t, of which 64% is deposited in the river bank and river bed of the Yellow River mouth. This deposition made the divided channel of the YRD become a frequently fluctuating 'hanging river', forming the fan terrain of gentle tilted land and inter-river depressions on the framework of river-built 'highland'. Under the action of the river and marine vessel power, various morphological patterns were established. The terrestrial part of the YRD can be divided into four types: river-built highland, gentle tilted land, depressions and river mouth sand spit. These are briefly described below.

River-built highland: Owing to accretion of the river channel, the riverbed and the accumulative bodies of both sides of the river are higher than the ground around them. Since June 1855, there have been 11 river diversions, forming many bifurcated river channels (old courses) radiating from the apex of the delta. The densely distributed river channels overlapped and formed finger-shaped mounds, termed river-built highland, which is 2–3 m higher than the ground around them.

Gently tilted land: This is a transitional morphological form, inclining from the river-built highland to inter-river depressions, with a slope of 1/3000 to 1/7000.

Depressions: These are relatively low lands on the delta plain, including inter-river depressions, humid land and so on.

River mouth sand spit: This is the bifurcated river channel and the natural levee banks either side of the channel extending toward the sea. It includes a small river mouth sand spit group, fan-shaped sand spit group, round stack sand spit group and ox-horned sand spit.

Subaqueous delta

The subaqueous delta is shown in figure 4. The subaqueous delta, consisting of many layered subaqueous subdeltas, is the expanding part of the terrestrial delta, surrounding the terrestrial delta with a half wide *clitellum,* covering an area of about 3000 km^2. The subaqueous delta lobe to the west of the Tiaohe River mouth is in a stage of dynamic equilibrium, with weak erosion and weak siltation. The subaqueous delta lobe from the Tiaohe River mouth to Shenxiangou River mouth is mainly being eroded. Not only is the front of the terrestrial delta falling into the sea, but the subaqueous delta is eroded flat under the actions of waves and tidal currents, and the coastline retreats and becomes straight. From Shenxiangou River to the Xiaoqing River mouth in the south, the present river mouth of the YRD is in the stage of strong progression, where subtidal muddy flats have developed at both sides of the river mouth.

According to the morphogenesis and its characteristics, the subaqueous delta may be divided into two large geomorphic units: subaqueous delta plain in the current river mouth area, being in a strong progression stage, and subaqueous delta bank-slope along the abandoned river bank, being in an eroding stage. It is composed of many geomorphic forms again such as tidal ditch-shaped bar, tidal ditch-shaped pool, estuary sand bar, estuary pool, mud and underwater drift and so on.

Tidal flats

The tidal flats are displayed in figure 4. Similarly to the subaqueous delta, the development of tidal flat is controlled by the dynamic processes of tidal current at the river mouth. Along the coast of the present Yellow River Mouth (YRM), deposition is the dominant process. Along the coast of the abandoned channels, dynamic geomorphologic conditions have reversed since the Yellow River mouth migrated to the south in 1976. Wave-scouring and erosion have become the main dynamic process, which has rebuilt the tidal flats into a series of particular dynamic geomorphic types and an ecological system that have been changing with time (Li et al 1992).

The tidal flats may be divided into two types: the super-tidal flat and the intertidal flat. The former is the area between the average spring high tide level and the average high tide level, with a width of 1–3 km. The latter is that between average high tide level and the lowest tidal level, and can be divided into three zones: high tidal flat, middle tidal flat and low tidal flat.

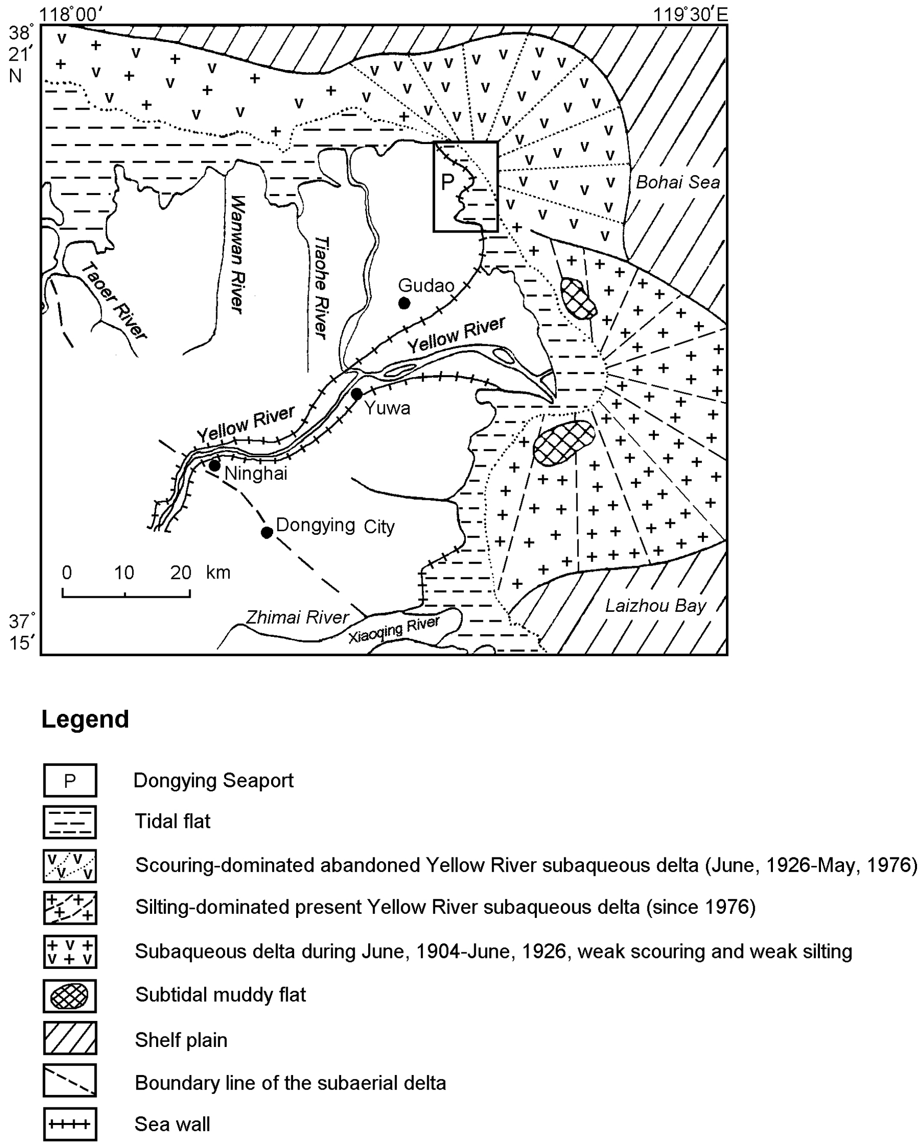

Figure 4 Geomorphic map of the subaqueous delta of the Yellow River

1. Dongying Seaport; 2. Tidal flat; 3. Scouring-dominated abandoned Yellow River subaqueous delta (June 1926 – May 1976); 4. Silting-dominated present Yellow River subaqueous delta (since 1976); 5. Subaqueous delta during June 1904 – June 1926, weak scouring and weak silting; 6. Subtidal muddy flat; 7. Shelf plain; 8. Boundary line of the subaerial delta and 9. Sea wall.

2.2.5 Sedimentation

Sedimentation in the upper distributaries and the estuary of the Yellow River

Many scientists have been studying and measuring the Yellow River for almost a century. Recently, Li et al (1998a) conducted a systematic study of the sedimentation of the Yellow River and its mouth.

As stated in section 2.2.4 (Geomorphology – terrestrial delta), the average annual sediment discharge of the Yellow river exceeds 1×10^9 t, of which 64% is deposited in the Yellow River mouth. The suspended sediments of the Yellow River are derived from the Loess Plateau where the sediment is loose and easily eroded by storms. High sediment concentrations of several hundred kg m^{-3}, at times exceeding 1000 kg m^{-3}, are often measured in the lower reaches of the Yellow River during floods. Although the concentration of suspended sediments falls significantly following large river flows in the delta areas, the sediment concentration remains more than 100 kg m^{-3} in the lower layer of the river. The grain size of suspended sediment is finer in the delta than in the Loess Plateau due to sorting along the lower reach of the river. The sediment transportation and fluid characteristics of the YRD have been observed and studied for the last 20 years (Li et al 1998a, Qian et al 1981, Van Den Berg & Van Gelder 1993, Wei & Li 1995). Major results are as follows.

1. The physical nature of water with a high sediment concentration was influenced by suspended sediments more than by temperature. The sedimentation on the distributary of the YRD is influenced by the tide, especially the sediment concentration during the flood period.
2. River and suspended sediment discharge into the modern YRD is affected by two factors, natural and anthropogenic. The 4–6 year periodicity reflects the natural changes in the upper part of the Yellow River basin because no rivers have entered the lower reach of the Yellow River since the bed became higher than the surrounding plain. As a result of the pumping of water from the river, the discharge has decreased and the sediment concentration increased since the 1970s. The mean river and suspended sediment discharge into the delta between 1970 and 1993 were 2.81×10^{10} m^3 and 7.1×10^8 t y^{-1}, respectively, which are different to earlier data from Milliman and Meade (1983). Up to now, the capacity of reservoirs that have been built along the Yellow River has exceeded the mean annual river discharge, forcing the government of China to pay attention to the shortage of water resources on the YRD.
3. According to the discharge distribution, each year can be divided into two periods: a flood season from July to October, with mean discharge of 1669 m^3 s^{-1} since the 1970s, and a dry season. During the dry season, the tidal water penetration is more than 20 km and the tidal current extends several kilometres in the lower distributary channel. During the flood season, the tidal wave penetration is commonly less than 15 km and no tidal current or tide elevation intrudes into the river. There is a so-called tidal sensitive zone inside the river mouth. The length of the zone is related to the discharge, amounting to 6–7 km with a river discharge rate of 1100 m^3 s^{-1}. This zone is very active in terms of sedimentation, and functions as a high velocity zone where the river bed is being eroded and the suspended sediment is dispersed into the delta front during the ebb periods, and as a low velocity zone where the suspended sediment carried by the Yellow River is trapped and deposited rapidly as the 'plastic' bed during the flood periods. The rapid deposition of the low velocity zone can be enhanced by the effect of salt permeation during the flood period. One dimensional current simulation and river-induced current computation show that the tidal sensitive zone is a major area where the kinetic energy of the river has been largely dissipated, and the so-called high velocity zone of the ebb is relative to the low velocity of the flood.

Sedimentation on the present subaqueous delta of the Yellow River

A large amount of observational data indicate that hyperpycnal underflows can be formed and move along the front of the delta when sediment concentration in the river effluent exceeds 18 kg/m^3 (Wright et al 1986, Wright et al 1988, Wright et al 1990). Because the mean sediment concentration is 25.3 kg m^{-3} in the distributary of the Yellow River, the frequency of hyperpycnal plumes is very high at the delta front (Li et al 1998b). The large amount of sediment transported by hyperpycnal plumes has been deposited on the delta front slope, especially at its base. A shear front, which obstructs the river inflows and small-scale circulations, has resulted in rapid deposition in the river mouth area (Li et al 1994). Since the mouth bar is accumulating rapidly and expanding seawards, the delta slope becomes steep and unstable. Submarine landslides have occurred due to instability (Yang et al 1990). Although the YRD and the Mississippi delta are both derived from large river systems, the YRD is typical of hyperpycnal underflows and thus different from the Mississippi delta in processes of formation and in environments of deposition (Coleman & Wright 1975, Li & Xue 1993). Conclusions about sedimentation on the present subaqueous delta of the Yellow River are as follows.

1. The Yellow River has transported a very large amount of sediment that accumulated on the modern delta resulting in rapid shoreline movement. The modern delta is composed of 12 individual delta lobes within 2 sub-deltas; one that was formed from 1855 to 1934, and another from 1934 to present. The distributary has often migrated on the delta and one lobe is formed from each migration. The last lobe has formed since 1976, growing at a mean speed of 1.29 km y^{-1}. The delta lobe is composed of many coalescing river mouth bars. When each new body of sediment is formed, three sedimentary environments are distributed in the subaqueous delta. The lower delta plain is composed of tidal flats influenced by high river discharge and distributaries influenced by tide. The delta front is composed of river mouth bar, delta slope and down-drift mud. The prodelta occurs off the 10-m isobath.

2. Two forms of river mouth bars occur in the Yellow River estuary. One is composed of a double-intertidal-lobe and a single-channel, which develops during high river discharge. The other form is composed of a double-channel and single-lobe, which develops during the dry season. The deposition rate on the river mouth bar is the highest among all environments in the delta. The quantitative distribution of the Yellow River sediments shows that about 30–40% of the sediment transported into the sea is deposited on the bar at the mouth. The sedimentary thickness can be in excess of 2 m in one mouth. The long axis of the bar, which is parallel to the general tidal current direction, indicates that the tidal current field dominates suspended sediment dispersal and deposition.

3. As mentioned above, the sedimentation rate of the mouth bar is the highest in the modern YRD because most of the kinetic energy of the river is dissipated there. The dissipation appears specifically in three ways. The first is the mechanism of a shear front that pushes the river plume landward (Li et al 1994) and forces convergence of the suspended sediments. The second is the small-scale circulation formed within the shear front, which returns water to the landward side of the river inflow. The last is the so-called ‘bulldozer’ effect in the tidal sensitive region inside the river mouth (see section 2.2.5 Sedimentation in the upper distributaries and the estuary of the Yellow River).

The low-concentration hyperpycnal plumes, which have a small density difference from the ambient water, have dissipated and accumulated approximately 20% of total sediment on the front of the delta.

There are two processes that disperse suspended sediment from the front of the delta. One is the hyperpycnal plume, which transports fine sediment into the down-drift mud adjacent to the river mouth, prodelta, and the centre of the Bohai Sea and north of the Yellow Sea under the action of residual currents. The second is the high hyperpycnal underflows, which drive the turbid body into the upper part of the prodelta to form the subaqueous delta rise. The subaqueous rise zone should be recognised as an independent geomorphologic unit, which occurs between the slope and prodelta (approximately 10–12 m depth).

2.2.6 Natural resources

Rich resources of oil, natural gas, water, brine and geothermic energy are located in the YRD, among which the reserves of oil, natural gas and brine rank first in the coastal area of China (Chen et al 1997, Environmental Monitoring Station of Dongying Municipality 1994).

Oil and natural gas resources

The oil and gas fields proven and extracted in the Shengli Oil Field – the second largest oil field in China – are mostly located in the area of the YRD. The proven reserves of geological oil and natural gas are 3.2×10^9 tons and 25.7×10^9 cubic metres, respectively. Presently, 64 oil and gas fields have been detected. Of these, 49 have been explored, including nine large oil fields with 61% of the proven geological reserve, ten intermediate oil fields with 18% of the geological reserve and 30 small oil fields representing the remaining 12%. The prospected oil reserve of Jiyang depression, in which the YRD is located, is 8×10^9 t.

Water resources

The Yellow River dominates the system for fresh water management in YRD. During 1950–87, the Yellow River at Lijin County had an average annual discharge of 40.4×10^9 m^3 of water and 1×10^9 t of sediment. However, the average annual discharges for the period 1987–1995 were significantly lower: 17.3×10^9 m^3 of water and 0.42×10^9 t of sediment. The Xiaoqing and Zhimaigou Rivers, originating in Jinan, are two regional rivers in the YRD, 34 km of which are within Dongying Municipality's boundary. They have a drainage area of 594 km^2 (within Dongying Municipality) and an average annual discharge of 580×10^6 m^3. Zhimai River, 48 km of which is within Dongying Municipality, originates in Gaoqing County in Zibo municipality. Its river basin covers 1129 km^2 (within Dongying Municipality).

The mean annual discharge through local rivers, due to the local precipitation surplus, is 448 $\times 10^6$ m^3 (related to 5500 km^2 of land surface). This water discharge is variable. In the past ten years a maximum of 746×10^6 m^3 was recorded in 1990 and a minimum of 258×10^6 m^3 in 1986. The discharge through the Yellow River is more than 60 times greater than the local run-off: an average of 27.5×10^9 m^3 per year (5000 mm) in the period 1973–1993. This discharge has shown a tendency to decrease in recent years, especially in spring. Zero-discharge in spring occurred at Lijin County from 1972–91 for 0–35 days per year, but since 1992 this has occurred 79–130 days per year.

The water resources of the YRD are subjected to a substantial amount of urban and industrial pollution. This is further discussed in section 3.2.4.

Underground brine

Underground brine is mainly found in alluvion and marine alluvium. The alluvion is located primarily in the river and its bank areas, in the form of a band with a depth of 1–7 (12) m. The marine alluvium is distributed mainly in the coastal areas with a depth of 3–10 (31) m. The total brine storage is about 7.4×10^9 m^3. There are many elements in the brine, such as K, Br, Mg, etc, indicating that the exploitation prospect is good.

Salt and halogens

The region is also rich in reserves of salt and halogens. The reserves of salt are located at a depth of 2900–4400 m, with an estimated geological reserve of around 600 × 10^9 tons. The reserve of underground halogens lie within a mineral bed of around 800 km^2, at a depth of approximately 2500–3000 m, and with an *in situ* reserve of about 3.5 × 10^9 m^3. To date, these resources have not been exploited.

2.2.7 Land types and use

Land types

Environmental differentiation in the YRD is great. Many geomorphologic units or land types have been formed by the interaction of the Yellow River and the nearby sea. The land types have been divided into units within three main geomorphologic types (table 2).

Table 2 Land types and their surface area in the YRD

Land type	Area (ha)	% of total
TERRACES		
Terrace uplands	16 295	2.4
FLOOD PLAIN		
Present flood plain	73 032	10.7
Abandoned river courses	128 815	18.8
Embanked former back-swamps	344 624	50.3
Isolated depressions	67 038	9.8
COASTAL ZONE		
Salt marshes and tidal flats	22 492	3.3
OTHERS		
Cities/towns	5 907	0.8
Water	22 492	3.7
Area for reed production	4 677	0.7

Terrace uplands are present in the YRD as small patches in the south, around Guangrao County. The general elevation of these terraces is high, over 10 m above sea level. The present flood plain is located along the present river channel. Abandoned river courses are composed of levees and crevasse-splays. Often, the sediment is sandy, and most of the land is used as farmland. The embanked back swamps are the most typical and widespread land type in the YRD. Most of the land is irrigated and used as farmland or for cattle breeding. At various places isolated depressions occur in the flood plain landscape. Depending on the impact of flooding by river water or by seawater, the land is used as farmland, as reed beds for cellulose production, as a site for fresh water reservoirs, or simply remains unused. The coastal zone is subdivided according to the varying influence of the sea. Thus, one form of salt marsh occurs above the mean high water level, with three types occurring between the high tide and low tide water levels (Land Management Bureau of Dongying Municipality 1993, Xu et al 1997).

Land use

The land resources of the YRD are abundant (~ 790 000 ha), with the surface area of the YRD being nearly 5.33 times the surface area of the Yangtze River Delta. Moreover, the process of accretion from sediment carried by the river continued to increase the amount of land (21 km^2 y^{-1}) for the period 1989–1995 (Chen et al 1997).

The population density in the YRD is approximately 210 persons km^{-2}. This is low in comparison with its surroundings – an average of 557.6 persons km^2 in Shandong Province. This low population density is mainly due to the previous unfavourable physical conditions in the new, low-lying land, with frequently shifting river courses. The revenues from oil and gas exploitation increased the potential for investments to improve these physical conditions, with infrastructure for agricultural and urban-industrial development. Consequently, the YRD is considered as a regional immigration area.

The various land uses of the YRD are shown in figure 5. Forestry and cattle breeding are concentrated in Hekou District and in Kenli County. About 90% of the total forest area and 90% of the total grassland are concentrated here. Irrigated agriculture is concentrated in the region to the south of the Yellow River. Paddy fields are concentrated around the cities of Dongying, Kenli, Hekou and Lijin, and in the neighbourhood of the Shengli Oil Field, in order to provide locally produced food to the local inhabitants. Industries are also concentrated in these regions. Aquaculture and salt pans are limited to the coastal zone. However, most of the coastal zone is unused land due to the high salinity.

Table 3 presents the area occupied by the various land uses. As much as one third of the land in the YRD is unused for agricultural or industrial production. Considering the rural land use, table 3 reveals the ratio between agriculture/forestry and cattle breeding is 4:1. The results of a land suitability assessment showed that this ratio should be 5.2:3. Thus, the present land use is not in balance with the land suitability, showing a relative over-development of agriculture, an under-development of cattle breeding and a serious under-development of forestry. Table 3 does not present the Nature Reserve as a specific land use unit, but as a mosaic of the various land use activities that are practised within its borders.

Agriculture in the YRD is predominantly classed as being ‘small-scale peasant economy’, or the so-called ‘grain-cotton model’. However, it is considered difficult to maintain sustainability with the grain-cotton model. Because of various unfavourable physical conditions (drought, infertility, impeded drainage and salinity), the agricultural productivity is low. At present, the surface areas of the irrigated and non-irrigated farmlands are similar, each occupying about 140 000 hectares. The existing water resources in the Yellow River are not fully utilised, so it is considered possible to make more land suitable for irrigation (Land Management Bureau of Dongying Municipality 1993, Xu et al 1997, Soil and Fertilizer Working Station 1988).

The coastal zone is incompletely used. However, the development of marine or freshwater aquaculture industries is considered to offer possibilities for intensification of the land use in this zone.

2.3 Biological attributes

2.3.1 Plant resources

The flora of the Yellow River Delta Nature Reserve (YRDNR) represents the natural flora in the YRD. The YRDNR is a newly formed wetland ecosystem, which has three features. First, due to the young age of the terrestrial land, various plant resources are still in the initial stage of succession and development. Second, because the terrestrial area of the reserve continues to increase with accretion at the river mouth, the plant communities are continuously extending toward the coast. Third, the formation, development and succession of various plant resources in the YRDNR are largely undisturbed by human impacts.

Flora

Flora composition: In the reserve, there are 393 species of plants, among which there are: 4 divisions and 116 species of phytoplankton; 3 families, 3 genera and 4 species of fern; 2 genera and 2 species of gymnosperm; 54 families, 179 genera and 271 species of angiosperm (11 families, 58 genera and 87 species of monocotyledons and 43 families, 121 genera and 184 species of dicotyledons).

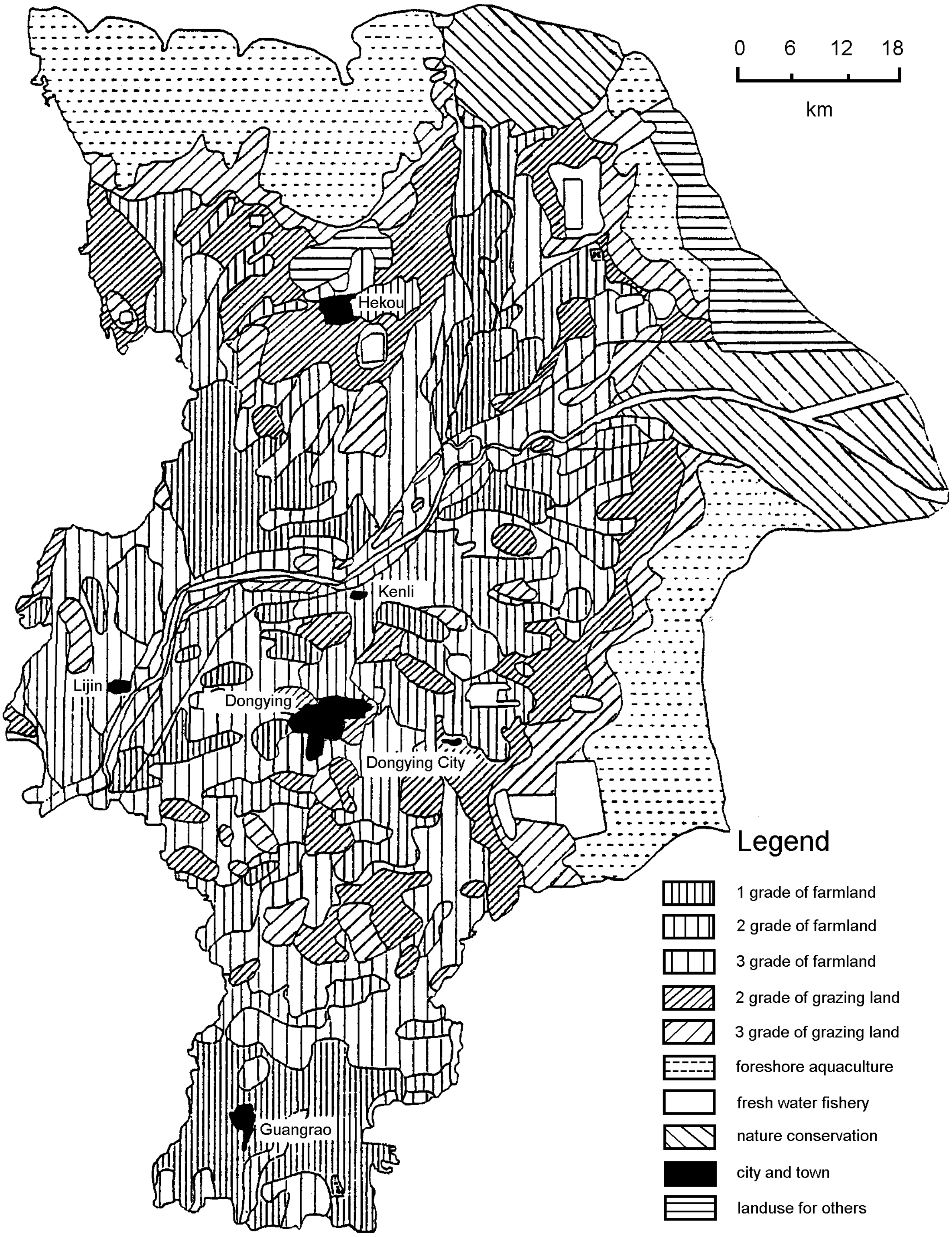

Figure 5 The evolution map of land suitability for agriculture in the YRD

Table 3 Distribution of land use in the YRD

Land use*	Area (ha)	% of total
URBAN INDUSTRIAL		
Residential area	31 886	4.1
Industry	7 653	1.0
Airport	335	0.1
AGRICULTURE		
Non-irrigated farmland	139 752	18.1
Irrigated farmland	148 611	19.3
Paddy field	28 135	3.7
Orchard	2 456	0.3
CATTLE BREEDING	83 417	10.8
FOREST	13 749	1.8
UNUSED	261 379	33.9
OTHERS		
Aquaculture	14 869	1.9
Reed land	24 216	3.1
Fresh water reservoirs	12 868	1.7
Salt pan	1 281	0.2

* The Nature Reserve is not classed as a land use type, instead being considered as a mosaic of the various land use activities practised within its borders.

Geographical components of flora: According to the classification in '*China Vegetation*', the YRD reserve occurs in the warm temperate broad-leaf forest zone, northern deciduous *Quercus* spp. subzone, Yellow River plain cultivation area. The flora in the reserve mainly comprises temperate components.

Vegetation forms

Based on the classification system in '*China Vegetation*', the vegetation in the reserve has been divided into five vegetation type groups, with 9 vegetation types, 26 plant formations and plant association, as outlined in table 4 (Zhao & Song 1995, Xu et al 1997).

Most of the vegetation in the YRDNR is natural vegetation. The main artificial vegetation in the reserve is *Robinia pseudoacacia* (English name: Black Loquat) plantation, which joins the *Robinia pseudoacacia* plantation around the reserve, forming the largest *Robinia pseudoacacia* plantation in coastal China.

Phytoplankton

The annual phytoplankton variation in the mouth of Yellow River old course is different from that in the current Yellow River mouth to the sea. There are two peaks of biomass, which occur in June (4.5 mg m^{-3}) and the end of August (3.2 mg m^{-3}). The nadir appears in July (2.8mg m^{-3}).

As mentioned above, there are 4 divisions and 116 species of phytoplankton. This includes 102 species of bacillariophyla, which account for 88% of the total phytoplankton.

The average total number of net phytoplankton is 2.26×10^6 m^{-3} from April to December, and 3.27×10^6 m^{-3} from December to February. The variation is different among different shallow seas.

Table 4 Classification of vegetation within YRDNR

- A_1 Broad-leaf forest
  - B_1 deciduous broad-leaf forest
    - C_1 Form. *Robinia pseudoacacia*
    - C_2 Natural Form. *Salix* spp.
- A_2 Bush
  - B_2 salt thicket
    - C_3 Form. *Tamarix chinensis*
- A_3 Meadow
  - B_3 typical meadow
    - C_4 Form. *Imperata cylindrica*
    - C_5 Form. *Artemisia capillaris*
    - C_6 Form. *Calamagrostis epigejos*
    - C_7 Form. *Cynodon dactylon*
    - C_8 Form. *Digitaria sanguinatis, Eragrostis pilosa*
  - B_4 salt-meadow
    - C_9 Form. *Suaeda heteroptera*
    - C_{10} Form. *Aeluropuslittoralis* var. *Sinensis*
    - C_{11} Form. *Phragmites australis*
    - C_{12} Form. *Trachomitium lancifilium*
  - B_5 salt-hygrocole meadow
    - C_{13} Form. *Phragmites australis*
- A_4 Paludous vegetation
  - B_6 herbaceous swamp
    - C_{14} Form. *Phragmites australis*
    - C_{15} Form. *Typha* spp.
    - C_{16} Form. *Triqueter* spp.
    - C_{17} Form. *Polygonum lapathifolium*
- A_5 Aquatic vegetation
  - B_7 submerged aquatic vegetation
    - C_{18} Form. *Ceratophyllum demersum, Hydrilla verticillata, Myriophyllum picatum*
    - C_{19} Form. *Potamogeton malainus*
    - C_{20} Form. *Potamogeton crispus, Vallisneria gigantea, Najas* spp.
    - C_{21} Form. *Ruppia rostellata*
  - B_8 *Hydrophyta natantia* vegetation
    - C_{22} Form. *Lemna minor, L. Trisulca*
    - C_{23} Form. *Spirodela polyrhira, Lemna minor*
    - C_{24} Form. *Potamogeton distinctus, P. Natans*
  - B_9 *Hydrophyta adnata*
    - C_{25} Form. *Nelumbo nucifera*
    - C_{26} Form. *Sagittaria sagittifolia* var. *Sinensis*

The phytoplankton can be divided into three ecological formations:

C1: Higher-halophilic formation: *Rhizosolenia alata findica, Chaetocero densus, Nitzschia pungens*, etc, are 29–30% halophilics.

C2: Lower-halophilic formation: *Chaetoceros abnormis, Skeletonema coata tum*, etc.

C3: Freshwater formation: *Scenedesmus quadricauda, Pediastrum* spp., *Cyclotella, Menghiana*, etc.

2.3.2 Animal resources

Fauna types

The animals in the YRD can be divided into two ecological communities: the terrestrial eco-community and the marine eco-community. There are 1466 species of wild animals recorded, among which there are 300 species of terrestrial vertebrates (20 species of mammals, 265 species of birds, 9 species of reptiles, 6 species of amphibians) and 664 species of terrestrial invertebrates (477 species of insects, 19 species protozoan, 18 species of protochors, 68 species of arachnids, 13 species of molluscs and 40 species of crustacean) (Zhao & Song 1995, Xu et al 1997).

There are 67 species of freshwater fish, among which 39 species are cyprinidal. Among the marine animals recorded, there are 5 species of mammals, 1 species of reptile, 85 species of marine fish, 99 species of molluscs, 82 species of polychaeta, and 25 species of medusa.

According to the geographic classification of the terrestrial animals of China, the terrestrial animals in the YRD belong to the Nearctic pattern, north-east sub-pattern, north China region, and Yellow River–Huaihe River Plain sub-region. It is a transitional zone from the Oriental pattern to the Nearctic pattern. In the geographic classification of marine animals for China, the marine animals in the YRD belong to the Yellow Sea–Bohai Sea fauna. It is also a transitional zone for the cold-warm water aquatic species and warm water species. The influx of fresh water brings a large quantity of nourishment and there are abundant mollusc and crustacean resources. Thus, the marine environment is exceptionally suitable for fish, resulting in the area being a major spawning ground.

With its large areas of shallow sea and bog, abundance of wetland vegetation and aquatic biological resources, YRD provides birdlife with exceptional habitat for breeding, migrating, and wintering, making the region an important ‘transfer-station’ for inland north-east Asia and around the western Pacific ocean for bird migration.

The Nature Reserve and importance for bird migration

Wetlands are considered valued components of the natural environment. Wetland habitats are recognised as being important for their biological diversity, as sanctuaries for migratory and resident bird populations, and for their contribution to estuarine and marine productivity. These values have been nationally and internationally acclaimed for the YRD.

In the YRD, wetlands occupy an area of 4500 km^2, of which 2000 km^2 is supratidal wetland, 1000 km^2 intertidal wetland and 1500 km^2 subtidal wetland. The ecological environment is vulnerable in the YRD, especially the river mouth, sub-delta tidal flats and coastal wetlands.

The Nature Reserve of the YRD is a newly-formed wetland ecosystem and is a conservation area mainly for the protection of rare and endangered birds. It is located at the Yellow River Mouth area and near the abandoned channel of the Yellow River before 1976. The total area is 1530 km^2, of which 65% is river, waterlogged and foreshore, 15% is grassland, 12% is forest, and 8% is farmland.

Due to deposition of large quantities of sand and silt carried by the Yellow River, areas of new mud flats are continually being formed (ie 21 km^2 y^{-1} for the period 1989–1995; Chen et al 1997). Thus, the reserve area increases continuously, making it one of the most rapidly expanding land reserves in the world. With its large areas of shallow sea and bog, abundance of wetland vegetation and aquatic biological resources, this reserve provides the birds with exceptional habitat for breeding, migrating and wintering. Therefore, the reserve is an important 'transfer station' for inland north-east Asia and the western Pacific Ocean for bird migration (Zhao & Song 1995).

The Yellow River Delta Nature Reserve (YRDNR) comprises the largest newborn wetland in China (figure 6). The Sino-Japanese Agreement for Bird Protection, lists 227 species of birds protected in China, of which 152 species (67%) occur in the YRDNR. In addition, 51 species in the reserve, accounting for 63% of the total species, were listed as protected birds in the Sino-Australian Agreement for Bird Protection (Zhao & Song 1995, Xu et al 1997).

The rare and endangered species of birds of YRDNR include the following:

Grus japonensis **(Red-crowned Crane)**: About 800 arrive in the reserve each year, of which 200 winter here. This is the most northerly wintering site for this bird (in mainland Asia). Its flocks often occur together with *Grus grus liffiordi.*

Ciconia boyciana **(Oriental White Stork)**: In the middle of October each year, this bird comes from the north and stays for a short time before continuing to migrate southward. In middle and late March of the following year, it returns from the south and stays several days before migrating northward. The maximum population recorded is 40 birds (of a global population estimated at 2500–3500 individuals; Rose & Scott 1997).

Otis tarda dybowskii **(Great Bustard)**: 700–800 Great Bustard winter here with a maximum population of up to 400. They migrate to the reserve in early November each year and leave for breeding grounds in late March of the following year.

Grus grus liffiordi **(Common Crane)**: This species migrates to the reserve for wintering in the middle of October each year with maximum numbers up to 6000 and a minimum population of about 300.

Cygnus cygnus **(Whooper Swan)**: About 2000 Whooper Swans winter at YRDNR. They remain in the reserve from the middle of November each year to the middle of the following April.

In recognition of the importance of the Reserve to Eurasian Cranes and Red-crowned Cranes, the Forestry Administration has nominated the area to be part of the East Asian Crane Site Network. This is an international cooperative program to promote the appropriate management of international important sites for migratory cranes.

The YRD is also an important area for passage and wintering of waterfowl, particularly herons and egrets (Ardeidae), swans, geese and ducks (Anatidae), shorebirds, and gulls and terns (Laridae) (Scott 1989). The area is considered to support over 500 000 shorebirds during their northward migration (Barter et al 1998). Recently it has been shown to meet the Ramsar Convention criteria for 15 species of shorebirds (Barter et al 1998). The key habitat used by shorebirds is tidal flat. In recognition of the area's importance for migratory shorebirds, the site has been nominated for the East Asian-Australasian Shorebird Site Network.

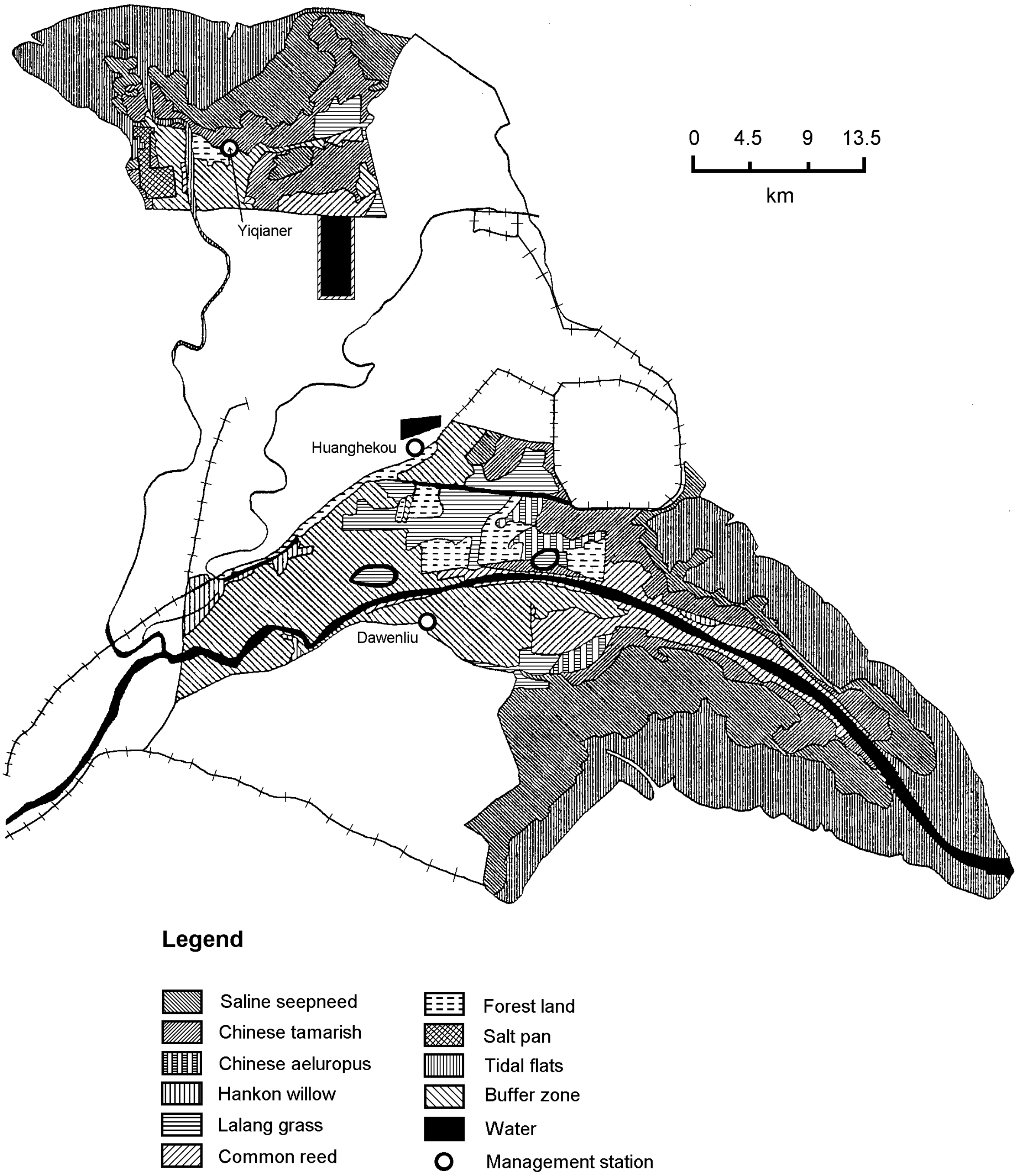

Figure 6 Vegetation and birds in the YRD Nature Reserve

2.4 Social, economic and cultural attributes

2.4.1 Administration and governmental structure

Dongying Municipality, Shandong Province, is located in the YRD. The population consists of 1.64 million people. Seventy percent of these (1.15 million) take part in agriculture, both directly and indirectly. The remaining 30% (490 000) take part in non-agricultural industries. Dongying Municipality is subdivided into five administrative units: Guangrao County, Lijin County, Kenli County, Dongying District and Hekou District (table 5; Wang et al 1997a, Wang et al 1997b, Statistical Bureau of Dongying Municipality 1994a,b).

Table 5 Area and population of the administrative units of Dongying Municipality

County	Area (ha)	Population	Persons/km^2
Guangrao County	115 100	461 600	401
Lijin County	106 800	288 900	271
Kenli County	211 800	208 700	98
Dongying District	116 100	489 800	422
Hekou District	233 600	172 100	74

The Yellow River Delta Nature Reserve (YRDNR) is located in the YRD, with a geographical position from 118º33´E to 119º20´E and from 37º35´N to 38º10´N. The Nature Reserve consists of two separate parts: the floodplains and abandoned river mouth in the north (approx. 40 000 ha) and the flood plains and active river mouth in the east (approx. 105 000 ha). The total area is 145 000 ha. The preserve was established in December 1990, approved by the Dongying government, and became a provincial Nature Reserve in November 1991. In October 1992, it was approved as a State Nature Reserve by the State Council of China.

2.4.2 Social infrastructure and social development

Based upon the current Official Statistical Issue of Economic and Social Development of Dongying Municipality, major aspects of the social infrastructure and social development are as follows (Wang et al 1997a,b, Statistical Bureau of Dongying Municipality 1994a,b):

- The total population in 1995 was 1 641 145 persons, of whom the non-agriculture population was 493 436, or about 30%.
- Urban income is 5666 Yuan/capita, with a nominal growth rate of 27.6%, and a real growth rate of 12%. Rural income is 1636 Yuan per capita, with a nominal growth rate 29.3% and a real growth rate 6.8%.
- Education: There are two universities and colleges with 7810 students enrolled and several middle level vocational schools with 7279 students enrolled in 1995. Nine-year compulsory education has progressed dramatically, now reaching 59 towns and villages of Dongying. In 1995, there were 157 ordinary middle schools and 584 primary schools, with total enrolments of 108 220 and 151 119 students, respectively. The data show that the total number of students presently in school is around 18% of the region's total population.

2.4.3 Present economic development

Gross regional product (GRP) and its components

The gross regional product (GRP) in 1995 was 21.74 billion Yuan, with a growth rate of 9.7%. The structure of production as measured by the shares of primary, secondary and tertiary sectors, and also their rate of growth is shown in figure 7a, while the change of GRP is shown in figure 7b (Wang et al 1997a,b). It can be seen that the economic structure of Dongying Municipality is dominated by the secondary sector, which is proportionately far greater than either the national or the provincial averages.

The agriculture sector

The total value added (VA) of the agricultural sector is 2.37 billion Yuan. The shares of its structural components (crop farming, forestry, animal husbandry and fishing) and their growth rates are shown in figure 8.

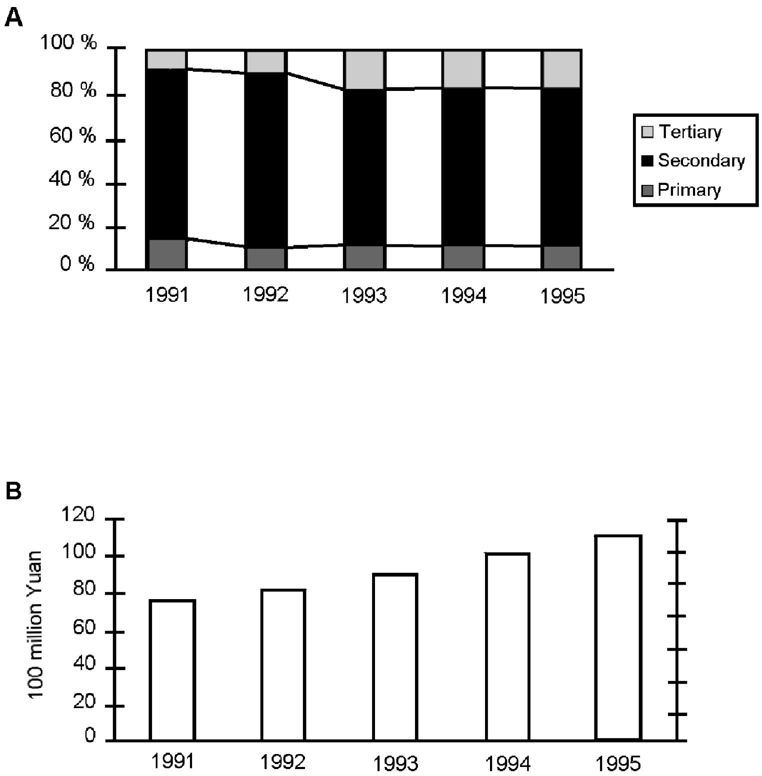

Figure 7 (a) Change in structure and (b) growth of Gross Regional Product (GRP) of Dongying Municipality from 1991–1995

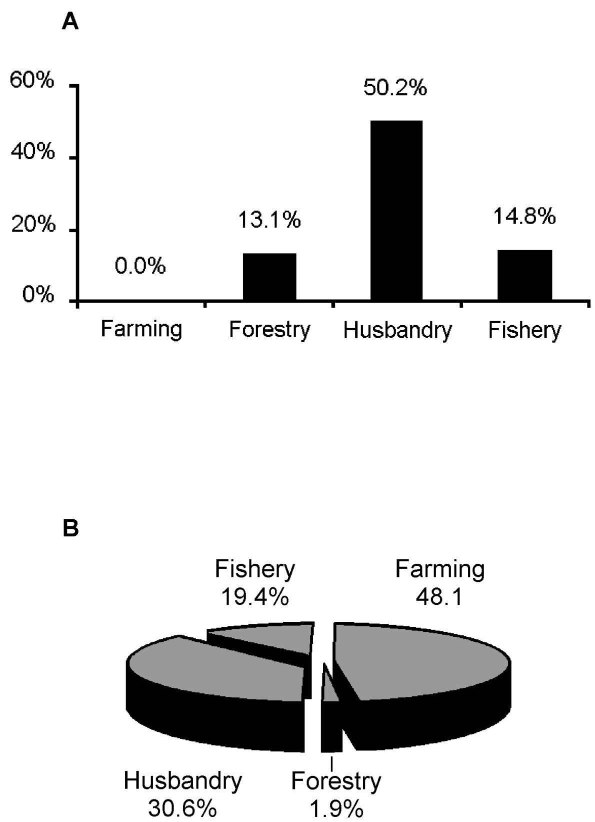

Figure 8 (a) Growth rate and (b) structure of primary sector output for Dongying Municipality in 1995

Industrial sector

The dominant products of the industrial sector and their growth rates are shown in table 6. As noted above, the principal activities are oil-related, although food processing, textiles, chemicals, and paper products make a sizeable, and rapidly expanding contribution (Wang et al 1997a).

Table 6 Features of the dominant industrial products of Dongying Municipality, 1995

Product type	Production	Compared with 1994 (±%)
Crude oil	3.00027×10^7 t	-2.9*
Natural gas	1.28524×10^9 m^3	-1.7*
Edible	2.3875×10^8 t	+112.4
Grain wine	6.5×10^3 t	+170.8
Beer	5.2×10^3 t	+205.9
Clothing	1.2216×10^6 t	+36.6
Machine-made, paper & paperboards	8.0301×10^4 t	+62.8
Chemical fertilisers	1.6×10^4 t	+110.5
Cement	6.9×10^4 t	+372.6

Note: The products with '*' had negative growth rate in 1995; they are listed due to their importance in Dongying Municipality

Investment

The value of fixed asset investment in 1995 was 9.778 billion Yuan, with a growth rate of 11.6% over 1994.

The retail sector

The total value of retail sales in 1995 was 3.588 billion Yuan, with a nominal growth rate of 23.4% and real growth rate of 11.2%. These were dominated by sales from state owned enterprises (SOE) and collectives, although rural and informal production both make a significant contribution to overall output.

Foreign trade

In 1995 the value of merchandise exported from Dongying Municipality was 2.207 billion Yuan, a decrease of 12.8% compared with 1994. Within this total, the export value of industrial products was 2.02 billion Yuan, and the export value of agricultural products was 0.187 billion Yuan.

Integrative development of the YRD

In China's Ninth Five-Year Plan, the government has promoted a coordinated economic development strategy, and seven cross provincial economic regions are outlined. One of these economic regions is the Bohai Rim Economic Region that includes Eastern Liaodong Peninsula Shandong Peninsula, Peking, Tianjin and Hebei Province. Dongying Municipality is an important component of this region and it should abide by the regional development strategy set up by the central government, of which one key aspect is the coordinated development and opening of new markets in order to promote common prosperity.

Acceleration of the comprehensive development of YRD and stabilisation of the river course to the sea is one of the strategic aspects of the development of the industrial belt of the Bohai Rim.

It is emphasised in the Ninth Five-Year Plan and Outline of the 2010 Long Term Target of Shandong Province that 'The Development of the YRD' should realise fully the comparative advantage of its concentration of oil and gas resources, the vast area of coastal beach and foreshore land, and other rich land resources. It should develop modern agriculture, chemical engineering with salt as one raw material, petro-chemicals, and industries for petroleum. It is necessary to enhance the comprehensive development of agriculture, effectively manage the downstream establishment of northern grass land, develop foreshore land, and accelerate the establishment of household farms and pastures with an appropriate scale. It is necessary to further improve the industrial structure, change the current state of mono-structure, create a petroleum substitute industry to be the leading industrial sector, and gradually establish nationally important bases for plantation, husbandry and fishery, petro-chemical industry, light and textile industries (figure 9).

3 Identification of forcing factors

The major current forcing factors affecting environmental, socio-economic and cultural attributes of the YRD include climate change, sea level rise, sedimentation in the YRD plain and the Yellow River mouth, the Asian monsoon, El-Niño and typhoons.

3.1 Natural forcing factors

3.1.1 Climate change

Climate change is divided into two components: natural change and anthropogenic change (human-induced change). The atmosphere is subject to natural variations on all time scales, ranging from minutes to millions of years (Bayliss et al 1997). However, vulnerability assessment is currently considered in the context of variation in climate that is expected to result, or has resulted, from human interference with atmospheric processes (Warwick et al 1993, IPCC 1994). The average rate of present climate warming probably would be greater than at any time in the past 10 000 years. As presented by IPCC working group I and group II (Watson et al 1996, Wang & Zhao 1995, Houghton et al 1992), global warming of about 0.3–0.6 ºC for the last 100 years has been detected. Warming of about 0.6–0.8 ºC in East Asia (China) for the last 100 years has been shown by Hulme et al (1992). Scenarios for global climate change due to human activity have indicated that global temperature and precipitation might increase further (Houghton et al 1990, 1992). Human activities are increasing the atmospheric concentrations of greenhouse gases, which alter radiative balances and tend to warm the atmosphere.

The changes in greenhouse gases and aerosols, taken together, are projected to lead to regional and global changes in temperature, precipitation and other climate variables. This may result in global changes in soil moisture, increase in global mean sea level, and prospects for more severe extreme high-temperature events, floods and droughts in some places. Based on the range of sensitivities of climate to changes in the atmospheric concentrations of greenhouse gases and plausible changes in emissions of greenhouse gases and aerosols, climate models project that by 2100, the mean annual global surface temperature will increase by 1.0–3.5 ºC, that mean sea level will rise by 15–95 cm, and that changes in the spatial and temporal patterns of precipitation would occur (Watson et al 1996).

Indirect effects of climate change would include predicted increases in the potential transmissions of vector-born infectious diseases resulting from extensions of the geographical range and season for vector organisms. Projections by models (that entail necessary simplifying assumptions) indicate that the geographical zone of potential malaria transmission in response to world temperature increases at the upper part of the IPCC-projected range (3.5ºC by 2100) would increase from approximately 45% of the inhabited area of the world to approximately 60% by the latter half of the next century. This could lead to potential increase in malaria incidence, primarily in the less well-protected temperate zone (eg China), subtropical and tropical populations (Watson et al 1996).

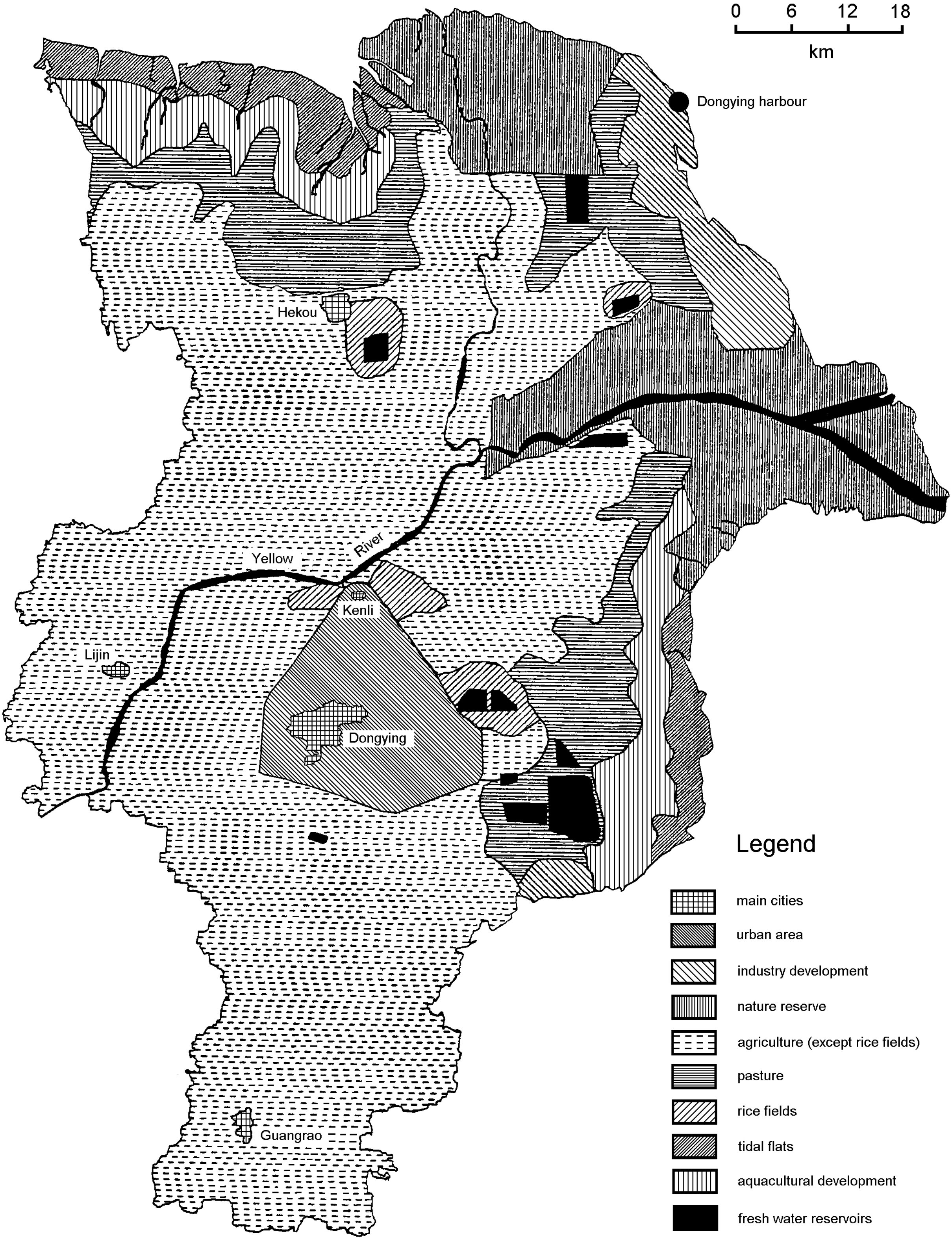

Figure 9 Integrative development of the YRD

Considering the global warming projection as simulated by the global social-economic-climate-impact model (GSECIM) combined with seven GCMs, the regional future climate change for China and East Asia has been calculated (Wang & Zhao 1995). Table 7 shows the future climate change scenario as simulated by the GSECIM model combined with the composite GCM (Hulme et al 1992).

Table 7 Climate change scenario for China and East Asia in the future (1991–2100) compared with the present climate (1951–1980) (DT: change of temperature, and DP: change of precipitation)

	Year										
	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
DT(ºC)	0.20	0.35	0.65	0.88	1.06	1.40	1.64	2.01	2.30	2.66	2.95
DP(%)	0.6	1.1	1.9	2.6	3.2	4.2	4.5	5.5	6.3	7.2	8.9

These data suggest that the change of temperature due to human activity in the future might be much more obvious than that of the precipitation in China and East Asia. For a more detailed investigation, the year 2050 has been chosen as a reference point for the present report. Distribution of the annual and seasonal temperature and precipitation in China for 2050 and the present climate have been calculated. The temperature might increase clearly from the present time to the year 2050. It is predicted that the effect of temperature induced by human activity might be much larger than that of precipitation in China. The more warming, the more evaporation is caused. The combined effects of both precipitation and evaporation might induce a drier climate in China, especially in the winter, spring and autumn seasons, and in north-east China (YRD is in east China).

Seasonal and annual changes of temperature and precipitation induced by human activity in broad regions of China were also estimated, and are shown in tables 8 and 9. Here, the regions chosen are North-east China (32.5–52.5ºN, 122.5–132.5ºE); East China (22.5–42.5ºN, 92.5–117.5ºE) and West China (32.5–47.5ºN, 77.5–87.5ºE), respectively. Overall, temperature and precipitation might increase in China, especially in winter (Wang & Zhao 1995).

Table 8 Change of annual and seasonal temperature (ºC) in East China , North-east China, West China and all of China from the present to the year 2050

	Months				
	Annual	**Dec-Jan-Feb**	**Mar-Apr-May**	**Jun-Jul-Aug**	**Sep-Oct-Nov**
East China	1.42	1.43	1.37	1.42	1.45
North-east China	1.47	1.53	1.47	1.37	1.52
West China	1.57	1.48	1.44	1.49	1.53
All China	1.49	1.48	1.44	1.49	1.53

Table 9 Change of annual and seasonal precipitation (%) in East China , North-east China, West China and all of China from the present to the year 2050

	Months				
	Annual	**Dec-Jan-Feb**	**Mar-Apr-May**	**Jun-Jul-Aug**	**Sep-Oct-Nov**
East China	3.3	4.2	4.5	2.9	2.2
North-east China	3.7	5.0	4.1	3.0	4.3
West China	4.9	8.0	5.8	2.4	3.4
All China	4.0	5.7	4.8	2.8	3.3

3.1.2 Sea level rise

The long-term geological record of sea level change

During recent years, studies on the Quaternary geology and geomorphology along the coast of eastern China and on the adjacent shelf have made considerable headway. In the coastal area, a few marine layers and relics of ancient shorelines have been found. On the shelf, non-marine layers and relics of submerged ancient shorelines have also been found.

In the process of a rapid descent of sea level of the late Wurm, beginning from 25 000 BP, the sea level took several intermittent stops, forming four buried terraces at 112, 136, 141, 155 m below present sea level. Based on the depths of these terraces and ^{14}C dating data, it is estimated that the sea level descended to -115 m at 23 700 BP, -137 m at 20 550 BP, -143 m at 17 600 BP, and from -150 to -160 in 16 000–15 000 BP (figure 10; Li & Zhou 1993, Zhao 1982, 1993).

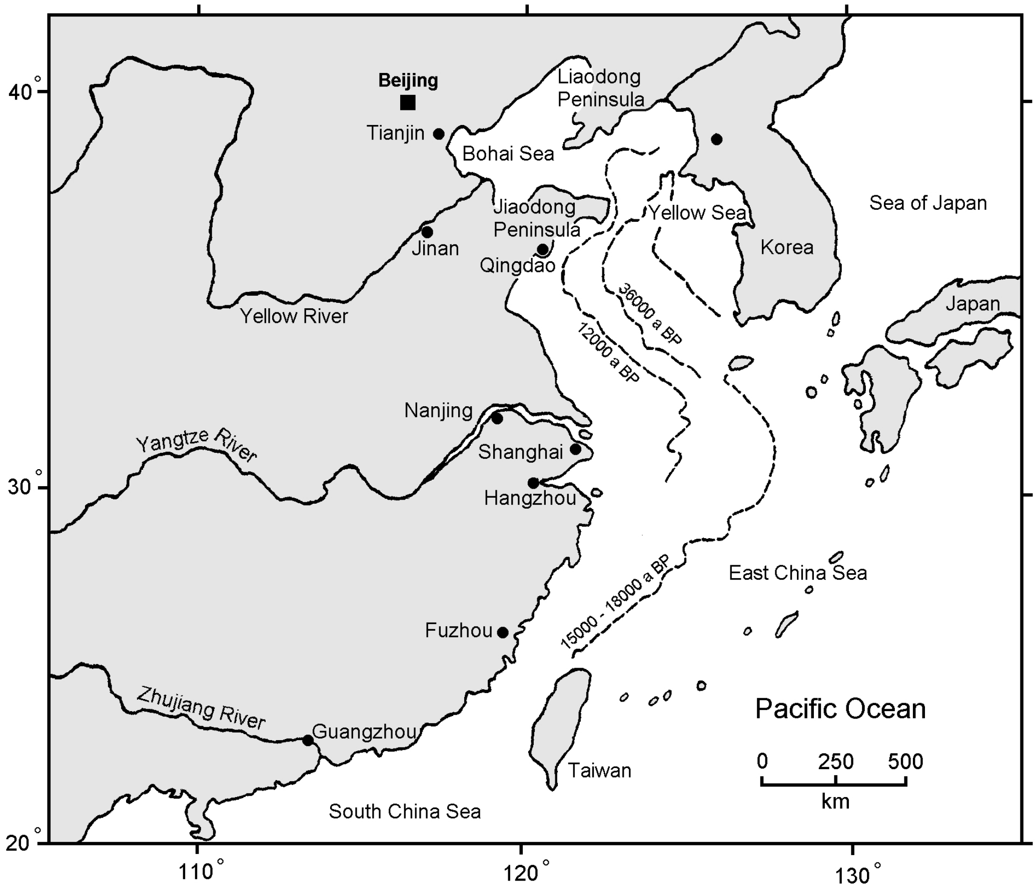

Figure 10 Late Pleistocene coastline changes in the Bohai Sea, the Yellow Sea and the East China Sea (based on Wang & Wang 1980; Liu et al 1987; First Institute of Oceanography, SOA 1989)

Along with the warming of the climate during the end of the late glacial period to the early postglacial period, the sea level also rose rapidly. If the change in sea level from -160 m at 15 000 BP to slightly higher than 0 m at 6000 BP is considered, the average rate of sea level rise reached 16.7 mm/yr. In the process of the rising of sea level, several stops or oscillations occurred, thus forming several obvious submarine terraces in the East China Sea: ie the -120–100 m and -75–60 m terraces (Li et al 1987).

Debate about the issue of whether or not the postglacial high sea levels have occurred has been ongoing. Some consider that the rising of sea level reached up to 3 m higher than that of the present by the end of the Atlantic stage, and since that time, the fluctuation of sea levels had an amplitude of 6 m (Zhao et al 1982, 1993). This is the theory of sea level fluctuation over the past 6000 years.

Predicted future sea level rise

In terms of global changes, sea level rise is one of the main possible consequences of warming of the global climate. Due to the gradual concentration of greenhouse gas in the last several decades, the greenhouse effect on the atmosphere is intensified day by day, with more and more solar heat held in the earth, and the temperature in the earth (atmosphere) has been raised. It is generally estimated that global sea level rise over the past 100 years has been 1–2 mm y^{-1} (Scor Working Group 1989, 1991); that is a total rise of 10–25 cm estimated by 1995 (Watson et al 1996). In addition, some studies show that the global sea level rise rate was close to 2 mm y^{-1} in the last several decades (Douglas 1991, 1995, IGBP 1992, Gornitz 1994). For the next century, global sea level will rise at a much faster rate, perhaps 2–4 times than at present, because of global warming (Warwick et al 1990, 1993). For example, additional sea level changes of 18 cm by 2030, 35 cm by 2050 (Woodworth 1990, Douglas 1992) and 44 cm by 2070 (Church et al 1991) have been estimated. The best estimate of global sea level rise over the next century is from the Intergovernmental Panel on Climate Change (IPCC 1992, Watson et al 1996): 18 cm (4.5 mm y^{-1}) by 2030 and 31–110 cm by 2100 (mean value of 66 cm, rate of 6.0mm y^{-1}).

The State Oceanic Administration of China (1996) summarised tide-gauge data from 44 stations along the China coast from 1959–1989. The mean rate of sea level rise was 1.4 mm y^{-1}. According to the geodetic survey data from nine stations along the China coast by the Station Survey Bureau of China in 1992, sea level rise during the last hundred years was 19 cm in the East China Sea, and 20 cm in the South China Sea. Thus, the rate of sea level rise has been 2–3 mm y^{-1}, which is predicted to continue in the future (Chen 1997).

The real net impact on a coastal area is the result of sea level rise combined with the crustal vertical movement in the area. After correcting for neotectonic vertical movements, the annual average rate of mean sea level rise along the typical coasts of China was calculated by Chen (1997). The YRD is located in the Bohai Sea neotectonic subsidence area for which the subsidence rate in the Quaternary is 5 mm y^{-1}. The estimated relative sea level rise rate in the YRD is 8 mm y^{-1} and the sea level rise will be 48 cm by the year 2050 (table 10).

Table 10 The predicted values of relative sea level rise of the main coastal areas of China (Yang & Xie 1985, Chen 1997)

Area	Sea level rise rate (mm y^{-1})	Subsidence rate of land (mm y^{-1})	Relative sea level rise (mm y^{-1})	Sea level rise by 2050 (cm)
Recent Yellow River Delta	3	5	8	48
Old Yellow River Delta	3	10	13	72
Coastal Plain of North Jiangsu	3	2	5	28
Yangtze River Delta	6	3	9	50
Pearl River Delta	6	2	8	44

3.1.3 Sedimentation

Sedimentation is one of the natural forcing factors controlling vulnerability of the YRD and it directly affects coastline changes, coastal wetland loss and expansion, land use and social and economic development of Dongying Municipality.

The modern YRD covers the fan areas north to the Taoer River mouth and south to the Zhimaigou River mouth, with an area over 6000 km^2 and a coast line of 350 km. The delta fan has been expanding at a rate of about 21 km^2 per year over the period 1989–1995 (Chen et al 1997). The Qingshuigou channel, ie present channel of the Yellow River into the Bohai Sea, can be divided into four sections, namely the delta channel section, the fluvial-maritime section, the current section and the offshore section (figure 11; Song et al 1997).

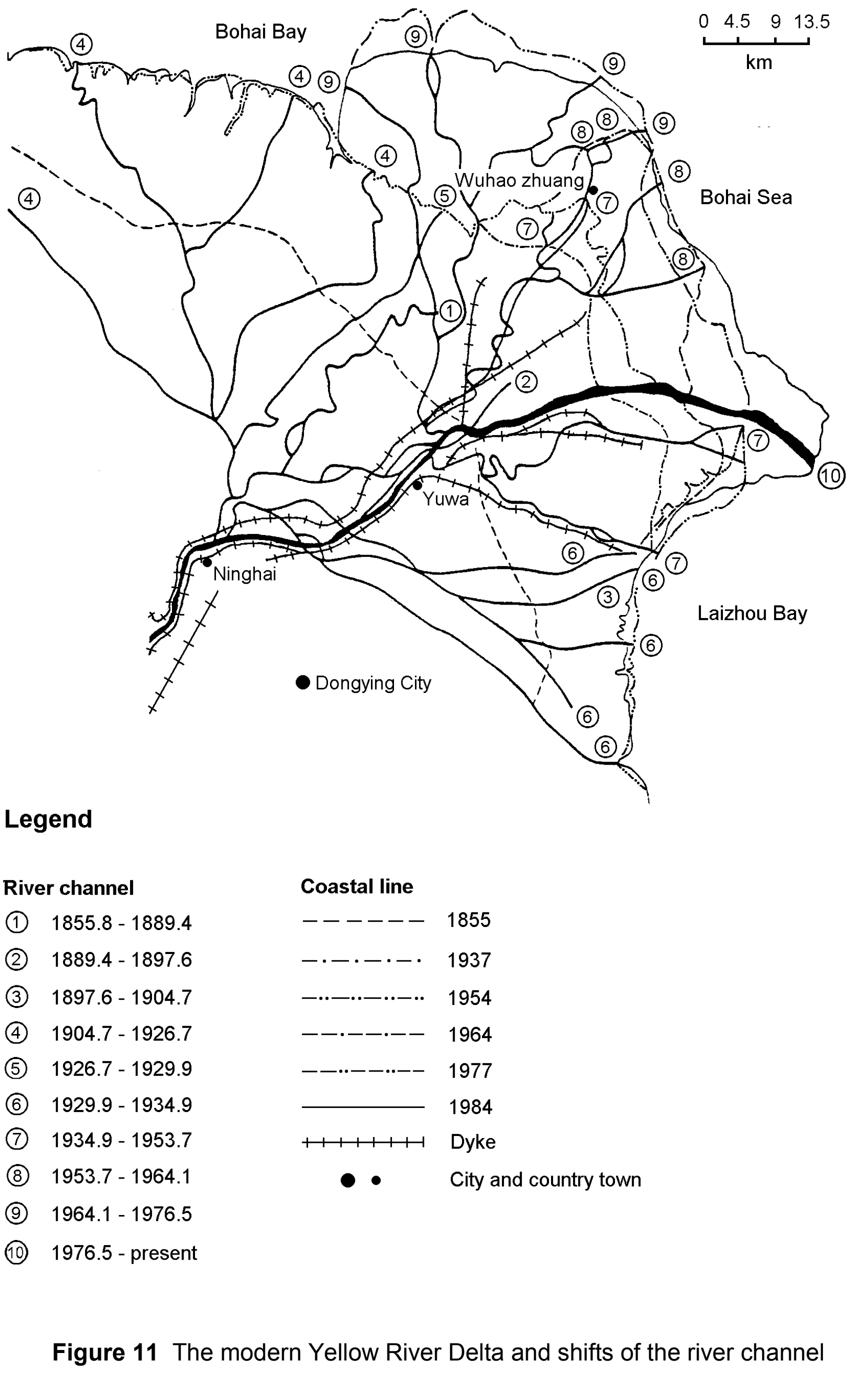

Figure 11 The modern Yellow River Delta and shifts of the river channel

In the delta channel section, upstream from Qing-8 (Q-8), the river is not affected by the tide. The fluvial-maritime section is between the upper boundaries of the tidal estuary and tidal current. The river bed in this section has a positive slope, but is affected by incoming water and sediment load, size and shape of the mouth bar, and height of tidal surges. Retrogressive erosion or siltation occurs in this section depending on the growth and reduction of the bar in the mouth of the river. This section is between Q-8 and Q-11 and is also called the mouth section (figure 10). The tidal current section extends from the river section to the shallow sea of depth 10 m. Both discharge flow and tidal current occur in this section and the river mouth bar develops in it. The section can be further divided into a negative bed slope, the mouth bar crest, steep front slope and gentle slope sub-sections. The length of the section is now about 10–15 km. In the offshore section, the sea water depth is over 10 m and the flow and sediment transport are controlled by sea currents.

Conventionally, the delta channel section and the fluvial-maritime section are called inner-mouth sections because the flow is confined between dykes. Correspondingly, the tidal current and offshore sections are called outer-mouth sections. The location of the mouth bar varies with tidal current over shore time periods. If the tidal current is strong and discharge weak, the mouth bar moves into the inner-mouth section. If the tidal current is weak and discharge strong, the mouth bar moves to the outer-mouth section. As the Yellow River Mouth is a weak tidal river mouth, the latter process usually dominates.

The sediment transporting capacity of the sea current affects the development of the river mouth. Sediment deposition at the river mouth results in the extension of the channel, but the extruding channel mouth is scoured back quickly if the sediment-laden flow is switched to a new channel. In addition, the sea currents may scour the river mouth in the non-flood season because the sediment transported by the river flow is less than the sediment carrying capacity of the sea currents. In 1988–1989, the river mouth was eroded by 4 km. The total eroded sediment in the 8 month period was estimated at 50×10^6 t. In 1995 and 1996, the river discharge was cut off for 122 and 133 days, resulting in considerable erosion of the mouth. If the annual sediment load:water ratio is less than 0.01 t m^3, the river mouth does not extend and the entire sediment load can be carried away by the sea currents. By comparing satellite images of the YRD in 1976 and 1988, the Diaokou channel mouth area was eroded by 5 m in depth while the Qingshuigou channel mouth area was silted up by 14 m in the same period. This demonstrates that the coast-scouring capacity of the sea currents is considerable in the development of the delta territory. Measurements proved that the sediment carried away by sea currents consists mainly of fine particles of diameter < 0.025 mm. According to long-term records, such fine sediment is about 40–60% of the total amount at the Lijin Station (Song et al 1997).

3.1.4 Asian monsoon

To date, the most critical uncertainties for climate change and sea level rise predictions in China are the lack of credible international projections of the effects of global change on the Asian monsoon or the ENSO phenomenon, which have great influence on river discharge and the Bohai Sea tidal currents.

The modern climate of China's mainland is principally controlled in winter by direct or modified polar continental air masses. The northerly winter monsoon, carrying cold and dry air from middle high latitudes, is prevalent in the lower layer of the troposphere. In summer, most of the mainland comes under the influence of tropical to subtropical marine air masses and tropical continental air masses. The southerly summer monsoon with its warm and humid air from the lower latitudes is prevalent in the lower layer of troposphere. The changes in prevalent wind from winter to summer are distinctive. As the monsoon advances and retreats, precipitation and surface air temperature show a distinctive seasonal variation. Hot summers have plentiful rainfall, while cold winters are dry.

There are two types of summer monsoon in China: the southeast monsoon originating from the Pacific, and the southwest monsoon from the Indian Ocean. Variations in the summer monsoon are often reflected by changes in summer precipitation and its starting time. Historical data suggest that the start of the rainy season from the south to the north in East China is a clear response to the northward progression of the rain belt, ie the northward movement of the summer monsoon. In Shangdong Province, such changes in rainy season precipitation are approximately the same as those in the lower Yangtze River basin (Zhang 1983). Rainy and dry spells have occurred in the Yangtze River basin during the last 800 years, with the major dry spells concentrated in periods – 1200–1264, 1523–1590 and around 1920 to the present – an indication of the so-called ‘phenomenon of clustered occurrence’. The yearly variation in precipitation in the rainy season shows quasi-cyclic changes over periods of about 2–3 years, 5 years and 20 years (Wu 1981), obviously a result of quasi-periodic variations in the monsoon circulation.

The reconstructed climatic sequence of plum-rain for the 18th century has provided certain details about the advance and retreat of the southeast monsoon (Zhang & Wang 1990). The plum-rains in the 18th century on average started on June 15th and ended on July 6th, with a mean length of about 20 days, while showing a 2–3, 5–6 and 34-year quasi-periodic change, also reflecting the oscillations of the summer monsoon circulation.

The winter monsoon of China is mainly characterised by the incidence and strength of cold waves or cold air masses. For example, in the past 500 years the periods 1440–1520, 1620–1720 and 1810–1900 AD experienced high incidence and strength (Zhang & Zhu 1978).

The configuration of land and sea is a critical factor in the generation of a monsoon-type climate. Sea level has fluctuated many times in response to global glacial-interglacial changes over the past 130 000 years. As a result, transgressions and regressions have taken place on the eastern coastal area of China and the extensive continental shelf area. The resultant changes of land-sea interaction have thus had a notable effect on variations in the East Asian monsoon.

According to much Chinese research, it can be concluded that, during the past 130 000 years, three major large-scale marine transgressions (125 000–70 000, 40 000–25 000 and 11 000–6000 BP) and two major regressions (50 000–45 000 and 18 000–15 000 years BP) took place in the coastal areas of East and South China, as well as on the adjacent continental shelf (Chen et al 1977, Yang & Xie 1985, Qin et al 1987). The temperature and rainfall patterns in present China and the eastern part of North-west China show isolines running approximately parallel to the general trend of the mainland coast, indicating that the air temperatures and precipitation values in these areas are closely related to their distance to the sea. For instance, at 18 000 years BP, the eastern coast of China shifted eastwards about 1000 km. At the same time, the heat source of the summer monsoon was concentrated in the west Pacific alone.

Geological records indicate that the East Asian summer monsoon was weak 18 000 years BP and that since about 12 000 years BP it has gradually strengthened. After about 9000 years BP the Holocene Climate Optimum began, lasting until 5000 years BP, and with the summer monsoon being strong. In the Holocene Optimum, the annual average temperatures in the southeast monsoon region were 2–3ºC higher than those of today, with annual precipitation values at least 100 mm higher.

The changing influence on temperature of proximity to the ocean is important for the origin and development of monsoon. During the late glacial monsoon, the exposure of the continental shelf as a result of sea level fall decreased by about two-thirds the area of the Yellow Sea and the Bohai Sea north of the Taiwan Strait, and about one-fifth the area of the South China Sea (Wang & Wang 1990), whereas the area reduction of the West Pacific was very small, with an indetermiate fall in water temperature. The marine heat source of the present East Asian monsoon is located in two areas, ie the west Pacific and the South China Sea. During the glacial period, however, the heat source was mainly concentrated in the West Pacific alone.

3.1.5 El Niño

El Niño is a periodic phenomenon of sea-atmosphere interaction. Opinions vary on its formation mechanism, physical process, warm-water source and dynamic exchanges between marine currents from the east and the west. El Niño phenomena not only coincide with years with higher atmospheric temperatures, but also can often bring about serious marine calamities.

The relationship between El Niño and China's regional precipitation has been studied recently (Mo et al 1995), and results showed that:

1. The variations of China's precipitation and the East Pacific equatorial surface temperatures occur over a 3.5 year cycle. The unusual equatorial Pacific surface temperature is positively correlated with precipitation in the Yellow River basin, the Yangtze River lower reaches and the southern areas, and consistent with the development of a typical El Niño. However, this typical El Niño process is very different from the influence on the precipitation in the flood season in the middle reaches of the Yellow River.
2. The longitudinal location where El Niño begins has a very important relation with the precipitation in the middle areas of the Yellow River basin and to the south of the lower reaches of the Yangtze River in the year following the El Niño year. For example, if El Niño begins at the central part of the equatorial East Pacific Ocean, it will greatly affect the precipitation in the flood season in the lower reaches of the Yangtze River and the southern areas.

Thus it can be said that El Niño can indirectly influence regional precipitation in China and in the important river areas in the flood season.

Across the world, the most serious recent natural hazards caused by El Niño were: the 1993 rainstorm from Japan to Mississippi, USA; drought in the south of Africa; forest fires in New South Wales of Australia; drought in Indonesia; storms along the Peru and Ecuador coasts; Brazil's most serious drought this century; and the floods from December 1993 to January 1994 in the south of England. In China, the most serious natural calamity caused by El Niño was large scale flooding in the drainage area of the Yangtze River from June to September 1998, resulting in a loss of more than 100 billion Yuan RMB, as well as many lives.

3.1.6 Flooding and storm surge

Whilst flooding and storm surge are often the direct or indirect result of several of the forcing factors described above, they are considered sufficiently important to be discussed separately.

Flood disasters

Flood disasters in the YRD include: floods in the Yellow River in summer; storm surge and typhoon induced sea surges; ice jam floods in spring; and local rainstorms and waterlogging (Lu et al 1997).

The Yellow River floods

The biggest flood disaster occurred in 1846 with peak discharge at Sanmenxia of 36 000 $m^3 s^{-1}$ and a total (12 days) discharge of 12×10^9 m^3. The second largest flood occurred in 1933 with peak discharge 22 000 $m^3 s^{-1}$. Because the capacity of the Yellow River channel downstream of Aishan is only 10 000 $m^3 s^{-1}$ much damage and loss is created by the floods. According to local historical records, the dykes of the Yellow River in the delta were broken at more than 70 places in 23 years within the period 1883–1938.

The Yellow River flood occurs in late July and August with high peak discharge but a short duration. The maximum discharge varies from year to year and the sediment concentration is high. If the dyke in the delta is broken, the possible inundated area varies with the position of the break. The closer the break to the river mouth, the smaller the inundated area. It takes more than 5 days for a flood to travel from HuaYuankou to Lijin, usually giving residents in the delta sufficient time to implement flood control measures.

Storm surges

When strong north-east winds occur, a large amount of water flows into Bohai Bay and Laizhou Bay through the Bohai Strait which results in surges at the YRD. If a surge occurs in conjunction with an astronomic spring tide, a resultant storm surge of 2–3 m can occur. Heavy disaster zones of storm surges are Zhanhua County, Wudi County and Yangjiaogou Town. Yangjiaogou lies to the south of the YRD. There are only poor and broken dykes along the coastal line of the YRD where high storm surges occur.

According to local records 96 storm surges of 2–3 m occurred in the Laizhou Bay from BC 48 to AD 1949, 21 of which were serious. In the last 100 years, storm surge occurred 15 times in the coastal area of the reserve, with a height of greater than or equal to 3.5 m. On 31 August 1938 the storm surge reached 3.6–4.1 m, subsequently inundating an area of up to 300 000 km^2. Since the foundation of the People's Republic of China in 1949, the total area inundated by storm surge has reached 112 000 km^2, resulting in 529.6 million Yuan (RMB) of economic loss (Science and Technical Committee of Shandong Province 1991, Yang & Wang 1993, Zhao & Song 1995). Storm surges with a wave height over 3 m (Yellow Sea System) will often cause serious disasters due to the low slope of the delta.

Ice-jam flood

The lower reaches of the Yellow River stretch from south-west to north-east. The ice covers in Henan Province begin to melt in early spring when the ice cover in the delta is still solid. Flow into the delta is blocked by the ice cover, resulting in an ice-jam. Prior to 1949, 26 ice jam floods occurred, resulting in major impacts.

Rain storm and waterlogging

Rainfall from June to September is about 70% of the total annual precipitation. The ground water table in the delta is about 2 m. A strong rain storm often causes waterlogging because the drainage system is not capable of discharging such high volumes of water in summer. Recorded data show that waterlogging disasters occurred in 27% of the years between 1500 and 1949. An additional impact of such waterlogging is a rise in the water table and subsequent salinisation of the soil.

3.2 Anthropogenic forcing factors

Although the YRD has a relatively low population it is of high economic importance at both the provincial and national scale. Arable fields cover 40% of the area, and are the dominant land use. About 30% of the area is not yet used by man; the tidal flats are included in this area. The remaining 30% of the YRD is used for pasture, residential and industrial purposes, oil production, forestry and various other purposes.

Neighbouring the Beijing-Tianjin-Tangshan economic zone in the north, and situated between the inland of north-east Asia and the Yangtze River Plain, Dongying Municipality is considered to be one of China's areas that will be opened economically to the outside world. The abundant oil and gas resources in the Shengli Oil Field provide a basis for the present economic development, and will further enforce the industrial capacity of the coastal area. In addition, Shengli Oil Field will be connected in the future with the coal mining areas in central and northern China, after the construction of Dezhou-Longkou Railway. The proximity of Dongying Harbour to the Korean Peninsula and Japan may facilitate the establishment of economical connections from within Dongying Municipality to the outside world.

3.2.1 Population increase

At present, the population density of Dongying Municipality or the YRD is 8053 persons per km^2. Prior to 1997, the annual population birth and death rates were 1.04% and 0.54%, respectively, resulting in an annual population growth rate of about 0.5%. This growth rate is currently lower than that of the entire country (0.8% per year) (Wang et al 1997b). However, with the high-speed development of oil and gas resources and interrelated industries and agriculture, a great number of people will migrate into the area to work and live, and the YRD will most likely have a higher than average population growth rate. The increasing population of the YRD will place greater pressure on a number of the region's resources including the supply and quality of the water resources (section 3.2.4).

3.2.2 Land tenure and use

Land tenure and use of the YRD has been described in section 2.2.7. However, one of the major consequences of land use for urban and rural development, both in the YRD and in the middle and upper reaches of the Yellow River, has been an increase in the occasions when the flow in the stream ceases and the channel dried. This phenomenon began in 1972. In the 1980s, the stream stopped flowing and the channel bed dried 1–2 times, lasting from several days to more than 10 days. In the 1990s, the frequency increased, the duration of no-flow conditions was prolonged, the first period of no-flow conditions was earlier, and the upstream distance increased. The annual average rate of discharge at the Lijin hydrological station since 1990 is 178 $m^3 s^{-1}$, 38% less than that in the 1980s (286 $m^3 s^{-1}$). The annual frequency of flow cessation and drying increased to 3–6 times and it lasted up to 2–4 months. In 1995, dry conditions reached to Jiahetan, a distance of 628 km. Table 11 lists the general information of stream cessation and drying in the Lijin hydrological station and the Xihekou hydrological station (Cheng & Xue 1997, Division of Policy & Shengli Oil Management Bureau 1994, Lu et al 1997).

Table 11 Stream flow cessation and drying in Lijin and Xihekou

Year	Lijin		Xihekou	
	No. of days	First day	No. of days	First day
1987	17	Oct 3	51	April 2
1988	13	June 27	59	June 18
1989	20	April 4	47	April 3
1991	14	May 16	54	May 15
1992	82	March 16	152	Feb 14
1993	61	Feb 13	82	Feb 11
1994	74	April 4	81	April 2
1995	119	March 4	154	Feb 20
1996	136	Feb 14	161	Feb 8

Another major consequence of the urban and industrial and rural land uses of the YRD is that of pollution. The water quality of the YRD is described in detail in section 3.2.4.

3.2.3 Oil and natural gas development

In the YRD, a dense network of oil and gas pipelines and distributing stations exists. The pipelines connect the oil fields with the big cities and industry. Some smaller oil fields are not yet exploited. At this moment, only two offshore oil fields, in the Bohai Sea, are exploited.

By exploration during the Eighth Five-Year Plan (1991–1995), the proven geological oil reserve of Shengli Oil Field increased by 0.5×10^9 t, and the proven natural gas reserve increased by 5.4×10^9 m^3. Approximately 160×10^6 t of crude oil was produced during this period, and the annual oil production was stabilised at approximately 30×10^6 t y^{-1} (Wang et al 1997b). The produced crude oil is mainly exported to oil processing factories in eastern China.

In the Ninth Five-Year Plan period (1996–2000), the annual increase of the proven oil reserve due to continued exploration is expected to be 0.1×10^9 t, and the annual increase of the proven reserves of natural gas is expected to be 1×10^9 m^3.

The exploitation strategies will include the following: stabilising the production of old oil fields, starting with production in less attractive oil fields (eg fields with a high water content, small fault fields, offshore oil fields), starting with production in new fields.

According to national planning, the total investment for the expansion of oil production will be 12 billion RMB (or 1.4 billion US dollars) during the Ninth Five-Year Plan period. The production of crude oil in 1996–2000 is expected to exceed the production during 1991–1995 by 23×10^6 t. The annual natural gas output has to be stabilised at a level over 1.1×10^9 m^3. The annual offshore oil production will amount to 2×10^6 t.

Dongying Municipality has grown from the establishment of Shengli Oil Field, and Shengli Oil Field is a resource based industry. In the previous central planning system, Shengli Oil Field produced mainly crude oil and sent the oil to other regions for processing into high value-added downstream products. In the future, the development of an oil refinery and downstream production activities must be supported at Shengli Oil Field, by expanding its 1.5×10^6 t heavy crude oil refinery to a 5×10^6 t capacity refinery, as well as producing downstream chemical products.

However, oil and natural gas resource development and use already result in significant pollution of the environment, as detailed in section 3.2.4 below.

3.2.4 Pollution

Although pollution is a direct consequence of the above three anthropogenic forcing factors, it is a sufficiently important issue to discuss separately. Pollution of the YRD can be divided into air quality, industrial solid waste, and water quality.

Air quality

The total annual amount of industrial atmospheric emissions in the YRD is approximately 27×10^6 m^3, of which 43.2% is emitted from crude oil production and processing, 36.7% from the generation of electricity via coal combustion or thermal utilisation, and 2.4% from the chemical industry (Mu et al 1997). The chief pollutants are sulphur dioxide (SO_2), reaching around 47 686 t y^{-1}, of which 9731 t originates from the petroleum industry. The other major air pollutants are smoke and dust, NO_x and CO, with annual emissions of approximately 18464, 7414 and 8760 t, respectively. The annual emission of hydrocarbons from the petroleum industry is approximately 2462 t.

Industrial solid waste
With poor treatment and a low utilisation rate, the amounts of industrial solid waste and urban waste have increased sharply. In 1994, the amount of industrial solid waste reached 71 × 10^6 t, of which only 20% was fully utilised. In the city outskirts solid wastes dumps contain approximately 120 × 10^6 t of waste. Occupying a total area of 11 000 ha. Oil residue, oil sludge, and other oily pollutants are the main sources of solid waste. Their untreated quantity reaches 65% of the total amount. Coal slag and power coal slag is mainly from industrial thermal and electrical power plants. Their untreated amount accounts for only 27% of the total (Mu et al 1997).

Water quality
In addition to the Yellow River there are many smaller rivers in the YRD. These rivers are fed by local rainwater and constitute a south-north water system to the Bohai Sea in the northern part of the YRD, and a west-east water system to Laizhou Bay in the southern part of the YRD. The south-north water system includes the local rivers – the Chaohe, Caoqiao, Tiaohe and Shenxiangou Rivers, and the regional rivers, the Zhimaigou and Xiaoqing. These rivers drain the rainfall surplus in the rain season and also urban and industrial waste water.

The various industries in the YRD produce over 40 × 10^6 m^3 of urban and industrial waste water annually (table 12), the majority of which is discharged into the sea through the local rivers. Waste water from outside the YRD, mainly from the cities of Jinan and Zibo, flows through the YRD to Laizhou Bay via the regional Xiaoqing River and Zhimaigou River, polluting the flood plain and the aquatic environment in the river, in their estuaries, in the adjacent tidal flats and the shallow sea.

Table 12 Industrial wastewater and its pollutants in the YRD

Industry	Discharge amount (10^4 T)	Rate of treatment (%)	Specific pollutants			
			COD (t)	Oils (t)	TSS (t)	Phenol (g)
Petroleum production	830	23.8	3266	197	718	11 115
Petroleum processing	168	81.9	248	65	134	1 415
Chemical	57	100.0	4	0	20	0
Paper	146	25.0	382	0	342	0
Thermal, electric power	385	99.7	173	1	88	43
Machinery electronics	87	88.3	36	2	15	2
Other	394	99.8	68	1	49	157
Total	2067		4123	266	1368	12 732

Surface water quality
Organic pollution is the main source of surface water pollution, and originates from those rivers whose complex index exceeds the 5th grade of the national water quality standard by over a factor of three. The detection frequency of organic pollutants such as BOD_5, COD and oil matter reaches 100%, while that of the volatile organic, phenol, is 90%.

Surface water near the city is heavily polluted. Water quality in Dongying town, through which the upper section of the Guangli River flows, has been slightly polluted, while the lower section is highly polluted due to urban and industrial sewage. In this region, four types of organic compounds exceed the national water quality standards. Consequently, it is urgent that the methods to control urban sewage water are tightened.

Surface water near industrial pollution sources has been polluted heavily. Water quality in the upper section of the Dongchun village of Tiaohe River is good, with only slight pollution. However, sewage from Shouzhan enters the river near the mouth, resulting in an increase in BOD_5 from 4.7 to 5.4 mg L^{-1}, COD from 143 to 442 mg L^{-1}, and oil matter from 0.303 to 0.721 mg L^{-1}. The water of the upper section of Shenxiangou River is supplied by the Yellow River through the west river mouth, so the water quality is good, and can reach the standard for recreational water. But the downstream reaches are polluted by effluent originating from paper product plants, with a resultant decline in water quality.

Water quality of the Yellow River and reservoirs

According to the 1990–1996 monitoring analysis on the Kenli profile, conducted by the Environment Protection Station of Dongying Municipality, overall water quality of the Yellow River is good (Division of Policy, Shengli Oil Management Bureau 1994, Geography Institute Academia Sinica et al 1991, Mu et al 1997). Concentrations of most chemical elements are within the 3rd grade of the national water quality standards (GB3838-88), except COD and oil matter, whose concentrations exceed the 5th grade of the national water quality standards. Thus, it can be concluded that although the water quality of Yellow River is good in general, it has already been polluted to some extent by such pollutants as oil. Table 13 details the surface water quality of local rivers in the YRD.

The concentrations of particular heavy metals in water of the reservoirs is as follows: the range of Pb is 0.002–0.003 mg L^{-1}; Cr(VI) 0.0075–0.015 mg L^{-1}; Cd 0.0017–0033 mg L^{-1}; and As 0.0017–0.0035 mg L^{-1}. These ranges are within the national drinking water standards.

Organic pollutants are detected in all the reservoirs of YRD. As far as the volatile organics such as phenol and cyanide are concerned, their rate is above 80%, a little below the 1st grade of the national water quality standards.

Dissolved oxygen (DO) in the reservoirs meets the 3rd grade of the national standards of surface water quality. DO in the reservoirs of Gudong, Guangnan exceeds 7 mg L^{-1}, thereby meeting the 2nd grade of the water quality standards. However, DO in the reservoir of Gubei is very low.

Ground water quality

The main feature of the groundwater of the modern YRD is a high mineralisation due to effects of high soil salinity and seawater. The salinity of the upper-layer water ranges from 7.7–67.5 g L^{-1}, with an average value of 24.6 g L^{-1}. The contents of different chemical components including positive and negative ions such as SO_4, Na, Cl and so on are 80% (Mu et al 1997, Division of Policy, Shengli Oil Management Bureau 1994, Geography Institute Academia Sinica et al 1991).

The concentrations of particular elements in the upper layer ground water, especially in some areas of the YRD, are higher than national standards for drinking water. These concentrations are mostly attributed to direct input from polluted surface waters. Due to the high salinity of the groundwater located to the north of Xiaoqing River in the YRD, it cannot be appropriated for use as a drinking water source.

4 Vulnerability assessment

This section assesses the current vulnerability of the YRD to existing forcing factors, and the future vulnerability of the YRD to predicted climate change and sea level rise. It is important that existing vulnerability is assessed in order to evaluate the significance of vulnerability due to predicted climate change and sea level rise. Essentially, it recognises that climate change and sea level rise represents just one of a number of forcing factors potentially impacting on a system.

Table 13 Surface water quality in the Yellow River Delta

Rivers	Section	Organic Pollutants (×)[1]	% over standard[2]	Water quality	Heavy metals (×)[1]	% over standard[2]	Water quality[3]
Xiaoqing River	Xiaoqiao	2.58	55.6	Serious pollution	0.462	0	20
	Shicun	3.71	66.7	Serious pollution	0.647	0	20
	Sancha	3.18	55.6	Light pollution	0.429	11.1	30
Guangli River	Dongyingcun	1.20	11.1	Heavy pollution	0.238	0	20
	Guangliqiao	2.20	44.4	Middle pollution	0.374	0	20
	Haigang	1.95	33.3	Middle pollution	0.197	0	20
Yihong River	Daoxiangcun	11.25	22.2	Middle pollution	0.502	20	40
	Kenlinan	1.59	33.3	Middle pollution	0.362	20	40
	Yangjichang	1.31	22.2	Middle pollution	0.587	20	40
Tiaohe River	Laoyemiao	2.08	22.2	Middle pollution	0.495	20	40
	Dongcuizha	1.11	13.3	Middle pollution	0.478	0	20
	Diaokouqiao	2.35	22.2	Middle pollution	0.232	0	20
Shenxiangou River	Gudaoxi	0.69	11.1	5th class water	0.228	0	20
	Wuhaozhuang	1.59	55.6	Heavy pollution	0.491	20	40
Zhimaigou River	Wangying	1.03	33.3	Middle pollution	0.386	10	30
Guangpugou River	Dongwanglu	1.35	11.1	Light pollution	0.450	20	40
Chaoqiaogou River	Sikouqiao	0.42	11.1	5th class water	0.219	0	20
Liupaigan River	Zhuanjinyicun	1.76	44.4	Middle pollution	0.476	20	40
Zi River	Dongzhou	23.60	44.4	Serious pollution	0.625	0	20

1 Average exceedence of the pollutant over the National Standard Class 5.

2 Percentage of samples whose pollution index surpasses the National Standard Class 5

3 Where 10: High-quality third class water; 20: High-quality fifth class water; 30: Fifth class water; 40: Low-quality fifth class water.

4.1 Vulnerability to current forcing factors

The YRD is very dynamic and depends highly on the fluvial process of the river. Historically, the river has shifted its channel regularly and frustrated long term development planning. The area is short of local water resources with the main water resource being the Yellow River. The Yellow River water is turbid and the annual discharge has decreased dramatically in the past decade due to water diversion from upstream reaches. Nevertheless, because the Yellow

River bed is several metres higher than the surrounding ground of the delta, floods including ice jam floods still pose a real threat to the local people. In addition, storm surges may induce seawater to flow inland for several tens of kilometres, inundating the coastal areas. Sea level rise could further exacerbate this (section 4.2). With the increase in economic development, water and air pollution have become more serious issues. Accordingly, sustainable ecological development of the delta requires stabilisation of the Yellow River channel, long-term strategies of water resources development, flood risk analysis and control measures, air and water pollution control and management and development of the wetland Nature Reserve (see sections 5 and 6).

According to the Ninth Five-Year Plan (1996–2000) and outline of the 2010 Long Term Target of Shandong Province for the period 2001–2010, the YRD will be developed at a large scale. Therefore, population pressure will increase within the YRD region irrespective of environmental change. This will be significant for the natural resources of the region through the demand for increased access to the resource base of the coastal wetlands. Strategic planning is required to address this problem at the biophysical regional level, and ensure that population growth and development can proceed in an orderly fashion and not degrade the significant environment values that underpin economic growth in the YRD. Major factors affecting the ecology and agricultural, industrial and economic development in the YRD and the life of the local people are the water resource, pollution, and storm surge and flooding, with the former possibly being the most significant. These are elaborated upon below.

4.1.1 Water resources

Impact of water resource utilisation on environment

The utilisation of water from the Yellow River affects the environment both positively and negatively.

The negative effects include: salinisation induced by irrigation percolation and by seepage from canals and reservoirs; occupation of land by water diversion works and reservoirs; displacement of inhabitants from submerged areas of reservoirs; impacts on coastal marine and wetland species due to a reduction of water and sediment flowing into these regions, and; desertification induced by the deposition of sediment from the diversion of heavily silt-laden flood water. Nevertheless, such effects on the environment can be reduced to the minimum by employing proper strategies.

The positive effects include: the development of industry and agriculture, improving water supply and enhancing the living standard of the local people; the development of forests and other environmental improvements; desalinisation of groundwater and prevention of salt-water intrusion due to the seepage of surface and irrigation water; localised climate changes such as increased humidity due to an increase in the water surface area; recreational use of surface water; improvement of soil quality due to the utilisation of highly silt-laden water from the Yellow River for landfill and ground level raising. In addition, to the south of the Xiaoqing River, water diverted from the Yellow River promotes the recharge of local ground water preventing groundwater depression.

Assessment of the water resources in the YRD

The YRD is poor in local water resources, with 314 m^3 per capita, much lower than the average values of Shandong Province (464 m^3 per capita) and all of China (2710 m^3 per capita). Nevertheless, the delta is rich in water resources derived from upstream. The water resources from the Yellow River are sufficient for long-term development of the area. The estimated discharge from the Yellow River for the years 2000 and 2010 is 4 and 3.6×10^9 m^3, respectively; both values are higher than the estimated demand for the corresponding years.

Nevertheless, most of this water flows to the delta between July and October. It is estimated that for a normal year the water available from March to June in the years 2000 and 2010 will be only 1.27 and 0.89 × 10^9 m^3, respectively. For a dry year, the corresponding estimates are 0.64 and 0.58 × 10^9 m^3. The highest water demand and water shortage occurs from March to June. According to the estimations of water demand by Dongying Water Resource Bureau, the water shortage in the dry season in the years 2000 and 2010 will equal 395 and 651 × 10^6 m^3, respectively. Measures to counteract this are discussed in sections 5 and 6. However, the present water shortage is not due to a lack of water resources but instead, from inadequate diversion and storage capacity. The shortage could be eased or solved by the construction of new hydraulic works, although significant investment would be required (sections 5 and 6).

Associated with the diversion of water for irrigation along the middle and lower reaches of the Yellow River has been a reduction in sediment discharge. In the Yellow River, the annual sediment discharge of the Yellow River has decreased from 11 × 10^8 t to be 9.5 × 10^8 t. It is estimated that more than 1.5 × 10^{10} m^3 of water per year has been taken from the Yellow River for irrigation over the last decade, representing about 1.74 × 10^8 t of sediment per year. The increasing diversion of water for irrigation and other purposes over the next decade will withdraw further sediment from the Yellow River.

The water demand in the YRD will reach a maximum value of 3.5 × 10^9 m^3 in 2010, assuming that water conservation measures will work and water demand per capita and per area farmland will reduce. The implication of this is that 91% of the estimated river flow will need to be extracted in 2010. The population of the delta is predicted to be 2.1 × 10^6 by 2030. If the water demand remains at 3.5 × 10^9 m^3 from 2010 to 2030, the water demand per capita will equal 1670 m^3, substantially higher than that of developed countries (about 1000 m^3 per person). At present, the water consumption per capita in the delta area is 979 m^3. This is much higher than the average value for China of 450 m^3 per capita, but lower than the average values for USA (2316 m^3 per capita), Canada (1507 m^3 per capita), Russia (1307 m^3 per capita) and Italy (986 m^3 per capita). As the increasing cost of land will most likely prevent the construction of more reservoirs, water conservation measures will become increasingly important.

During 1995 and 1996, the stream was dry for almost half a year, which coincided with the maximum season of water use (table 11). As a result, the crop production in Dongying decreased by about 5 × 10^6 kg; and about 117 000 ha of irrigation area and 1 million people were affected. It also caused the loss of a billion Yuan in industry and 10 million Yuan in agriculture. Moreover, the shortage of water resources most probably induced over-exploitation of the ground water, possibly leading to problems such as salinisation and alkalisation in soil. About 153 000 hectares of national conservation area are also affected by stream dessication. The shortage of available water resources has become an important restriction towards sustainable development, and the conservation of the coastal wetlands and Natural Reserve in the YRD.

The water quality of the Yellow River is sufficient for irrigation and urban use, being qualified as second class water. However, river water in other areas of the delta is qualified as fourth class and fifth class, while the groundwater resource is polluted by salt water and polluted surface water. Thus, the Yellow River, is now also threatened by increasing pollution. The pollution index of the Yellow River is 12.4 and that of other rivers is also higher than 10. Serious attention needs to be paid to the control of pollution of the region's water resources. Pollution of the YRD is further discussed below.

4.1.2 Pollution

As the YRD is located on the coast of the Bohai Sea, the air capacity is enlarged by the effects of sea-land breeze and air exchange. Thus, air pollution generated from Dongying City does not remain in the region for long periods. As a result, the general air quality in Dongying is good, not exceeding the standard air quality limits. However, with economic development and an increase in population, air pollution may become a significant factor.

As detailed in section 3.2.4, the water quality of the Yellow River is generally good, but not so for the YRD as a whole. According to the monitoring results from Kenli section from 1990–1994, the contents of most chemical elements are within the state standards of 3rd class water quality (GB3838-88), except the excessive contents of COD and oil matters whose values exceed the state standards of 5th class water quality (Environmental Monitoring Station of Dongying Municipality 1994). Thus, it can be concluded that although the water quality near the river month is generally good, it has been lightly polluted by such organic pollutants as oil in some way.

The concentrations of heavy metals in sediments of the rivers such as Xiaoqing River and Zhimaigou River are higher than that of heavy metals in sediments of other rivers in China, especially for Cr and Pb, which range from 1.5 to 5 times higher than the average high values of national and foreign rivers. While, the concentrations of Cu, As, Zn and Ni are within the average range, they are mostly in the upper limits of the range. Given this, it is essential that more attention be paid to the problems of heavy metal pollution in the YRD.

Due to the influences of saline soil and seawater, the main feature of the groundwater is high salinity. The salinity of upper layer water is 7.7–167.5 g L^{-1} with an average value of 24.6 g L^{-1}. The concentrations of pollutants in the groundwater upper layer are higher than the state drinking water standards. The groundwater in most place of the north side of Xiaoqing River is not suitable for exploitation as drinking water. Groundwater quality in the south side of Xiaoqing River, where salinity is less than 1 mg l^{-1}, is good and can be used for well irrigation. From 1975 to 1993, the groundwater level decreased rapidly from 7.6 to 11 m, due mostly to uncoordinated water usage.

Problems of water pollution have become more and more complex. Many industries are allowed to discharge sewage without any form of treatment. However, the development and construction of sewage treatment facilities requires large investment. With further urban development, the domestic sewage output will increase rapidly. According to the plans for city development and growth of industrial production, sewage discharge will increase 8.2% by 2000. Therefore, by the end of this century, if untreated, its discharge will reach 6.1×10^6 t, and then 6.56×10^6 t in 2010.

4.1.3 Storm surge and flooding

Hazard and risk are viewed as key issues as they relate to physical impacts on the natural and built environment. These terms are often applied to assessments of the effects of extreme events, be they natural or human-induced. For example, there are hazards arising from storm surge events which may place property and people under varying degrees of risk depending on the nature of the event and the location or circumstances of the property or person. In turn, hazardous conditions place property, people and plant and animal communities at risk. That is, life and location at risk in a hazardous situation have a probability of being lost, destroyed or damaged.

Storm surge often occurs in the coastal area of the YRD in spring. In the past 100 years, storm surges with heights over 3.5 m (Yellow River system) occurred six times, in 1845, 1890, 1938, 1964, 1969, and 1992. The storm surge induced seawater to flow inland for several tens of kilometres. The stage in the river is often much higher than the ground level because the ground elevation along the coast is only 1–2 m (Yellow River System). According to recorded data, the 1 in 100 years, 1 in 50 years and 1 in 10 years storm surge heights are 3.93 m, 3.70 m and 3.10 m, respectively. They threaten the delta seriously. Embankments along the coast line protect the coastal wetlands, except to the south of the river. The elevation of the embankments is 4.9 m. To the south of the river the coastal dykes are unable to protect the land against storm and tidal surges. The system is vulnerable, especially if a storm surge coincides with a typhoon. Therefore, it is important to strengthen the embankments.

Several other factors make the YRD more susceptible, and therefore vulnerable to flooding. The gradual increase in sedimentation at the river mouth, and the closed dykes built to protect the oil fields and the Nature Reserve, both reduce the flood discharge capacity of the river, increasing flood risk. In addition, the delta flood control system as a whole may not be strong enough to control a 1 in 100 year flood; the newly constructed dykes have yet to experience high floods, while many of the dykes to the south of the Yellow River are weak and require reinforcing. Finally, continued urban and industrial development within the YRD will simply serve to increase the amount of infrastructure and people at risk.

4.2 Vulnerability to climate change and sea level rise

Based on the range of sensitivities of climate to changes in the atmospheric concentration of greenhouse gases (Watson et al 1996) and plausible changes in emissions of greenhouse gases and aerosols, climate models project that the mean annual global surface temperature will increase by 1–3.5^{o}C by 2100, and that changes in the spatial and temporal patterns of precipitation would occur. The average rate of warming probably would be greater than any seen in the past 10 000 years, although the actual annual to decade rate would include considerable natural variability, and regional changes could differ substantially from the global mean value. These long-term, large-scale human-induced changes will interact with natural variability on a time scale of days to decades (eg El-Niño phenomenon) and thus influence social, cultural and economic well-being. This is discussed below.

4.2.1 Climate change

As stated in section 3.1.1, climate warming might induce a drier climate in China, particularly in winter, spring and autumn. As a result of this, the mean agricultural yield in the YRD would probably decrease due to reduced water availability. This means that by 2050, the net balance between precipitation and evaporation would be negative and moisture stress would be more severe than today, although precipitation by 2050 would increase somewhat. Therefore, the probable impact of climate warming on agricultural production in the YRD region would be unfavourable.

Climate warming may cause an increase in the frequency of the occurrence of typhoons and storm surge. Scientific research indicates that the frequency of occurrence of typhoons along the Chinese coast may increase by a factor of 1.76 each time the air temperature rises by 1.5ºC (Wang & Tong 1992). According to IPCC (1995), there could be an increase of 3–5 ºC in air temperature in the next 100 years. If so, the frequency of occurrence of typhoons along the Chinese coast could increase by a factor of 3.5.

The coastal system is economically and ecologically important and is expected to vary widely in its response to changes in climate and sea level. Climate change and sea level rise or changes in wind and storm surges could result in the erosion of shores and associated habitat, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in the mouth of the Yellow

River and the Laizhou Bay, changes in sediment and nutrient transport, a change in the pattern of chemical and microbiological contamination in the mouth and the coastal areas, and increased coastal flooding. Some coastal ecosystems are particularly at risk, including saltwater marshes and coastal wetlands. Changes to these ecosystems would have major negative effects on tourism, freshwater supplies, fisheries, and biodiversity. Such impacts would add to modifications in the functioning of coastal oceans and inland waters that already have resulted directly from pollution, physical modification, and material inputs due to human activities.

The warming of the climate or the 'greenhouse effect' will have a significant influence on agriculture in the YRD region. The direct results of climate warming are the increases in evaporation, saturation deficit of the air, wind velocity and the variation in high-wind days, which, in turn, will lead to a decrease in the retention of rainfall in soil, thus extending drought periods. In addition, as these natural hazards intensify, the growth of crop plants will be seriously influenced, leading to a decrease in production and quality of the farm products.

Furthermore, climate warming may lead to an increased incidence of plant diseases and insect pests, as follows. Firstly, as the temperature in winter becomes higher, insect pests and viruses could better survive the winter season, hence leading to an increase of the initial number of insect pests and viruses. Secondly, the high temperature in winter may also lead to a decrease of the hibernation stage of pest species. As a result of the increased initial number of pest species, and their extended plague period, the probability of harm to farmland increases.

In summary, an increase in mean surface temperature will cause the following problems to agriculture in the YRD region: (1) instability of agricultural production, an increase in the occurrence of meteorological hazards to farming and an increase in plant diseases and insect pests leading to a decrease in crop production and the quality of the products; (2) patterns and structures of agricultural production systems will have to be changed, and some practical adjustments made; (3) farming conditions will be changed, which will lead to a great increase in the cost of farming.

4.2.2 Sea level rise

Climate warming is predicted to cause a rise in sea level in the recent YRD region. The estimated relative sea level rise rate in the YRD is 8 mm y^{-1} and the sea level rise could be 48 cm by the year 2050 (table 10). This will lead to critical impacts such as the frequency/intensity of storm surges and El-Niño events, beach erosion and landward retreat, wetland loss, salt water intrusion and land salinisation.

Sea level rise will result in a higher base from which storm surge forms. The sea level rise will probably increase the impacts resulting from wind and storm surge. If a sea level rise of 48 cm occurs along the coast of the YRD by the year 2050, one in a hundred year wind and storm surges would become one in fifty year events, and in some cases, one in ten year events. Therefore, coastal erosion and the loss of existing beach areas will increase. The coastline will retreat many tens of kilometres, and the coastal wetlands and Nature Reserve area will be damaged or possibly disappear. In the vicinity of the Yellow River estuary, coastal retreat in the past years was around 36 m y^{-1}. Along the abandoned coast of the Diaokou River coastal retreat was 2–5 km from 1954 to 1980 and the total eroded area was 65 km^2. While such coastal erosion has generally been a result of natural evolution, more recently, sea level rise has facilitated the retreat in some coastal sections.

Relative sea level rise also leads to a higher lowest water level in coastal areas. As a result, it could partly or even completely paralyse the existing drainage system designed for the present discharge of water from the region. If the future relative sea level rises 48 cm, the drainage systems of the YRD will be shortened for 5–10 hours. Consequently, large amounts of water and sediment will be retained in the hinterland. Sea level rise also lowers the level of capacity of the existing disaster prevention facilities (eg dykes). If sea level rises 0.5–1 m, the actual flood control functionality of the flood prevention walls along the Yellow River and the coast of the YRD will be degraded from the protection level of 'one in a hundred years' to 'one in ten years' or even 'one in five years'.

Sea level rise also implies the raising of the level of mean erosion plain of the river and the alteration of the hydrodynamic conditions in the Yellow River mouth. Thus, sediment siltation in the lower reaches of the river and estuaries will be accelerated. Hence, drainage will not be effective during flood seasons in the areas with a number of river outlets, while the siltation rate will be faster if tidal gates are constructed at the outlets.

Sea level rise will increase the water depth of the submarine coastal slope, and gradually decrease the winnowing action of waves on submerged coastal sediments, but erosion on upper beaches by breaking waves is likely to be enhanced. At the same time, the slopes of riverbeds will be reduced, decreasing fluvial sediment discharges. However, human impacts involving diversion of river discharge for urban water supply, and the construction of dams for irrigation, have also decreased sediment discharges enormously (section 4.1.1). As a result of both natural and human influences, a reduction in sediment supply to the coastal zone is a world-wide phenomenon, and one that will be further enhanced when combined with increased frequency of storm surges and El Niño events accompanying climate change and sea level rise.

The coastal region of the YRD with a mean present elevation lower than 2 m covers an area of more than 4000 km^2, more than 60% of which is waterlogged or partially waterlogged lowland. So, in the coastal region, particularly low-lying land, impacts from typhoons and storm surge will be greatly intensified by a rise in sea level. The frequency of flooding, inundation of low-lying land and level of destruction will increase. Thus, sea level rise and associated factors will cause some part of the coastal zone and low-lying land to be submerged or turned into wetland. Estimates indicate that as a consequence of a 1 m sea level rise and storm surge of 2–3 m, about 40% of the YRD area (301 300 ha) will be inundated. Whether the coast will really be submerged in the future depends not only on the relative sea level rise but also on the protection facilities such as coastal dykes in the area (sections 5 and 6). However, it is certain that sea level rise will increase the risk of submergence of coastal wetlands.

An increase in sea level will exacerbate the current severe problems of tectonically and anthropogenically induced land subsidence in the YRD. Saltwater intrusion into aquifers and surface waters in coastal areas also would become more serious. The destruction of precious fresh water resources in coastal areas resulting from relative sea level rise will exert an adverse impact both on the lives of coastal inhabitants and on industrial and agricultural production. This kind of phenomenon has occurred in the YRD coastal zone and the coastal cities along the Yellow Sea and Bohai Sea. In the Laizhou Bay Plain, to the south-east of the YRD, the rate of salt water intrusion has increased from 90 m y^{-1} in early 1980s to 400 m y^{-1} at present (Mo et al 1995, Li & Xue 1993). According to an investigation conducted in the Laizhou Bay, a total of cultivated land of 333 km^2 has lost its irrigation capability and 40 km^2 has turned into salinised land in the past several decades, dropping the local agricultural production by 20–40%. Sea level rise will increase the intrusion of salt water upstream along the Yellow River, resulting in the expansion of estuarine areas in the upper reaches. It will not only increase the salinisation of water in estuarine areas, but also degrade the aquifer and ground water quality on both banks of the river.

By using the Bruun rule, the response of major tourist coastline in the Yellow River Delta Natural Reserve has been estimated. It is predicted that it will lose more than 80% of its present area if sea level rises to 48 cm by the year 2050. Protection and nourishment of the Nature Reserve beaches provide the principal management solutions to these problems.

The continuing rise of sea level at the rate of a few millimetres per year, although not threatening spectacular damages of the sort described earlier, is still important. The situation will be aggravated if sea level rise increases by the amounts predicted to accompany global warming in the future. The YRD, a developing region with about 2 million people living in the low-lying land of the coastal areas, is especially vulnerable to future sea level rise. Many people will be affected, and direct and indirect economic losses and mitigation activities will pose serious financial burdens. Of course, whether disasters caused by sea level rise will occur in the YRD depends on several factors, ie not only the sea level rise, but also the adequacy of the local protection facilities, local vertical crustal movement and so on. Hence it is very important for the relevant authorities to conduct a disaster/hazard evaluation for the area now, in order to formulate a specific policy and corresponding measures for the reduction of prevention or possible disasters from the sea level rise in the area.

5 Current responses to existing forcing factors

5.1 Storm surge and extreme wave

5.1.1 Analysis of the consequences of storm surges

Figure 12 shows the calculated inundated areas by storm surges. The estimated inundated areas for several storm surge intensities are shown in table 14. The inundated areas are large because the landscape is flat with minimal changes in altitude.

Table 14 Storm surge influence in the YRD

Position	5 years WSS		10 years WSS		50 years WSS		100 years WSS	
	ESS (m)	NDH (m)	ESS (m)	NDH (m)	ESS (m)	NDH (m)	ESS (m)	NDH (m)
Yangjiaogou	2.81	4.0	3.04	4.3	3.54	4.8	3.75	5.0
Shenxiangou	2.22	3.4	2.39	3.6	2.92	4.1	3.29	4.1
Chaohe	2.60	3.8	2.81	4.0	3.46	4.7	3.46	4.7
Flooded area (km^2)	1355		1442		2672		2952	

WSS: Wave storm surge

ESS: Elevation of storm surge

NDH: Necessary dyke height

5.1.2 Control of storm surges

The tidal dyke in the north of the YRD can withstand assaults of one in 20 years storm surges. However, in the east of YRD there are only low and broken tidal dykes. There are no tidal dykes in Guangrao County. Therefore, the east part of the YRD is under the threat of storm surge. To safeguard the delta against sea surges, the tidal dykes in the east part must be completed and enhanced. Table 15 presents designed crest elevations of tidal dykes against sea surges of different frequencies.

Table 15 Designed crest elevations of tidal dykes against storm surges of different frequencies

	Sea surge frequency					
	0.002	**0.01**	**0.02**	**0.05**	**0.10**	**0.20**
Yangjiaogou	5.5 m	5.0 m	4.8 m	4.5 m	4.3 m	4.0 m
Shenxiangou mouth	4.5 m	4.1 m	4.0 m	3.8 m	3.6 m	3.4 m
Chaohe mouth	5.1 m	4.7 m	4.5 m	4.2 m	4.2 m	3.8 m

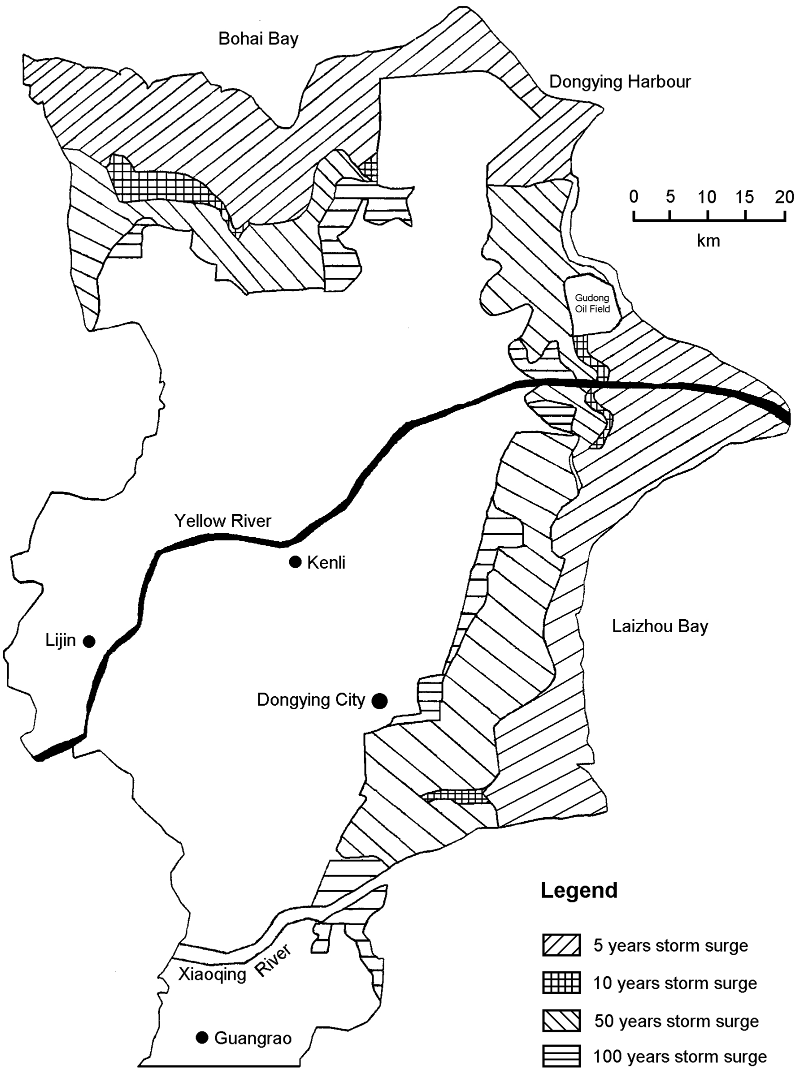

Figure 12 Areas inundated by storm surge in the YRD

5.2 Stream dessication and water resource shortages

The YRD area experiences seasonal shortages in water supply for agricultural purposes. Major strategies to overcome this include optimisation of river flow, enhancing water utilisation efficiency, taking water conservation measures, constructing more reservoirs and diversion engineerings, and greater utilisation of silt-laden water during the flood season. Strategies for different districts should be selected according to local situations.

From the long-term development perspective, the utilisation of highly sediment charged flood water from the Yellow River is the main strategy and should be studied further. Irrigation quotas for the Dongying Municipality are considerably higher than those of Shandong Province (table 16). Therefore, there is a great capacity for the farmers in the delta to save water in irrigation practice and enhance water use efficiency.

Table 16 Comparison of irrigation quotas at the Provincial and Municipal level ($m^3\ ha^{-1}$)

Water source	Dongying Municipality		Shandong Province (Agric. Dept)	
	2000	2010	2000	2010
Canal	5 670	5 670	3200–3880	2660–3200
Paddy field	16 200	15 150	11 250	9750
Pumped well	3 255	3 210	2340–3045	2790

The present capacity of reservoirs in Dongying Municipality is $485 \times 10^6\ m^3$. This is planned to increase to $769 \times 10^6\ m^3$ by 2005 and to $1125 \times 10^6\ m^3$ by 2010 (Ninth Five-Year Plan and the development plan for the period 2001–2010). Thus, water shortage is not anticipated to be a major obstacle to economic development.

5.3 Flooding

Since 1949, the government has paid particular attention to flood control in the Yellow River basin and to marine hazard control along the coast of the YRD. Flood control for the delta had been listed in the Comprehensive Plan of Flood Control in the Lower Reaches of the Yellow River. Following development of the local economy, especially the Shengli Oil Fields, the flood and marine hazard control system was reinforced on an ongoing basis. This system comprises the following (Zhang et al 1997, Lu et al 1997):

Flood control system

The dykes upstream of Siduan are natural dykes and have been enhanced three times since 1949. The third dyke enhancement was completed in 1985 and is capable of controlling a 22 000 $m^3\ s^{-1}$ flood at HuaYuankou, and a 10 000 $m^3\ s^{-1}$ flood downstream of Dongping Lake. The dykes between Aishan and Siduan were designed according to 11 000 $m^3\ s^{-1}$ flood stage with a freeboard of 2.1 m. Downstream of Siduan the South Dyke, flood control dyke, North Dyke and East Dyke were constructed one by one. The dykes were designed to control a 8000–11 000 $m^3\ s^{-1}$ flood with a freeboard of 0.8–2 m. In addition, the Nanshan dyke on the south bank of the river at Lijin, and the Xiaojie flood retention basin strengthen the flood control system and safeguard the oil fields. In addition,the government has proposed a plan to stabilise the current channel of the Yellow River for 100 years.

Wind storm surge control system

In the period 1982–1997 the Shengli Oil operators built long dykes at several places to protect the oil field against wind storm surges. The dykes have since been linked to form a continuous structure capable of protecting against a one in one hundred year flood event. The dyke crest was enhanced several times and it is now 3.5–4 m (the Yellow Sea system).

Ice-jam flood control system

The major measures for controlling ice-jam floods are (1) to break the ice cover by explosion, bombing by air and ice breaker vessels; (2) to operate the Sanmenxia Reservoir, also the Xiaolangdi Reservoir in the future, to release 800 $m^3\ s^{-1}$ discharge at the beginning of the ice/frozen season. In this way the onset of freezing can be delayed and the thickness of the ice cover is decreased, maintaining a larger wetted area beneath the ice cover. In spring when the ice cover begins to melt, the released discharge from the Sanmenxia Reservoir is controlled below 200 $m^3 s^{-1}$; (3) ice flood diversion projects, such as Xiaojie and Nanshan flood diversion projects. The Nanshan flood retention basin can be used for flood control and ice-jam flood control.

Drainage system

The drainage system consists of 11 rivers, including the Chaohe River, the Zhanli River, the Shenxiangou to the north of the present Yellow River, and the Guangli River, the Zhimaigou River, and the Xiaoqing River to the south of the Yellow River. The discharge capacity of the Xiaoqing River and the Zhimaigou River is 360 $m^3 s^{-1}$ and 491 $m^3 s^{-1}$, respectively. The Dasun and Qinghu gates in the Nanshan dykes share a total drainage capacity of 87 $m^3 s^{-1}$.

Moreover, the First Phase Engineering Project, when it is completed, will greatly enhance the flood control capacity for the delta. As a result of living with flood risks, the local people of the YRD have accumulated experience through their flood control practices. They understand the laws of flood propagation and can take emergency measures to reduce flood damage if necessary. In addition, as the local economy grows, it will be more capable of funding flood control measures, such as river dredging and dyke reinforcement.

6 Future responses to climate change and sea level rise

6.1 Environmental monitoring

Environmental monitoring is required in the YRD to provide data and information for: i) further understanding of the processes and extent of environmental change; ii) development of management strategies and action plans; iii) implementing management prescriptions; iv) auditing the effectiveness of management actions; and v) assessing the performance of the overall management processes.

Management of the coastal wetland and Nature Reserve of the YRD requires that effective monitoring programs are implemented and that the results are effectively utilised. Monitoring of ecological change in wetlands can be undertaken at several levels and with vastly different techniques. Satellite imagery, often linked to a GIS, aerial photography, flora and fauna surveys at the species and community levels, physico-chemical analyses and biomonitoring of the coastal wetlands of the YRD and the Yellow River all have particular advantages and disadvantages.

Monitoring also encompasses social, economic and cultural dimensions of change in the coastal zone of the YRD. Social science survey techniques are needed to monitor levels of awareness and community attitudes to the effects of environmental change. Such work should be undertaken in a manner to ensure that the biases do not overwhelm all community interests, as well as to ensure that there is a high level of community involvement in ongoing assessment of environmental change.

Apart from monitoring to assist with maintenance of the intrinsic values of the region, there is a need to provide national and international benchmarks from which to measure changes in the East Asian Monsoon environment in Chinese coasts. The east China coasts, and especially the YRD, provide an excellent opportunity for the establishment of a Coastal Wetland Environmental Reference Center for the coastal regions with the East Asian Monsoon. The circumstances that make this region special are that it has a sound history of research, and that there is a considerable body of material that could be collated and synthesised to provide baseline descriptions of the essential characteristics and attributes of change in this type of environment. The State Administration of Oceanography, China (SAOC) and Yellow River Delta Conservation and Development Research Center (YRDCDRC) have a considerable infrastructure already in place to facilitate continuous measurement of climatological and hydrological parameters, and a number of permanent sampling stations have already been established.

6.2 Counter measures and strategies

The strategies for environmental protection and sustainable development of the YRD are listed as one of the two main national development strategies in the Ninth Five-year National Economic and Social Development Plan and 2010 Long Term Target. However, there is still much work to be done in order to implement the strategies. It is recommended to integrate sound environmental planning in the governmental planning documents and there is also a need to improve the environmental monitoring system, particularly for the nature preservation zone in the YRD. Learning from international experience is useful, and Japanese experience on monitoring the natural environment is quoted below, for reference.

In Japan, environmental monitoring of various parameters of the environment is conducted with systematic networks consisting of a number of monitoring stations, which cover the whole country. Although China's National Bureau of Environmental Protection has also established such monitoring stations, the monitoring of the natural environment in China needs further strengthening and improvement. The Japanese experience of 'Green Census' is extremely useful for reference in providing basic data on management of natural environment.

Specific recommendations for future responses and strategies towards recognising, understanding and managing for the potential impacts of climate change and sea level rise are presented below.

1. Implement a system of monitoring sea level rise, environment and management

The environmental protection mechanisms of Dongying Municipality and Shengli Oil Field include quite good monitoring systems for environmental pollution. However, their capability is still weak in monitoring of changes in the ecological and physical environments. Therefore, it is necessary to develop and implement the following monitoring stations and information systems:

- A system of monitoring sea level changes and coastline evolution, ie an integrated survey system between sea and land on the same datum plane (mean sea level of the Yellow Sea) by using standard methods for remote sensing, geographical positioning systems and GIS.
- Fixed tide-gauging stations in the Yellow River mouth region and along the coast of the Nature Reserves.
- A number of fixed monitoring stations for the ecological environment in the coastal zone that is most sensitive to environment changes.
- A dynamic monitoring system equipped with advanced technology and methods such as remote sensing GIS, which can provide information and early warning of environmental effects in time.
- Earth digital information system that includes data about natural, social, economical and cultural attributes at every important site of the YRD and the coast of the YRD.

2. Harnessing the mouth and tail course of the Yellow River

Continued efforts to stabilise the mouth and tail course of the Yellow River are needed to enable ongoing regional development. Although the quantity of water and sediment flowing from the Yellow River's upper and middle reaches has decreased markedly in recent years, resulting in longer dry periods in the lower reaches, the Yellow River's flood peaks during the flood season still place the YRD under relatively high flood risk.

3. Consideration of flood risk in urban and industrial planning

The layout of local economic development should be based on flood risk analysis. Industries should be arranged in the zones with less flood hazard. If a zone of high flood hazard is needed to develop industry or important economy, a flood control dyke system capable of controlling floods and wind and storm surges needs to be constructed. Although the flood control system of the YRD has been greatly reinforced, the sustainable development of the YRD and protection of the coastal wetlands require higher standard flood control systems and more studies on risk analysis and flood control strategies.

4. Protection and management of coastal wetlands and the Nature Reserve

The YRD, most of which is in relatively primary condition, boasts the youngest estuary wetland ecosystem in the world. The conservation status of this area aims to protect the newly formed wetland ecosystem and rare birds in imminent danger. It plays an important role in protecting and maintaining the ecology of the region, and is also a valuable site for carrying out scientific research. A major aspect of this recommendation is the need to monitor the waterbird (both migratory and non-migratory) populations.

The Nature Reserve of the YRD is located in a high risk zone of storm surges. The construction of dykes should not disturb the environment of the Nature Reserve. It is suggested that a flood diversion channel through the Nature Reserve may favour the fresh water ecological environment.

5. Vegetation belts and eco-forestry

Development of vegetation belts should be continued. These include the Chinese Tamarisk forests close to the shore and coastal protection forest belts, shelterbelt forests along the great dykes of the Yellow River and the branches of other river systems, forest belts in farmland, and greenery patches and parks in cities and towns.

6. Effective urban and industrial pollution control

The Shengli Oil Field, local industries, villages and township enterprises all have the responsibility to control pollution. All waste water must meet the relevant standards before being discharged. Particular attention should be given to the Shenxiangou River, Yihong River, Guangli River, Xiaoqing River and other rivers, which have been seriously polluted.

7. Water conservancy project system of irrigation-drainage-storage-prevention

The establishment of reservoirs on the plains of the YRD should be a priority. In addition, the irrigation and drainage network should be sufficient to make full use of the water and sand resources, to drain salt water to prevent salinisation, and to lower the underground water level. At the same time, tidal barrages along the sea beach need to be built and existing ones repaired. Such measures will help alleviate the problems of soil salinisation and impacts of natural disasters.

8. Increase community awareness of environmental protection

The nation's awareness of, and concern over the ecology and environmental protection of the YRD must be increased. We propose that activities for eco-environmental protection should be sponsored jointly by the Propaganda Departments of Dongying City and Oilfield, the Education Bureau, the Environmental Protection Bureau, the YRD National Nature Reserve Management Bureau, and the Broadcasting and Television Station. Geography and biology teachers should be at the forefront of development of a popular science network. There is a need to increase community awareness of the environmental issues associated with the development of the YRD, including those related to climate change and sea level rise.

6.3 Management of the YRD Nature Reserve

It is an extremely difficult task to effectively administer the Nature Reserve of the YRD. Firstly, the ecological environment is very vulnerable; secondly, the YRD has just started to be comprehensively developed on a large scale. The local people have a strong desire to develop the economy. Petroleum recovery is what the country needs urgently and is the potential pillar of economic development. So there is a striking contradiction between environmental protection and economic development. In addition, random cultivation and herding, burning grass on wasteland and hunting make it even harder to manage the Nature Reserve.

In order to administer the Nature Reserve scientifically and effectively, the following recommendations are proposed:

1. Develop an administrative system and effective management patterns

In addition to the development of an administrative system within the Administrative Bureau of the Nature Reserves, a United Protection Committee of the Nature Reserve should be established. The municipal government, together with Shengli Oil Field, Agricultural Bureau, Husbandry Bureau, Fishery Bureau, Land Bureau, Environmental Protection Bureau and the Bureau of Public Security should take important problems concerning nature protection into consideration before decisions are made. In addition, they should address and manage as best as possible the contradiction between protection and development and the relationship between each aspect and the Nature Reserve.

2. Draft and implement laws and regulations and administer legally

Lay down concrete laws and regulations for the protection of the Nature Reserve in accordance with the laws for nature protection made by the state.

3. Separate time and space – multi-use administration

Wetlands can be used in many ways as resources. With protection as the main task, the Nature Reserve should develop a more diversified economy to become powerful economically, and hence to promote development of nature protection. The key to the relationship of a diversified economy and nature protection is the separation of time and space. At present, the Nature Reserve is divided into a core zone, buffer zone and experimental zone. Landscape management measures, such as fixed tourist routes, cutting of reed separately and seasonal closure of the Nature Reserve during nesting need to be implemented. Given the presence of oil in the Nature Reserve, strict environmental guidelines need to be developed. If oil recovery is to be continued and further developed in the reserve, industry should control oil pollution strictly, limit the amount and land use for oil wells and improve technology and working practices as far as possible. Funds could be established for nature conservation, to be fed into environmental management of the region and the further conservation and development of the Nature Reserve. Some ecological compensating measures also can be implemented. For example, the establishment of another ecological environment of the same type and same area elsewhere, for balance of resources.

4. Strengthen scientific research to provide a basis for management

It is necessary to set up fixed observation stations and an ecological monitoring system. As well as the study of natural science, effective nature protection is the combination of applied ecology and social science.

5. Enhancement of people's consciousness of ecology and environmental protection

The Nature Reserve, or more specifically the Nature Reserve Management Bureau, should make contributions to the enhancement of community awareness of ecology by means of publicising popular science, undertaking or promoting teaching practice at colleges and high schools, and ecological tourism. It should set a good example through self-development and encourage local community involvement in protection and management, such as working as bird protectors.

6.4 Proposals for future research

1. **Monitoring of the Yellow River mouth evolution and sea level changes and their effect on the YRD environment**
   - a To analyse, evaluate and forecast the transformation of the Yellow River mouth flow path and effect on the environment of sea and land areas made by the Yellow River's water and sand changes.
   - b To analyse, evaluate and forecast the impacts of future sea level changes (on the environment and economic development of the YRD) and to put forward further countermeasures.
2. **Study of land management, environmental improvement and disaster prevention and alleviation**
   - a Countermeasures for alleviation of disasters resulting from flooding and storm surge and the effect of sea level rise on low land.
   - b Engineering and biological protection of the YRD's eroded sections.
   - c Ecological restoration of degraded land.
   - d Cleaning and production technology of serious industrial pollutants.
3. **Study of biodiversity and natural conservation and management of coastal wetland**
   - a Ecological study of endangered and migratory rare birds.
   - b Protection and rational development and use of coastal wetland resources.
   - c Effect on the natural reserve made by harnessing the river mouth and developing oilfields.
   - d Coordinated development of the natural reserves and the YRD.
   - e Study of laws and regulations for management of natural reserves.

4. **Study of ecological agriculture patterns and sustainable development of large agriculture in the YRD**
   a To study various kinds of ecological agriculture patterns suitable to the YRD through typical demonstration stations.
   b Develop a scheme for land utilisation and optimisation on the basis of a sound cycle of ecology and high efficiency output.
   c Transformation of salinised soil and efficient use of water and sand resources.
   d Selection, introduction and breeding of salt-resistant tree species and suitable crops.
   e Breeding and intensive processing of *Spirulina*.

7 Major conclusions

The study area of the project was the modern YRD where Dongying Municipality is located. The main scope included the coastal wetlands, the tidal flats and the submersed parts in the delta. The vulnerability assessment was based on an assessment of present, past and geomorphic changes in the coastal zone and predictions of likely further change. An ecological assessment was then superimposed. Information specific to the region was supplemented from studies carried out in adjacent coasts and bays. The assessment provided views of change at a biophysical regional scale for the coastal wetland of China, and for the Nature Reserve within the YRD as an example of a local scale assessment.

This vulnerability assessment was undertaken using a cause and effect framework. The approach used recognised that climate and sea level rise need to be examined in the context of the natural variability of the processes affecting the coastal wetlands of the YRD. Two sets of forcing factors have been identified – natural and anthropogenic (human). These affect natural, social, economic and cultural systems and result in a range of governmental responses.

The Yellow River is the river with the highest sediment contents of all rivers in the world. The YRD and the YRD Nature Reserve is the most rapidly expanding delta system and wetland region in the world. With its large areas of shallow sea and bog, abundance of wetland vegetation and aquatic biological resources, the Nature Reserve provides the birds with exceptional habitat for breeding, migrating and wintering. Therefore, the reserve has become an important 'transfer station' for north-east Asia and the western Pacific Ocean for bird migration.

The greatest asset of the YRD is its rich land resource, averaging 0.48 ha per capita, which is 5.33 times that of the Yangtze River Delta. In addition, there are land resources that are yet to be developed and utilised. There are also rich fisheries resources, while salt and halogen resources are also considerable. Major oil and natural gas reserves are the most important source of production of the YRD. The water resource comes mainly from the Yellow River. In recent years, river flows have decreased dramatically, and there are now serious seasonal shortages of water.

Understanding of biodiversity and nature preservation must be considered as one of the issues for the development of the YRD. Wetlands and other marshes, once considered as useless obstacles to economic development, are now recognised as an environmental resource for their great values in recycling chemical substances and their biological diversity. The wetlands of the YRD provide habitat for hundreds of species of animals and plants.

Petroleum exploration and production is a dominant factor for economic development of the YRD. However, this will continue to have adverse impacts on the Nature Reserve unless management practices are improved. The geological survey will affect the breeding of birds, fishes and shrimps. Spillage of petroleum, high voltage transmission lines, and highways and dykes, all have some negative impacts on the Nature Reserve. If oil recovery must be undertaken in the reserve, there should be strict guidelines regarding pollution control, minimisation of habitat loss, and ongoing technological improvements. Additionally, industry could be required to contribute funds that go towards the effective conservation and environmental management of the Nature Reserve.

Forcing factors impacting on the YRD include natural and anthropogenic factors. Major natural factors include climate warming and sea level rise, the East Asian monsoon, El-Niño events, sedimentation and erosion in the river and along the coast. Flooding and storm surge, phenomena caused by several of the above factors were also considered forcing factors for the purposes of this study. Major anthropogenic forcing factors include population increase, oil and natural gas development, land use, economic development and environmental pollution. These factors together will cause a series of hazards and risks such as disasters of wind and storm surges, coastal erosion and retreat, coastal wetland loss, floods and drought, salt-water intrusion and land salinisation, and a loss of biodiversity.

Climate change and sea level rise, as well as being natural processes, are also being significantly influenced by anthropogenic factors. The temperature in China could increase by about 0.88 ºC in 2030, 1.40 ºC in 2050 and 2.95 ºC in 2100, due to anthropogenically-induced climate change. Precipitation also could increase by about 2.6% in 2030, 4.2% in 2050 and 8.9% in 2100. These figures indicate that the change of temperature due to human activity might be much more obvious than that of the precipitation in China. The more warming, the more evaporation caused, potentially resulting in a drier climate in China, including the YRD, especially in winter, spring and autumn seasons. Predicted climate change and sea level rise could increase the frequency of occurrence of storm surges, typhoons, high-speed winds and El Niño events, which, in turn, could cause serious damage to the natural and non-natural resources of the YRD. Effects might also include drought and changes to the seasonality of precipitation in the upper and middle reach region of the Yellow River, leading to longer durations of stream dry out in the lower-reach of the Yellow River. However, given the potential increase in extreme events, flood hazards will still exist during storm periods.

A direct effect of an increase in mean global surface temperature is sea level rise. Although this effect will occur slowly and with a delay in time scale, it could result in major impacts. The predicted relative sea level rise rate in the YRD is 8 mm y^{-1} with a predicted overall sea level rise scenario of 48 cm by the year 2050 (table 4). Combined with storm surge and more extreme storm events, sea level rise will result in adverse impacts including beach erosion and landward retreat, wetland loss, saltwater intrusion and land salinisation, loss of infrastructure and agricultural damage. If the sea level rises along the coast of the YRD by 48 cm by 2050, a one in one hundred years recurrence of wind and storm surge would change into one in fifty years, and possibly even one in ten years. Sea level rise will also obstruct the drainage of water on land and urban and industrial runoff water of cities and towns, thereby increasing the incidence and magnitude of flooding and pollution. This would exacerbate the shortage of water both for industry and domestic use.

The Yellow River is the major source of water supply in the YRD region. With the economic development in the upper and middle-reach areas, the volume of water dammed and used has increased consistently, while the volumes of water and sediment discharged to the lower reach of the river has consequently decreased, and the duration of drying of the river has increased. Since the 1980s, the precipitation in the watershed area of the Yellow River has decreased by 30–50%, and the drought, which is potentially related to climatic warming, has greatly intensified. If the climate continues to warm and precipitation continues to decrease in the future, the Yellow River will very likely become a seasonal river, which will also greatly intensify the shortage of water resources in the YRD region. It has been predicted that by 2010, 91% of the estimated river flow will be extracted for domestic, industrial and agricultural purposes.

The quality of freshwater resources is deteriorating. The major rivers are considerably polluted. The groundwater resources are under stress from both industrial and urban pollutants, and saltwater intrusion. The ongoing development of the YRD and sea level rise in the future will further degrade the environmental condition of water resources. If the process of environmental deterioration is not efficiently controlled, and the quality of water of the Yellow River, which is the major source of water supply in the YRD region, cannot be improved, water shortages will cause major impacts to the ecological and socio-economic development of the YRD region.

The YRD is a precious land. It has great potential for development because of its rich resources and favourable location. However, attention should be paid to the disadvantages of this region. There are a lot of restrictive factors since this region is the border where the river and the sea meet and the land and the sea connect. With continuing development, the environment will be under great pressure and the region will be in urgent need of land restoration and environmental protection. Special attention should be paid to the main conflicting factors affecting YRD's sustainable development: those between large scale development and a vulnerable environment; the region's future development plans and the restrictions imposed on them by the Yellow River (eg the Yellow River's flowing water is restricted by how much water is used in the upper reaches); future development and the potential impacts of predicted climate change and sea level rise; and present industrial structure and the non-reproducibility of mineral resources. In land renovation and restoration, priority should be given to the key problems such as realignment of the Yellow River mouth and the flow path lowering underground water level, protecting the ecological environment and restoring salinised soils.

In dealing with the relationship between environmental protection and economic development, we need to acknowledge that for the sustainable development of the YRD, both issues need to be considered in unison. The sustainable development strategy put forward in Our Common Future and the 21st Century Agenda aims at promoting the harmony between human beings and nature, and person to person. Therefore, importance should be attached to the protection of fragile ecological systems, minimising industrial polluting sources and the building of rural ecological environments. Large and important projects should not be planned in areas where the ecology is fragile. Dynamic environmental monitoring and management systems should be set up and improved for efficient management and control. The public's awareness of the environment, ecology and sustainable development should be strengthened, thus assisting in further development being undertaken on the basis of scientific knowledge and understanding.

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Vulnerability assessment of Olango Island to predicted climate change and sea level rise

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Executive summary

The Asia-Pacific Network for Global Change Research (APN) funded a study assessing the vulnerability of Olango Island, in the Central Philippines, to predicted climate change and sea level rise. The study was coordinated by the Environmental Research Institute of the Supervising Scientist (***eriss***), in Australia, and Wetlands International–Oceania, with the major local collaborator being the Philippines Department of Environment and Natural Resources (DENR).

The study's major objectives were to raise awareness of the issue of climate change and sea level rise in the Asia-Pacific region, to provide advice and training to national and local agencies on procedures for Vulnerability Assessment, and specifically, to obtain a preliminary understanding of the potential impacts of climate change and sea level rise on the biological, physical and socio-economic attributes of Olango Island.

Olango Island was chosen as a study site for several reasons: It is a small, coral reef island (~6 × 3 km) with low topographical relief and a maximum elevation above sea level of only 9 m; it sustains a population of over 20 000 and is already under pressure from anthropogenic activities including fishing, groundwater extraction and mangrove harvesting; it is a major wetland site for shorebirds, being nominated for the East Asian–Australasian Shorebird Reserve Network and listed as a wetland of international importance by the Ramsar Wetland Convention. Due to its importance as a flyway stopover site, a 920 ha wildlife sanctuary was established in the south of the island.

The vulnerability assessment included the following steps:

- describing the physical, biological and socio-economic attributes of Olango Island;
- establishing a predicted climate change scenario based on existing literature;
- identifying existing natural and anthropogenic 'forcing factors' and their impacts;
- assessing vulnerability to existing forcing factors;
- assessing vulnerability to climate change and sea level rise;
- documenting current responses to coastal hazards;
- recommending future monitoring requirements and management strategies;
- identifying information gaps and research priorities.

Information was obtained from existing literature. In addition, the outcomes of a workshop with participants from local, regional, national and international government and non-government agencies were used in the assessment.

The major physical attributes of Olango Island include the low topographical relief, sandy shorelines and limestone outcroppings, the groundwater lens and the monsoonal climate. The major biological attributes include mangrove forests, seagrass beds, coral reefs, birdlife and other wetland fauna. The major socio-economic attributes include the large population in general, livelihood activities such as fishing and shell and seaweed collection, infrastructure and freshwater supply.

The predicted climate change scenario for Olango Island was based on predicted regional scenarios by the Intergovernmental Panel on Climate Change (IPCC) and the Philippine Atmospherical, Geophysical and Astronomical Services Administration (PAGASA) where possible. Where such information did not exist, estimates from IPCC global scenarios were used.

The predicted scenario for Olango Island is:

- A rise in mean sea level of 30 cm by 2030, and 95 cm by 2100;
- An increase in mean global sea surface temperature of 0.5°C by 2010 and 3°C by 2030;
- A 20% increase in typhoon intensity;
- A tendency for increased rainfall, intensity and frequency.

The major existing natural forcing factors on Olango Island are the south-west and north-east monsoons, typhoons, storm surge and El Niño. Some of these have positive impacts on the island, by way of recharging the underground water supply, while the major negative impacts include flooding, erosion and infrastructure damage. The major anthropogenic forcing factors involve the exploitation of natural resources, such as over-fishing and illegal fishing, over-extraction of groundwater, mangrove harvesting and coral extraction. These factors could result in erosion, saltwater intrusion, shortages of freshwater, habitat destruction and the loss of biodiversity.

Assessment of the vulnerability of Olango Island to existing forcing factors indicated that the island is already under enormous pressure, mostly from natural resource exploitation, although typhoons and associated storm surges also exert negative impacts. Many of the natural resources are already severely degraded, particularly the fisheries and the under ground supply of freshwater. The sustainability of these resources is in doubt, although recent management recommendations have provided the first step towards long-term sustainability.

Climate change and sea level rise will undoubtedly place additional stress on Olango Island and its attributes. Given its low elevation and topographical relief, more than 10% of the current land mass would be lost in the event of a 95 cm rise in sea level. In addition, more severe typhoons and storms surges would result in an even greater portion of the island being subjected to inundation and flooding. Given that the majority of human settlement on the island occurs in close proximity to the shoreline, this represents a major problem. An increase in sea level would also facilitate saltwater intrusion into the underground freshwater lens, although this could be offset by an increase in rainfall. Potential effects on the biological attributes include loss of mangrove stands due to an inability to recolonise inland, bleaching and death of corals due to increased sea surface temperature, and loss of feeding grounds and roosting habitat for resident and migratory shorebirds. Potential effects on socio-economic attributes include the displacement of people, loss of infrastructure and loss of livelihood options.

While the current issues facing Olango Island are immediate and serious, the vulnerability of the island to climate change and sea level rise is sufficiently great to require consideration in future management plans.

Current responses to the current and future hazards facing Olango Island include a number of resolutions and ordinances at the local (Barangay) level, such as the declaration of local fish sanctuaries and marine reserves, and prohibition of sand extraction and illegal fishing. Regional responses, such as the Mactan Integrated Master Plan address land use issues for Olango Island, while DENR has drafted management recommendations for the wildlife sanctuary, in which the issue of climate change and sea level rise is recognised. DENR also conducts a bird monitoring program in the wildlife sanctuary. The USAID-funded Coastal Resource Management Project (CRMP) has completed a Coastal Environmental Profile of Olango Island, which will assist in developing a coastal zone management plan. On a national scale there also exist a number of plans and policies relating to coastal zone management and mitigation/protection plans against coastal hazards.

Major parameters recommended for future monitoring are outlined. They include: geophysical parameters such as storm surge, shoreline erosion, mean sea level, groundwater salinity and water and air temperature; biological parameters such as bird populations, mangrove growth and distribution, seagrass cover, coral cover and reef fish biomass; socio-economic parameters such as tourism growth, population structure and infrastructure development. A number of future management strategies are also proposed, including the creation and maintenance of buffer zones, the provision of livelihood opportunities for the local people and developing awareness of techniques for natural resource management. Management measures to address potential impacts of climate change and sea level rise include reviewing the feasibility of physical barriers to protect against storm surge, prohibition of shoreline vegetation harvesting, regulation of groundwater extraction, protection of the groundwater catchment area, establishing fish sanctuaries, seeking alternative livelihoods, developing a formal education program and reassessing future coastal development plans.

A number of information and research gaps were also identified. There were major deficiencies in storm surge data, the quantification of coral and sand extraction, natural disaster damage estimates for lives, property, and natural resources, groundwater salinity and transmissibility data, the biology and ecology of endangered species, and the impacts of mangrove forestation on the seagrass beds. In addition, the lack of a detailed topographic map made it difficult to make precise estimates of the potential impacts of sea level rise on the island.

The vulnerability assessment highlighted the magnitude of the immediate threats facing the local comunities and natural resources of Olango Island. First and foremost among these threats are the increasing population and the associated depletion of the fisheries and underground freshwater supply. Even in the absence of climate change and sea level rise, sustainability of these resources will not be achievable if management plans do not address the problems. Olango Island possesses many characteristics that make it highly vulnerable to climate change and sea level rise; it is a small, low-lying coral reef island with a large, technologically poor population. Thus, climate change and sea level rise will only serve to place further stress on those natural resources that are already under threat. Subsequently, recently drafted local, regional and national management plans need to recognise and address the possible consequences of climate change and sea level rise.

1 General introduction

1.1 Background

The archipelagic nature of the Philippines with more than 32 400 km of coastline makes the country susceptible to climate change, be it global or localised in magnitude. Its coastal zone can change drastically, but often times gradually and imperceptibly. About three decades ago, very few people discussed the issues of global warming, El Niño phenomenon, seawater intrusion nor the idea of ozone depletion. In recent years, particularly in the 1990s, these issues have become bywords among Filipinos, children and adult alike, and more often than not are associated with terrifying events. Such events include the Mt Pinatubo eruption in 1991, the destructive fires in Indonesia in 1997 and Hurricane George in 1998 that devastated some parts of the United States. In addition, China had its worst flood in many years, coinciding with the onset of the La Niña phenomenon.

A key to effective sustainable management of the country's coastal zone is the understanding of the changes occurring within and around it. This is made even more urgent and imperative because millions of lives and economic investments depend on its stability and sustainability. Changes to the coastal resources, be they biological or otherwise, can be attributed to both human and natural causes, and climate change can exert a profound impact on them. These issues are well illustrated in the Philippines, such as the example of Olango Island, a small, coral reef island located in the Central Visayas, between Mactan Island and Bohol (figure 1).

The concept of climate change has prevaded the thinking of many people in the Philippines. This has been expressed by comments about temperature and rainfall extremes and variability. In such terms the general populace is aware of apparent changes in the climate, if not the actual extent and consequences of such change. This has been most noticeable with a general increase in awareness of the El Niño phenomenon and its influence on the weather.

1.2 Rationale for the selection of Olango Island

The benefits conferred by wetlands to humans, plants, and animals and to the environment are increasingly being recognized (Dugan 1990, Maltby et al 1994, Finlayson 1996). They not only provide food, wood, water and protection but also serve as habitat to many aquatic and terrestrial creatures including migratory birds.

In 1998, the Asia Pacific Network for Global Change Research funded a project entitled 'Vulnerability assessment of major wetlands in the Asia Pacific Region'. Sites were selected based on the importance derived by the community from the wetland and its conservation value. The selection of sites was also linked to areas of international importance for migratory shorebirds. Olango Island in the Philippines was selected for the vulnerability assessment for the following reasons:

- At the southern end of Olango is a wildlife sanctuary, the first Ramsar site in the Philippines, which serves as a habitat for thousands of birds, both migratory and resident. From the east coast southward and westward, stand natural and man-made mangrove forests, seagrass beds and fringes of coral reefs (CRMP 1998). Together with the birds, these features constitute a vital coastal resource that are likely to be vulnerable to climate change and sea level rise.
- The island has a low slope and maximum elevation of only 9 m. Thus, it is deemed vulnerable to sea level rise resulting from climate change, and impacts on its coastal

resources, livelihood, tourism and transportation should be a major concern. The island is considered susceptible to inundation, erosion and storm surges.

- The island is overpopulated and this puts extreme pressure on the limited coastal and terrestrial resources of the island (area of 1029 ha and a combined population of more than 22 000).

1.3 Objectives of the assessment

The aim of the vulnerability assessment for Olango Island is to consolidate and collate basic information on the resources and existing developmental structures, policies and other responses that might be affected by climate and other anthropogenic changes, and to formulate strategies to minimise the impact of such changes. To accomplish this, a number of specific objectives were set:

1. To assess the vulnerability to current forcing factors, climate change and sea level rise.
2. To determine the likely impacts of current forcing factors and climate change and sea level rise.
3. To recommend management strategies and responses to current forcing factors, climate change and sea level rise.
4. To recommend schemes to monitor climate change and sea level rise.
5. To increase the awareness of local and national decision planners and makers to the potential impact of climate change and sea level rise.
6. To encourage planners and leaders to incorporate the vulnerability assessment framework into local and national management processes for managing natural resources.

2 Introduction to vulnerability assessment

2.1 Definition

The Intergovernmental Panel on Climate Change defined and explains vulnerability as follows (Watson et al 1996):

> Vulnerability defines the extent to which climate change may damage or harm a system. It depends not only on a system's sensitivity but also its ability to adapt to new climatic conditions.
>
> Sensitivity is the degree to which a system will respond to a change in climatic conditions (eg the extent of change in ecosytem composition, structure, and functioning, including primary productivity, resulting from a given change in temperature or precipitation).
>
> Adaptability refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or anticipation of changes in conditions.

In recent years, scientists, researchers, environmentalists, managers and leaders have formulated guidelines for sustainable utilisation and conservation of wetlands in the Philippines (eg Calumpong et al 1997, Magsalay et al 1989a,b, Davies et al 1990). This reflects the committment of the Philippine government to conserving the country's remaining coastal resources.

2.2 Historical background

In the early 1970s, there was growing concern in the global scientific community about the greenhouse effect and the resultant increase in atmospheric temperature. Thus, global warming was suspected to induce the melting of polar ice caps, thereby increasing sea level (Watson et al 1996). These changes coupled with the occurrence of El Niño phenomenon and other climatic disturbances encouraged the international community to convene the First World Climate Conference in 1979. It was during this conference that the World Meteorological Organization and the United Nations Environment Program conceived the World Climate Program. This research program ushered in the creation and the eventual ratification of the Montreal Protocol in 1988, which is aimed at reducing the levels of ozone and carbon dioxide in the earth's atmosphere. In the same year the Intergovernmental Panel on Climate Change (IPCC) was convened (Houghton et al 1990). At about the same time the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) sponsored the Greenhouse 1988 Conference, Planning for Climate Change (Pearman 1988).

The IPCC was given the task of assessing the scientific data related to climate change and its impacts on the environment, society and economy, and formulating strategies to manage the greenhouse effect. In 1990, a group of experts from the IPCC was created to develop and assess a common methodology or approach for coastal vulnerability assessment, which would be acceptable and applicable worldwide. The initial methodology was conceived at the first meeting (IPCC & Coastal Zone Management Subgroup 1991). Two years later a meeting was convened in Venezuela where case studies from participating countries were reported applying the vulnerability assessment framework (Houghton et al 1992). The report from this meeting was presented during the Earth Summit in 1992 in Rio de Janeiro, and was accepted as the basis for Agenda 21, Chapter 17 of the United Nations Conference on Environment and Development (UNCED) on matters concerning the oceans and coasts.

Agenda 21 requires countries to 'cope with and adapt to potential climate change and sea level rise including development of a globally accepted methodology for coastal vulnerability assessment, modelling and response strategies, particularly for priority areas such as small islands and low lying coastal areas' (Houghton et al 1990). The common methodology has been applied in many countries. Australia was one of those that first used and assessed the applicability of the methodology (Kay & Waterman 1993, Waterman 1996) in the Alligator Rivers Region, which incorporates Kakadu National Park, in the Northern Territory (Bayliss et al 1997).

In January 1991, Manila hosted a regional workshop on Climate Change and Vulnerability and Adaptation in Asia and the Pacific which was attended by experts from 20 countries and territories. Other workshops were also conducted in Africa, Europe and Latin America. In 1992, the Philippines Inter-Agency Committee on Climate Change (IACC) was created and was co-headed by the Department of Science and Technology and Department of Environment and Natural Resources. Its function was to address the various issues of climate change and to implement the Philippine Strategy for Sustainable Development. A national symposium on Climate Change was held in Manila in October 1998. The outcomes of the symposium included the identification of three major sectors as sensitive to climate change; water resources, agriculture and coastal resources (Perez 1998).

3 Approach of the assessment

3.1 Overview

The approach used in this report followed the common methodology of vulnerability assessment based upon that devloped by the IPCC-Coastal Zone Management Subgroup (1992) and modified by Waterman (1995) and Bayliss et al (1997). The approach focused on the existing environmental changes resulting from both human activity and prevailing climatic conditions. These were evaluated based on published scientific data on coastal attributes, climate model predictions, perceived forcing factors, relevant policies and regulations, management plans and mitigating measures applicable to Olango Island. The generalised assessment framework is outlined in figure 1.

The framework included several activities:

1. Identification of the study site.
2. Search of secondary information on climate change and sea level rise predictions on global, regional and localised scales.
3. Literature inventory and profiling of the biogeophysical and socio-economic and political attributes of the island.
4. Identification of perceived forcing factors and their impacts.
5. Assessment of the vulnerability of the various attributes to both current forcing factors and climate change and sea level rise.
6. Identification and formulation of response strategies and monitoring requirements.
7. Identification of information and research gaps.

3.2 Data sources

Published scientific papers, reports, unpublished manuscripts, workshop and symposium papers, management plans, master plans, maps, aerial photographs, and tide tables that were solicited from the following agencies, offices and universities were the main sources of information in this report:

- Department of Environment & Natural Resources, Region 7 and Cebu City (DENR-Region 7)
- Department of Agriculture (DA)
- Department of Public Works and Highways (DPWH)
- Philippine Tourism Authority (PTA)
- Philippine Coast Guard (PCG)
- Philippine Atmospherical, Geophysical and Astronomical Services Administration (PAGASA), Mactan and Manila
- Lapulapu City Government
- Local Government Units, Olango Island
- Cebu Provincial Government
- Mines and Geo-Sciences Bureau (MGB).

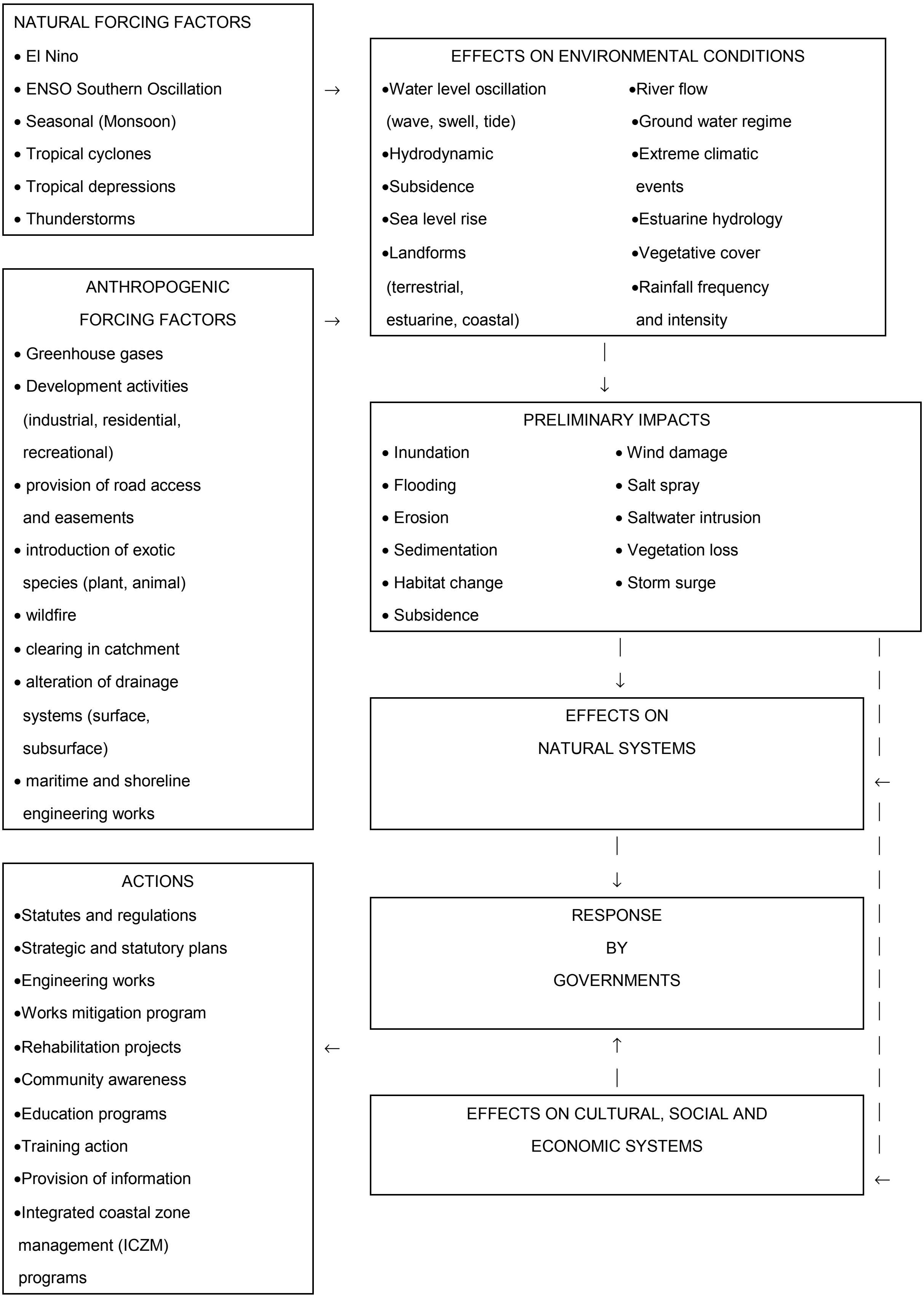

Figure 1 The framework used in the vulnerability assessment (after Bayliss et al 1997)

- Silliman University (SU)
- University of San Carlos – Marine Biology Section (USC-MBS)
- University of San Carlos – Water Resources Center (USC-WRC)
- Coastal Resource Management Project (CRMP)
- National Mapping and Resource Information Administration (NAMRIA)
- Save Nature Society (SNS)
- Ninoy Aquino International Airport (NAIA)
- Environmental Research Institute of the Supervising Scientist (***eriss***), Jabiru, Australia
- Wetlands International–Oceania (WI-Oceania), Canberra, Australia.

3.3 Activities

A workshop on the vulnerability of Olango Island to climate change and sea level rise was conducted on 8–9 December 1998 at Mactan Island to identify issues that were specific to the island, provide further, specific information towards the vulnerability assesment, and formulate management strategies to address the issues (Vulnerability assessment of major wetlands in the Asia-Pacific region 1999). The output of the workshop forms an integral component of this report.

A number of support activities relevant to the vulnerability assessment of Olango were undertaken, including:

- Monthly monitoring of birds of Olango Island.
- Validation of identified threats, disturbances and perceived anthropogenic forcing factors.
- Presentation of the vulnerability assessment to the Association of Barangay Councils, Lapulapu City.
- Identification and validation of additional islands/sites deemed vulnerable to climate change and sea level rise.
- Consultation with the Barangay (local council) communities on vulnerability and proposed measures and responses.
- Conference with the Marine Biology Section of the University of San Carlos on the vulnerability of the flora and fauna of Olango Island.

4 Climate change and sea level rise

4.1 Definition

Climate is an environmental condition where all physical and chemical attributes interact with each other producing a local environmental temperature, humidity and rainfall peculiar to a particular region or place. The IPCC (1994) defined climate as:

> the summation of all interacting atmospheric processes and weather conditions affecting a locality. The atmosphere is subject to natural variations on all time scales, ranging from minutes to millions of years. However vulnerability assessment is currently considered in the context of variation in climate that is expected to result, or has resulted from human interference with atmospheric processes.

Any decrease or increase in the magnitude of the climatic factors is deemed within the bounds of climatic change.

4.2 Concepts of climate change

A number of ideas and concepts have been proposed to explain the causes of climate change. One such concept is the greenhouse effect resulting from the accumulation of carbon dioxide, methane and other gases. Human activities for the past one hundred years or so have resulted in increased levels of many gases, primarily carbon dioxide, methane, chlorofluorocarbons and nitrous oxide. These are better known as ‘greenhouse gases’ and tend to warm the atmosphere in a process known as ‘greenhouse effect’. In the Philippines, the most important effects of climate change are expected to be on sea-level rise, intensification of typhoons and the El Niño Southern Oscillation.

IPCC (1992) summarised the ‘greenhouse gases’ process as follows:

> The earth absorbs radiation from the sun. This is then redistributed by the atmosphere and ocean, and re-radiated to space. Some of the thermal radiation is absorbed by the greenhouse gases including water vapor and re-radiated in all directions. The result is the surface loses less heat and stays warmer. This phenomenon is known as the greenhouse effect. Any factor which alters the radiation received from the sun or lost to space and the redistribution of energy within the atmosphere and between the atmosphere, land and ocean will affect climate. Increased greenhouse gases will reduce the efficiency of the earth to cool and will tend to warm the lower atmosphere and surface. Any changes in the radiative balance of the earth, including those due to increase in greenhouse gases or aerosols will tend to alter atmospheric and oceanic temperature and the associated circulation and weather patterns.

Changes in the levels of greenhouse gases and aerosols are projected to cause regional and global changes in climate and its parameters, such as temperature, precipitation and sea level (IPCC 1992).

4.3 Predicted climate change scenario

4.3.1 Global and regional

To predict climate change is not as ‘simple’ as predicting the weather in a television news report, but rather its methodology utilises quantitative and qualitative data that are analysed to produce a scenario. Pittock (1993) describes a climate change scenario as ‘a description of a possible future climate based on a number of assumptions including emission rates, model sensitivity and regional patterns of climate. Scenarios are used as reference to determine what will be the outcome if such events will take place. It is a picture of the future climate based on quantitative information.’

Modelling and predictions of potential climate change are being carried out in many developed countries based on an increasing number of scientific studies, which a group of experts from the IPCC have assessed in several reports since 1990. Some major predictions and conclusions of the IPCC (Houghton et al 1990, 1992; Watson et al 1996) related to global climate change are summarised below:

1. Greenhouse gas emissions will continue to increase during the next century and due to burning of fossil fuels, land use change and agriculture will lead to concentrations that are projected to result in changes to the climate.
2. Increases in greenhouse gases have resulted in warming of the surface of the earth.

3. Increase in global mean surface air temperature relative to 1990 of about 2°C by the year 2100.
4. Average sea level is expected to rise as a result of thermal expansion of the oceans and melting of the glaciers and ice-sheets.
5. Global prediction of sea level rise is between 8–30 cm by 2030 and 15–95 cm by 2100. Beyond 2100 the sea level will still rise.
6. Small island nations maybe forced to impose controls on the internal and international migration of human populations.
7. About 46 million people per year are at risk of flooding due to storm surge. A 50 cm sea level rise would increase it to 92 million; a 1.0 m sea level rise will raise it to about 118 million people.
8. Land losses prediction due to sea level rise are 6% for the Netherlands, 17% for Bangladesh and 80% for Majuro Atoll in the Marshall Islands.
9. The coastal area of Japan will be threatened with 50% industrial production being lost if sea level rises by 1.0 m. Ninety percent (90%) of the beaches in Japan will disappear.
10. Changes in precipitation and its frequency and intensity will affect the magnitude of runoffs, floods and droughts.
11. It is predicted that extreme events will change in magnitude and frequency more rapidly than the average (more hot days, more floods and dry spell).
12. El Niño and La Niña will continue to occur, resulting in droughts and floods.

Further predictions and conclusions related to regional, or local climate change in the Philippines (Perez 1998) include:

1. The temperature in Lake Lanao watershed in Mindanao will increase by 2–4°C (table 1).
2. A 3.1°C increase in temperature in Angat Dam in Northern Luzon (table 1).
3. A 1.0 m sea level rise by 2100 will inundate coastal areas in Manila Bay.
4. A 0.3 and 1.0 m rise in sea level will inundate about 2000 and 5000 ha of land in Manila, respectively.
5. Highly populated areas in Manila will experience severe storm surges.

Table 1 Changes in annual rainfall and temperature of Angat Dam and Lake Lanao in the Philippines, based on three global circulation models (Perez 1998)

Site	GCM*	Rainfall Ratio	Change in Temperature (°C)
Angat Dam	CCM	0.94	2.0
	UKMO	1.03	3.1
	GFDL	1.15	2.4
Lake Danao	CCM	0.95	2.0
	UKMO	1.15	2.6
	GFDL	1.25	2.3

* Global circulation models – UKMO: United Kingdom Meteorological Office; GFDL: Geophysical Fluid Diagnosis Laboratory; CCM: Canadian Climate Center Model.

4.3.2 Predicted climate change for Olango Island

The predicted climate change scenario for the Cebu region of the Philippines in the next century is based on the following predictions:

- A rise in sea level of 8–30 cm by 2030, and 15–95 cm by 2100 (Houghton et al 1990).
- An increase in mean global surface temperature of 0.1–0.5°C by 2010 and 0.4–3.0°C by 2030 (Whetton et al 1994; table 2)
- An increase in typhoon intensity by up to 20% that is linked to sea surface temperature, and increase in storm surges (Henderson-Sellars & Zhang 1997).
- A tendency for increased rainfall, intensity and frequency (Whetton et al 1994; table 3).

Table 2 Temperature (°C) change scenario for 2010 and 2070 (Whetton et al 1994)

	Year	
Region	**2010**	**2070**
Indonesia, Philippines, Coastal South and Southeast Asia	0.1–0.5	0.4–3.0
Inland South and Southeast Asia (not South Asia in June/July/August)	0.3–0.7	1.1–4.5
Inland South Asia in June – July – August	0.1–0.3	0.4–2.0

It is predicted that in areas that are affected by the south-west monsoon, particularly in the western part of the Philippines, the intensity of rainfall will not increase significantly up to 2010, but by 2070, there will be a tendency towards an increase in rainfall (table 3). In the eastern parts, however, which are greatly affected by the north-east monsoon, there will be no significant increase in rainfall up to 2010 but there will be an increase in rainfall intensity during both the dry and wet seasons by 2070 (Watson et al 1996; table 3).

Table 3 Rainfall scenario for 2010 and 2070, expressed as % change (Whetton et al 1994)

	Year			
	2010		2070	
Region	Wet season	Dry season	Wet season	Dry season
South-west Monsoon Region :	0	0	0 to 10	-10 to +10
India, Pakistan, Bangladesh, Philippines (western part) and Vietnam (except east coast)				
North-east Monsoon Region: Indonesia, Philippines, Vietnam, Sri Lanka, Malaysia	0 to -5	0	-5 to +15	0 to +10

The Philippines Atmospheric and Geographical and Astronomical Services Administration (PAGASA) has reported that the surface temperature in the Philippines has increased, while sea level has also risen by 2 cm from 1963 to 1993 based on tidal gauge readings in Manila Bay (PAGASA 1998).

Bengtsson et al (1995) suggested that there will be a decrease in the number of typhoons in the southern hemisphere but the distribution in the region will remain the same. Holland (1997) suggested there is a possibility that the intensity of typhoons may increase, particularly in areas where the sea-surface temperature can reach between 20–29°C. Henderson-Sellers and Zhang (1997) suggested that the maximum potential intensities of cyclones will remain the same or undergo an increase of up to 10–20%. Warwick et al (1993) claimed that even if intensity and frequency did not change, damage caused by such storms would be likely to increase simply due to the effects of sea level rise.

The Environmental Center of the Philippines Foundation (1998) reported that:

> temperature in East Asian seas are expected to increase by 1°C. The resulting enhanced evaporation and increased precipitation or rain will affect water salinity. The rain will wash more nutrients out to sea, which can be either good or bad for seagrasses and coral communities depending on the actual load. Increased erosion will alter nearshore areas and adversely affect the breeding and nursery function of the ecosystem. A rise in the sea level within the predicted range of 20 cm by the year 2025 is likely to be insignificant compared with human-induced influences on the coastal environment. Nevertheless, it will most likely harm the seagrasses and coral communities, which will be battered by more frequent and severe storms and wave surge. They will also suffer due to greater shoreline erosion, changes in dynamic coastal physical properties, and damage to shoreline protective structures and facilities.

4.4 Predicted impacts of climate change

Watson et al (1996) report that:

> sea level rise is the most obvious climate related impact in coastal areas. Densely settled and intensely used low lying coastal plains, islands and deltas are especially vulnerable to coastal erosion and land loss, inundation and sea flooding, upstream movement of the saline/freshwater front, and seawater intrusion into freshwater lens. Especially at risk are the large deltaic regions of Bangladesh, Myanmar, Vietnam and Thailand, and the low-lying areas of Indonesia, the Philippines and Malaysia. Socio-economic impacts could be felt in major cities, ports and tourist resorts; artificial and commercial fisheries; coastal agriculture and infrastructure development. International studies have projected the displacement of several million people from the regions' coastal zone in the event of 1 m rise in sea level.

Following are some conclusions drawn from the assessment made by the IPCC (Houghton et al 1992) on the information available for the Asian region, including the Philippines and Olango Island:

> Projected increase in evapotranspiration and rainfall variability will have a negative impact on the viability of freshwater wetlands resulting in shrinkage and desiccation. Sea level rise and increases in sea surface temperature are the most probable major climate change related stress on coastal ecosystem. Coral reefs maybe able to keep up with the rate of sea level rise but will suffer bleaching from higher temperatures. Landward migration of mangroves and tidal wetlands is expected to be constrained by human infrastructure and activities. Increased population and increased demand will put additional stress on water resource. Agricultural areas are vulnerable to episodic extreme events, floods, droughts, cyclones and El Niño phenomenon. Low-income rural populations that depend on traditional agricultural systems or marginal lands are vulnerable. Coastal lands are vulnerable. Sea level rise is the most obvious climate related impact. Densely settled and intensely low lying coastal plains, islands and deltas are vulnerable to coastal erosion and land loss, inundation, sea flooding and salt water intrusion. Socio-economic impacts could be felt in tourism resorts, commercial fishing, artisanal fishing, coastal agriculture and infrastructure. It is projected that several millions of people will be displaced assuming a 1.0 metre rise in sea level and the cost of response could be immense.

The various impacts of climate change and sea level rise on coastal areas and small islands including Olango may take the form of ecological changes, socio-economic damage and physical disturbances. Watson et al (1996) listed five impacts on various coastal resources that can be attributed to climate change and sea level rise (table 4).

Table 4 Climate related events that impact upon attributes of coastal zones and small islands (Watson et al 1996)

Attributes	**Climate Related Events**				
	Coastal Erosion	**Flooding Inundation**	**Siltation Intrusion**	**Sedimentation Changes**	**Storminess**
Human settlement	Yes	Yes			Yes
Agriculture		Yes	Yes		Yes
Freshwater Supply		Yes	Yes		
Fisheries	Yes	Yes	Yes	Yes	Yes
Financial Services	Yes	Yes			Yes
Human Health					Yes

In a report entitled *Local Action Plan on Climate Change for the Coastal Resource Sector*, Perez (1998) detailed ten impacts predicted to occur as a result of climate change (table 5).

Table 5 Predicted impacts of climate change on the various attributes of coastal zone (Perez 1998)

Attribute	**Predicted impacts**
Ecological	Redistribution of wetlands.
	Damage to coral reefs.
	Reductions in biological diversity.
	Wildlife extinction.
Socio-Economic	Loss of natural and man-made structures.
	Dislocation of population.
	Change of livelihood.
Physical and Chemical	Shoreline erosion.
	Saltwater intrusion.
	Change in salinity.

Some of the major points are outlined below:

- There would be an increase in erosion of beaches and cliffs due to the direct removal of materials by wave action.
- Direct inundation of low-lying islands can occur as they are submerged beneath the rising waters. This includes coastal wetlands that are vulnerable to rapid rates of sea level rise.
- High sea levels can cause saltwater intrusion into surface and groundwater affecting the amount and quality of potable water supply.
- Mangrove growth and other habitats of benthic organisms will be affected by changes in salinity.
- Sea level rise will increase the risk of flooding and storm damage. Vulnerability becomes higher with increase in storm surges and typhoon frequency and intensity.
- Wetlands and tidal flats may disappear where supply of sediments become inadequate, or where there is limited space for them to move inland changes in erosion and sedimentation characteristics will affect geographic features. The roles of wetlands and tidal flats as habitats will be diminished. Coral growth will be significantly affected by increased sedimentation, turbidity and water temperature.

5 Description of Olango Island

5.1 Geophysical attributes

5.1.1 Topography

Olango Island lies between latitudes 10°13’ and 10°16’ North, and between longitudes 124°02’ and 124°04’ East. It is located in the centre of the political jurisdiction of Region 7, Central Philippines. Around it are the bigger islands of Leyte in the east, Bohol in the south, and Mactan and Cebu in the west (figure 2). Associated with Olango are the islets of Caubian in the north-east; Camungi, Pangan-an, Caohagan and Nalusuan in the southeast; and Sulpa and Hilutungan in the south-west. The island is bordered by four bodies of water: the Camotes Sea in the north; Cebu Strait in the south; Olango Channel in the east; and Hilutungan Channel in the west (figs 3 & 6).

Olango is a low lying limestone island with an area of about 1030 ha. It is approximately 4 km east of Mactan Island and 15 km east of Cebu City. It is 3 km across at its widest part and about 6 km long. It has a tidal range of about 1.0 m and a low topographic relief with a maximum elevation of not more than 9.0 metres at its highest point, close to the centre of the island. The northern part of Olango is slightly elevated and has a rocky shoreline (plate 1). Other parts have a very gentle slope with a sandy coastline and small areas of flat and outcropping limestone. This slope allows a quick flow of tidal seawater exposing vast tidal flats during low tide and submerging the same during high tide (plate 2).

In the mid-western section of the island, adjacent to Santa Rosa, are two limestone depressions or bays very close to the shoreline (fig 3). The bay substrate is composed of sandy limestone and clay with open holes (figure 5).

5.1.2 Geology

Olango is a raised coral reef on top of another larger coral reef. It is composed of Plio-Pleistocene Carcar Formation and Quaternary Alluvium (DENR 1995). The Carcar Formation is composed mainly of shells, algae and other carbonate materials containing macro and microfossils. The Alluvium is found mostly in the coastal areas and made of calcareous sand from the weathering of limestone with fine to coarse grain sand and shell fragment (figure 4).

The south-eastern coast has a sandy substrate while the south-western isthmus has sharp limestone outcroppings. Both have a sandy shoreline.

On the southern part of Olango is a wildlife sanctuary with an area of about 920 ha. It is situated in a bay bordered by Barangay Sabang in the east; by Sitio Aguho in the north; and by the sitios of Basdaku and Bascoral in the west. The southern part of Olango Island, and the majority of the sanctuary, is composed of vast sandflat, flat limestone, seagrass bed and mangrove plantation (figures 4, 5 & 6).

5.1.3 Hydrology

There are no freshwater streams or rivers on Olango, but in the south of the island there are shallow channels through which seawater flows with the tides. Precipitation either evaporates or seeps into the sand to form a shallow freshwater lens.

The groundwater of Olango moves along the interconnected holes and systems of porous coralline limestone rock base in its substrate (Ligterink 1988). The groundwater recharges from June to December during the wet season. Close to the centre of the southern part of the island, water recharge is slow because of the poor permeability of the substrate to rainwater. In the southern part, near the sanctuary, the water lens extends far to the south because at low tide the sea level recedes farther. But between Aguho and Sabang, the groundwater level is much lower because of the sandy substrate in the area.

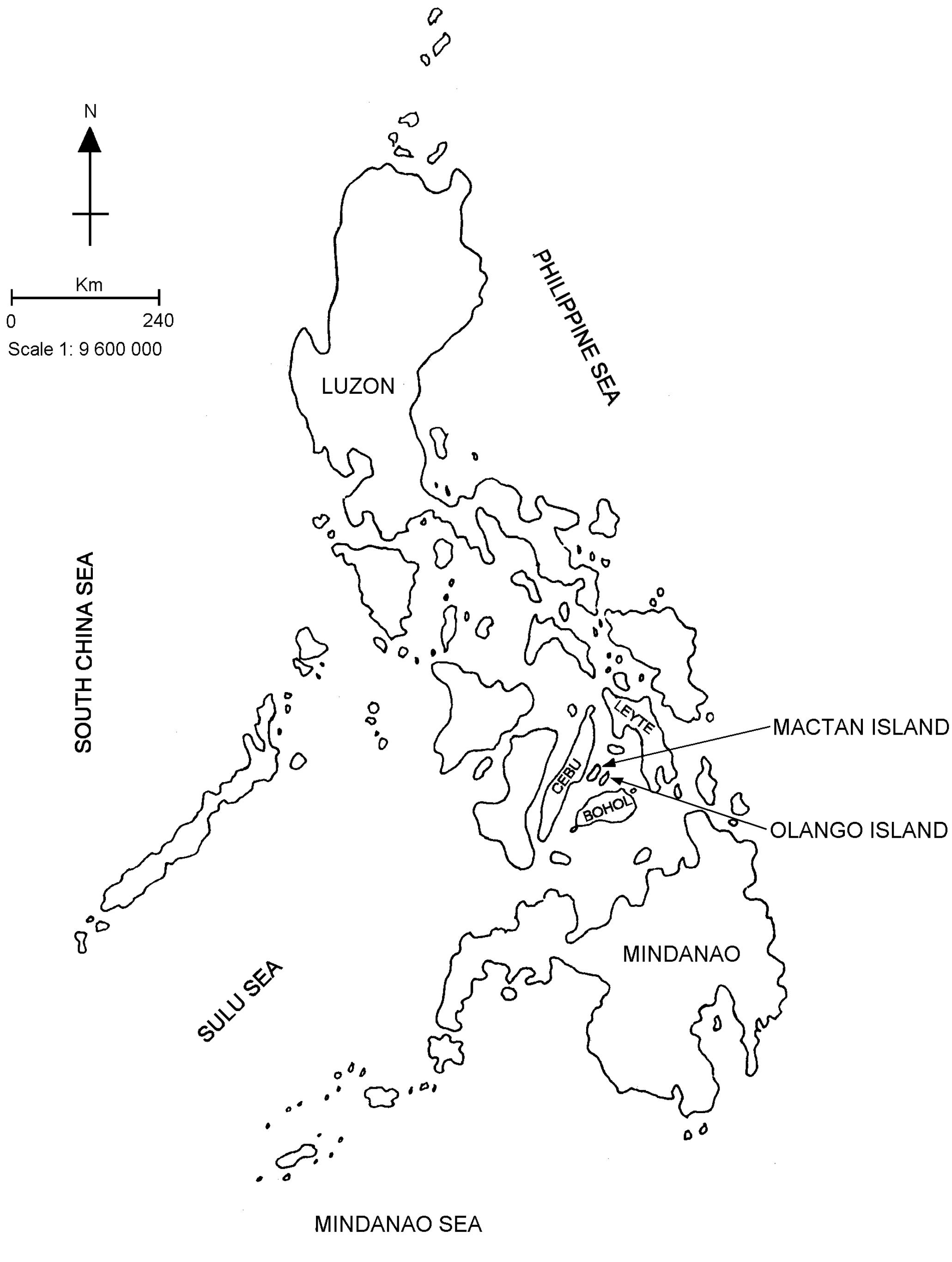

Figure 2 Map of the Philippines showing the location of Olango Island

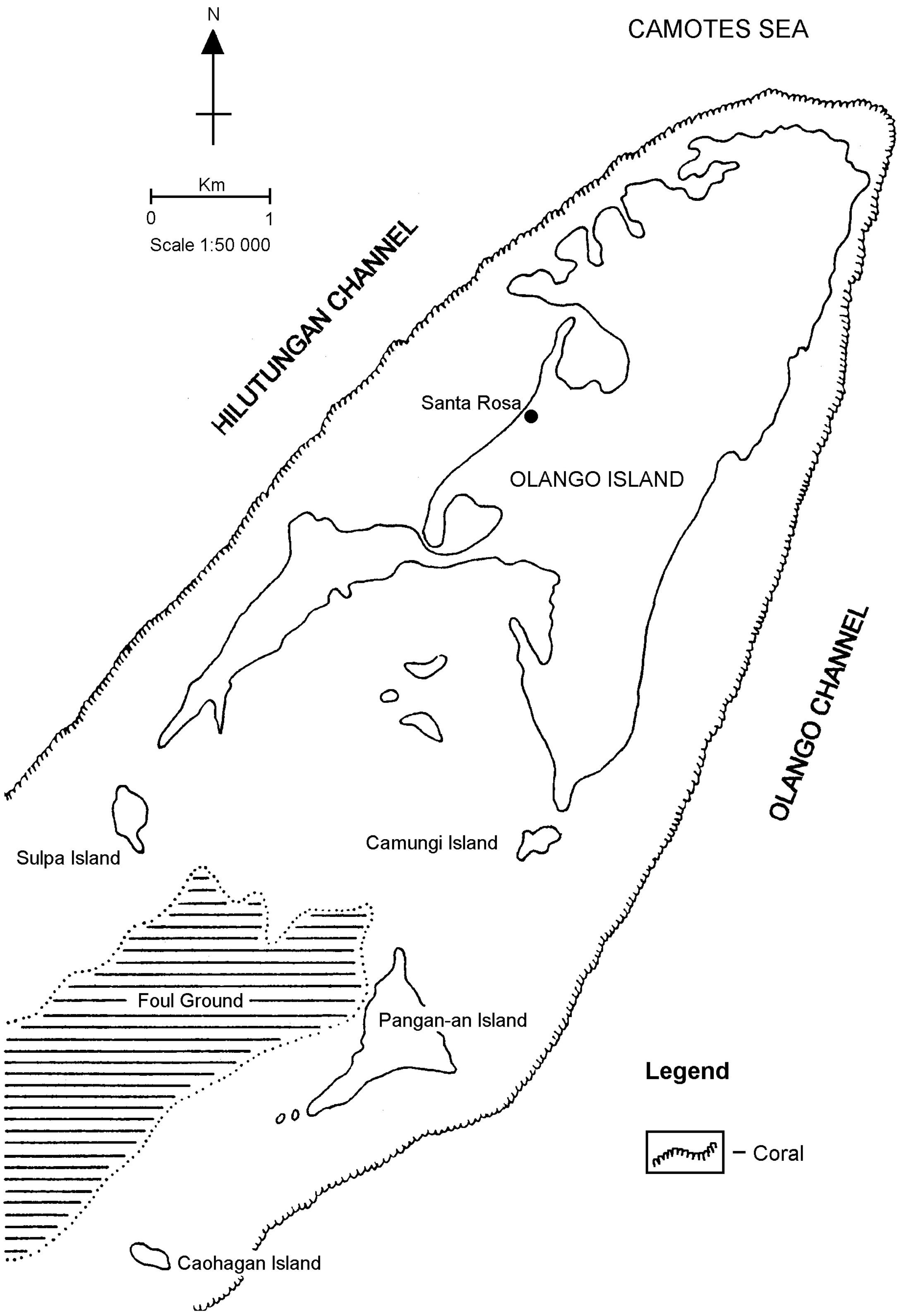

Figure 3 Map of Olango Island showing the major geographical features

Plate 1 Aerial photograph of Olango Island, looking southward, with the northern, rocky coastline in the foreground

Plate 2 Aerial photograph of the southern, sandy coastline of Olango Island, looking eastward. The Wildlife Sanctuary lies approximately within the delineated area. The jetty at Santa Rosa can be seen on the near (western) side of the island.

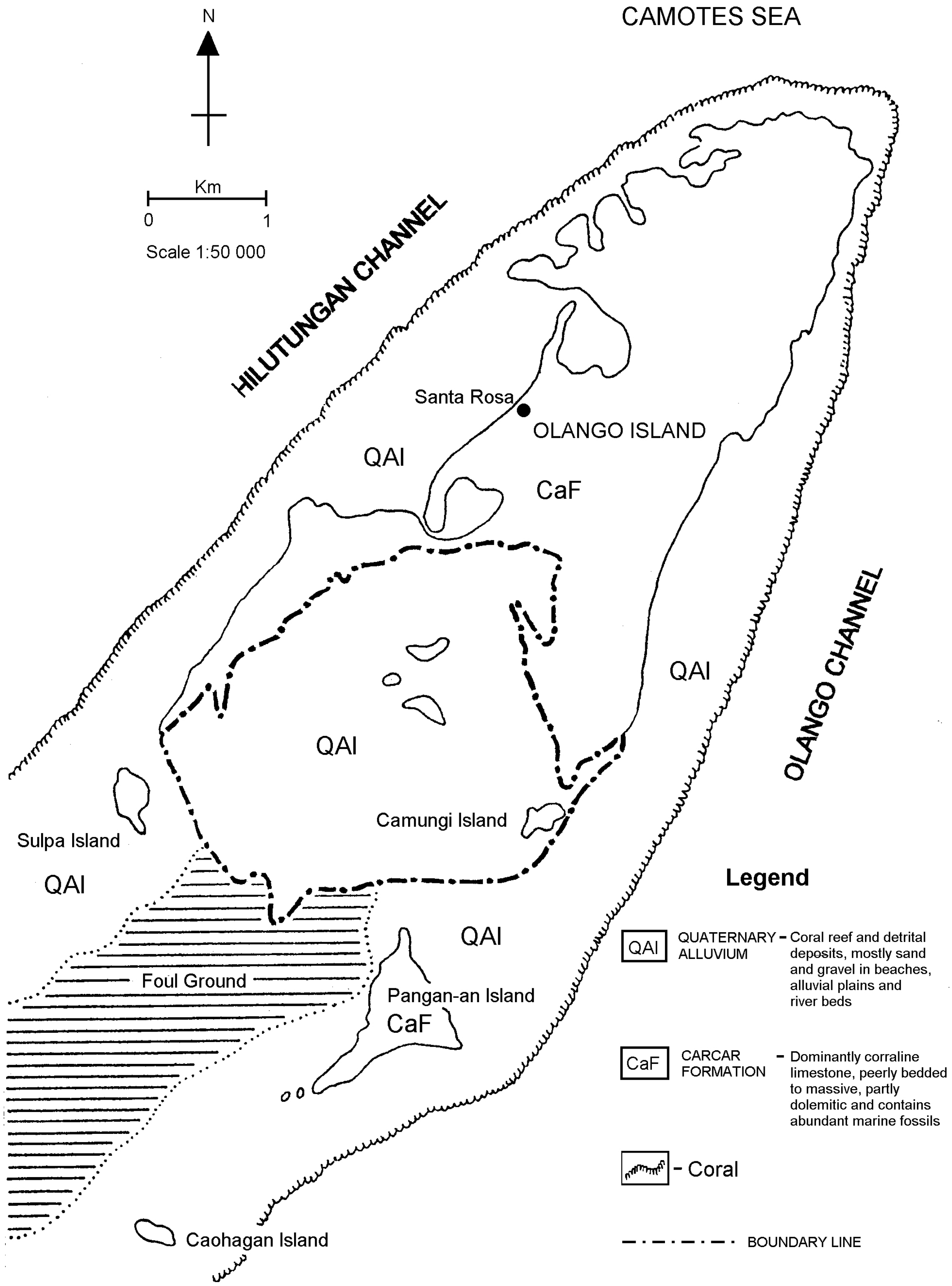

Figure 4 Geological map of Olango Island (Lapulapu City 1996)

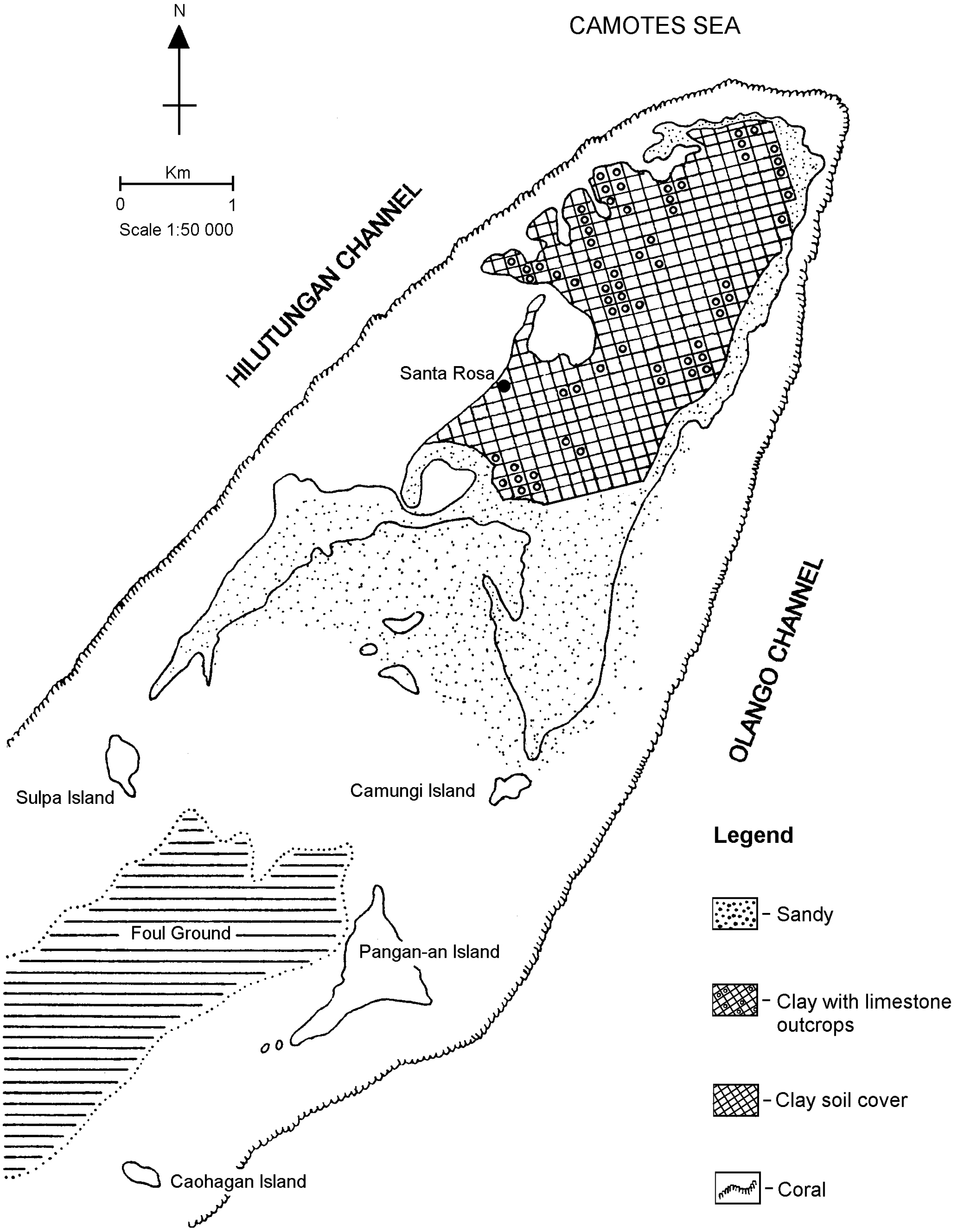

Figure 5 Soil map of Olango Island

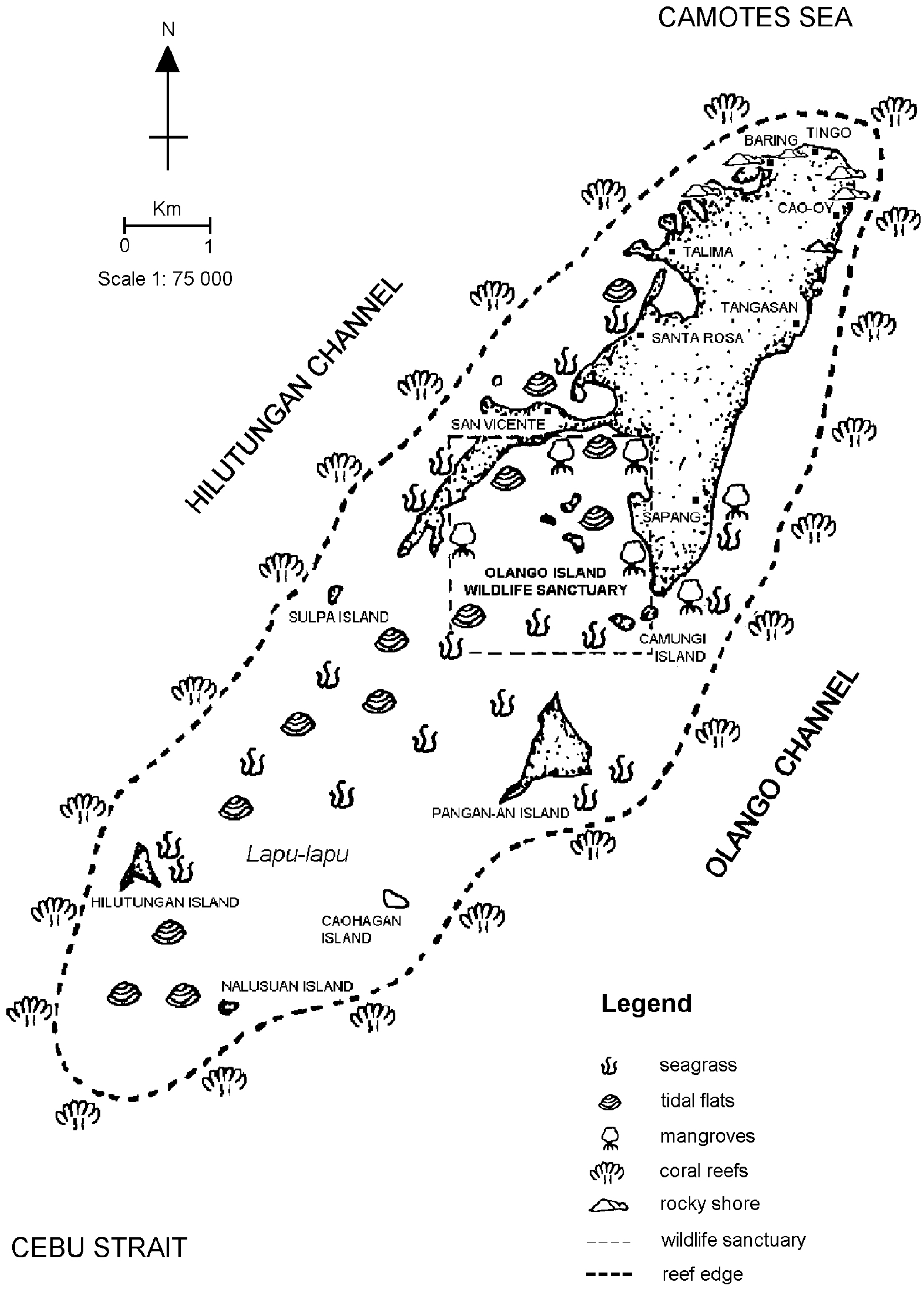

Figure 6 Map of Olango Island showing the distribution of various habitats (from Paras et al 1998)

In some areas, the groundwater extracted is brackish because of seawater intrusion particularly in the vicinity of the two bays. Freshwater wells are concentrated in the centre of the island although there are some that produce brackish water if there is over-extraction of freshwater. Measurements of water depths in the wells correlated with tidal gauge measurements show that freshwater is mixed with seawater during high tide from the force of the sea current and storm and when the wells are dug too deep.

5.1.4 Water current and tidal regime

The tidal regime around Olango is considered moderate with current measurements ranging from 0.19–0.36 m/s during peak flood tides and 0.09–0.23 m/s during ebb tide (Perez 1998). The water current along Olango Channel is non-reversing and flows in a south to south-eastly direction. In the Hilutungan Channel the water current is reversing, the direction being northerly during the flood tide and south-west during ebb tide.

The tidal range of Olango is about 1 m and as a result of its low topography, the island increases in area during low tide. Inundation is dependent on tidal fluctuation. During low tide only the shallow channels in the south of the island retain water.

From the dry months of February to May, spring tides occur during the day and neap tides at night. The reverse is true during the wet season from June to January. Highest tides occur in the early morning or late evening, fluctuating in the middle of the day, late afternoon or early evening.

From 1950–1969 and 1970–1989, the mean sea level in Cebu was measured at 1.728 m and 1.744 m, respectively, which are extremely high compared with the 23 October 1987 mean sea level of 0.714 m, 0.754 m and 0.770 m (tables 6 & 7). The latter measurements are lower as they only represent one measurement time.

Table 6 Mean sea level (m) for five stations in the Philippines (Perez 1998)

Station	Mean sea level (m)		40 year change
	1950–1969	1970–1989	
Manilla	2.228	2.541	+0.313
Legazpi	1.591	1.675	+0.084
Davao	1.887	2.020	+0.137
Cebu	1.728	1.744	+0.016
Jolo	1.993	1.988	-0.005

Table 7 Tidal ranges (m) observed at Olango Island on 23 October 1987 (Ligterink 1988)

Mean low tide	Mean high tide	Mean sea level
-1.437	0.10	0.714
-1.400	0.0109	0.754
-1.441	0.099	0.770

Table 8 presents the decadal trend in mean sea level rise in Cebu and four other stations in the Philippines (Perez 1998). There appears to be an increasing trend in the mean sea level rise from 1950 (-0.080 m) to 1989 (+0.069 m).

Table 8 Decadal trends in mean sea level rise (m) for five stations in the Philippines (Perez 1998)

Station	1950–1959	1960–1969	1970–1979	1980–1989
Manilla	-0.070	+0.083	+0.183	+0.142
Legazpi	+0.044	-0.071	+0.074	+0.165
Davao	-0.099	-0.024	+0.069	+0.165
Cebu	-0.080	0.078	+0.027	+0.069
Jolo	-0.090	-0.065	-0.020	+0.009

5.1.5 Soil

Olango has a very thin layer of topsoil. The soil is described as the Bolinao Clay type with a reddish colour underlain by Carcar limestone that can either be porous or cavernous. The intertidal substrate is a mixture of coralline limestone, soft, sandy mud and sand. On parts of Olango the limestone is exposed. Surface soil is created from weathering of limestone. Sediment in the channels near the western border of the sanctuary consist of coarse coralline sand and soft decaying vegetation matter of algae, seagrass and mangroves (SUML 1997, figure 5).

5.1.6 Climate and weather

Climate is the result of the interaction of precipitation, temperature, humidity, wind, sunlight and cloudiness over a certain period of time. The Philippines being located slightly north of the equator has a tropical climate, rain and temperature are the most important factors determining the weather.

Based on climatic charts for the Philippines, Olango has a Type III climate characterised by not having a pronounced wet season, but having a short dry season (Davies et al 1990). It is open to both south-west and north-east monsoons.

Olango has a tropical climate, hot and humid with mean daily temperatures ranging from 26°C, humidity ranging from 60–94% and daily rainfall ranging from 0 to 99 mm with an average daily rainfall of 4–5 mm. It is dry from February to May and wet in June until January with the heaviest rainfall in November and December.

Typhoons are climatic disturbances consisting of an eye of warm air that is surrounded by huge air masses that circulate counter-clockwise at low levels, and clockwise at the upper levels. The wind velocity increases towards the centre of the eye of the typhoon. Typhoons hit the country between June to December and form more often in the Pacific Ocean east of Bicol, Samar, Leyte and Surigao. At times, typhoons originate in the Pacific Ocean east of northern Luzon. Cyclonic storm and typhoons constitute the general climatic feature of the Philippines and approximately 19 typhoons pass by the country every year (PAGASA 1998). The strongest typhoons were super-typhoon Ruping in November 1990 and super-typhoon Besing in April 1994 (table 9).

The north-east and the south-west monsoons are the major wind systems that greatly determine the general climatic condition of the country. The south-west monsoon is formed by a low-pressure area over the northern part of Indo-china, while the high-pressure area over Celebes, Australia and New Guinea then blows to the country during the months of June to December. A high-pressure area forms the north-east monsoon over mainland Asia including Siberia and China, and blows to the country during January until March. During April and May, south-easterly and easterly winds prevail.

Table 9 Strongest typhoons to hit Cebu Province (1951–1995) (from PAGASA 1998)

Name of typhoon	Passage date	Maximum wind recorded (kph)	Typhoon diameter	Highest one day rainfall (mm)
Amy	Dec. 10, 1951	240	Unknown	195.3
Netang	Sept. 2, 1984	176	100	42.2
Undang	Nov. 5, 1984	90	200	70.6
Ruping	Nov. 13, 1990	205	250	276.1
Puring	Dec. 20, 1994	120	250	105.0
Besing	April 14, 1994	120	300	174.0
Goding	Dec. 21, 1994	60	100	16.0
Pepang	Oct. 28, 1995	90	100	166.1

The average annual precipitation for Olango is 1140 mm while the average annual evapotranspiration is 1100 mm (PAGASA 1998). For a period of 25 years from 1973–1997, the highest total annual rainfall recorded in Lapulapu City was 1860 mm in 1994. The driest year was 1987 with only a total annual rainfall of 859 mm, with March, April and May as the driest months with a total monthly rainfall of approximatelt 3 mm each. In 1997, the lowest total monthly rainfall of 30 mm was recorded in January, and the highest monthly rainfall was in July with 340 mm. The wet season is supposed to start during this month but did not; instead the monthly rainfall started to decrease and by December only 31 mm of precipitation was measured. This was actually the period when the El Niño phenomenon was influencing the country's climate. In 1998 the lowest total monthly rainfall of 1 mm was recorded in April, after which the rainfall increased to 443 mm in August, around the time when La Niña began to influence the Philippines (see section 5.1.7).

January appears to be the coldest month, with the hottest being May (PAGASA 1998). Night-time temperatures range between 18–20°C, and day-time temperatures between 28–32°C. Maximum temperature during the day may reach up to 38°C (Davies et al 1990). The lowest temperature recorded was 19°C in February 1976, and the highest temperature recorded was 36°C in May 1979.

5.1.7 El Niño–Southern Oscillation (ENSO)

This phenomenon has recently been the attention of many scientists worldwide because it has greatly affected the climate on a global scale (Perez 1998). El Niño was first detected as a large mass of water originating in South America which spread towards Asia, exhibiting changes in atmospheric pressure between the South Pacific and Indian Oceans. When there is low pressure in the South Pacific Ocean, there is high pressure in the Indian Ocean (Southern Oscillation). The El Niño is the warming of the ocean and the atmospheric disturbance is the Southern Oscillation or the ENSO. This phenomenon occurs every two to seven years and was observed to be intense until the increase of global warming.

The start of ENSO is signalled by the early onset of a prolonged dry season, very low precipitation, and weak monsoon rains.

5.2 Biological attributes

Olango is richly endowed with diverse natural ecosystems, which serve as habitats for various kinds of plants and animals (Paras et al 1998). Surrounding the island are mangrove forests, vast seagrass beds, tidal flats and coral reefs (figure 6).

5.2.1 Mangrove forest

The principal vegetation in the landward portion of the intertidal area around Olango is mangrove forest, with a total area of about 367 ha. A large area is found in the northern half of the sanctuary and some smaller patches are growing in the eastern and western shoreline. A mangrove plantation has been established on a seagrass bed on the southern border of the sanctuary.

A total of 33 mangrove species and associates have been identified in Olango (appendix 1). Barangay Tungasan has the highest percent mangrove cover of 84%, followed by Sabang with 72% (table 10).

Table 10 Percentage mangrove cover in some Barangays of Olango Island (CRMP 1998)

Area	Mangrove cover (%)
Santa Rosa	14
Talima	16
Tungasan	84
Sabang	72
San Vicente	36

In a 1989 study, the mangrove stand in the sanctuary had a maximum height of only 5.0 m and a minimum height of 0.6 m (Magsalay et al 1989a). *Avicennia lanata* attained a height of 3.0 m, while *A. officinalis*, *A. marina*, and *Xylocarpus moluccensis* reached a height of 2.0 m. *Lumintzera racemosa* and *Osbornia octodonta* attained a height of only 0.6 m. *Thespesia populnea* and *Terminalia catappa* attained a height of 5.0 m. The most dominant mangrove species are *Rhizophora* and *Osbornia* spp and both are found in the sanctuary (Magsalay et al 1989a). The stunted growth of most of the mangrove plants in the sanctuary is due mainly to the unsuitable sandy coralline substrate and overcutting for wood and forage by the local people. Under optimal conditions, *Rhizophora* species usually grow taller than 1.5 m.

The mangrove plantations outside the sanctuary respond very well to the planting spacing distance of less than 0.5 m. The trees are then subjected to thinning and rotational cutting to allow the trees to grow in diameter.

5.2.2 Seagrass beds

There are vast areas of seagrass beds around the island, but not in the northern part where the area for seagrass colonisation is limited (DENR 1995). In the southern part, just south of the vast sandy coralline flat of the sanctuary is a vast expanse of seagrass bed. It is in this area where a mangrove plantation was established in mid 1993.

A total of eight species of seagrasses and another 72 species of macrobenthic algae including Sargassum have been identified (appendix 2). *Cymodocea* and *Thalassia* are the most abundant seagrasses. The seagrass beds have been classified as altered and disturbed due to gleaning and shell collection with push nets.

5.2.3 Terrestrial vegetation

The terrestrial vegetation of the island includes patches of coconut palms, which are located relatively close to the shore, grasses and shrubs, which cover most of the island, and patches of trees in most of the Barangays except Baring, Tingo, Santa Rosa and Sabang (Ligterink 1988) (figure 7). A total of 16 species of terrestrial plants are cultivated and used as fuelwood in the island (appendix 3).

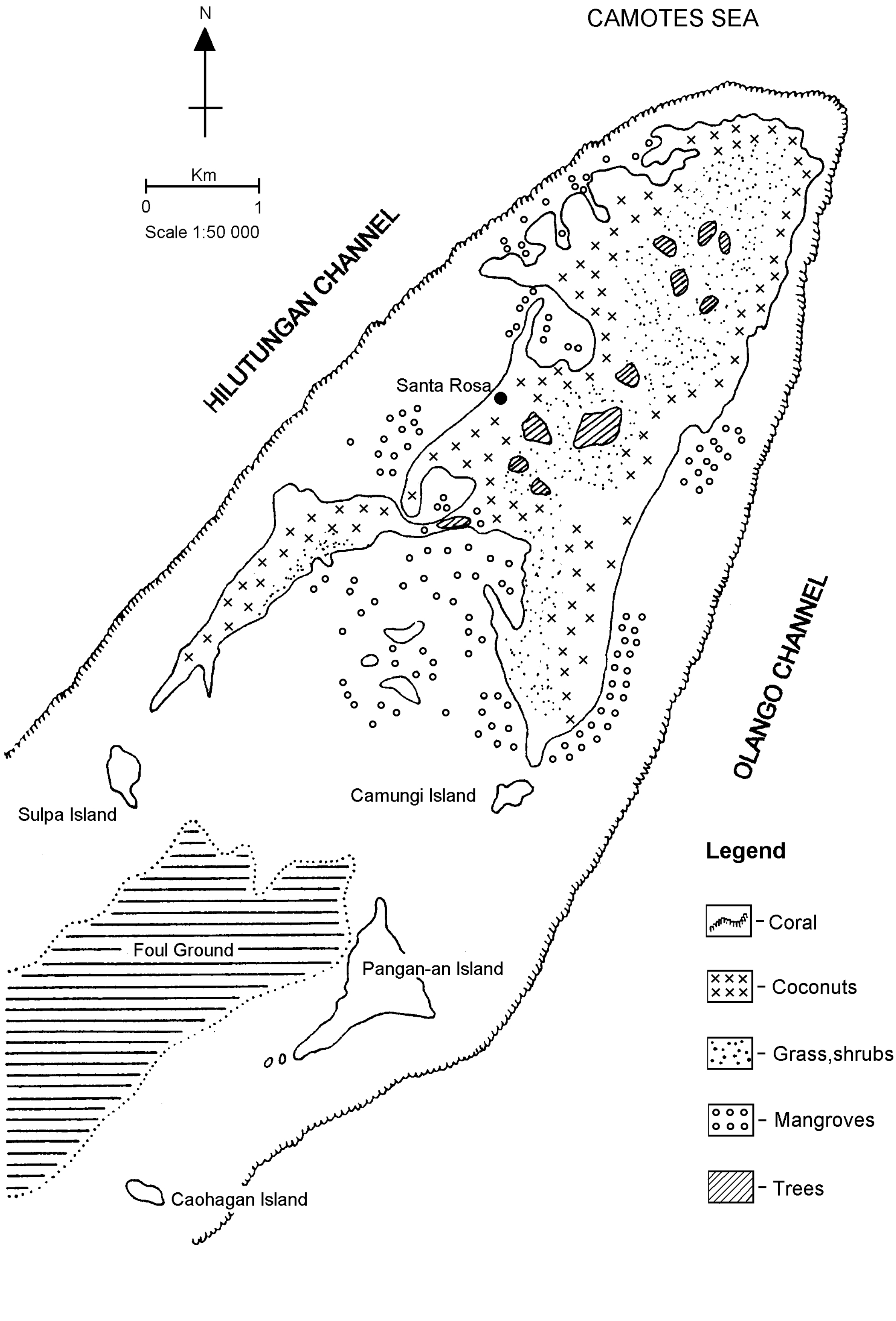

Figure 7 Vegetation map of Olango Island (Ligterink 1988)

5.2.4 Coral reefs

Coral reefs abound around Olango but not in the southern part where the sanctuary is located (CRMP 1998). The total reef area is estimated at 41.5 ha with a live coral cover of about 24%, which is considered a poor coral cover. A total of 117 coral species have been identified representing the reef building, non-reef building and soft corals (appendix 4). The seaward edges of the reefs in the deeper waters have a higher coral cover than the landward edges in the shallower waters. The reef cover in Olango was once considered fair, however, activities such as harvesting, and cyanide and dynamite fishing have led to the degradation of reef cover (SUML 1997). Barangay Sabang has the lowest coral cover of 9% while Santa Rosa has the highest live coral cover at 34% (table 11).

Table 11 Percentage live coral cover of some areas on Olango Island (CRMP 1998)

Area	Live coral cover (%)
Santa Rosa Site A	34
Santa Rosa Site B	10
Talima Site A	10
Talima Site B	20
Baring	15
Tinago	19
Cao-oy	13
Sabang	9
San Vicente Site A	27
San Vicente Site B	29

Coral reefs are used as fishing grounds, for aquarium fish collection, and as SCUBA dive and snorkeling sites. Coral heads are collected as decorative items. These issues are further discussed in section 6.2.2.

5.2.5 Aquatic fauna

A total of 23 families representing 137 species of fish have been identified around Olango, 33 species of which inhabit seagrass areas and the other 107 species are reef dwellers (SUML 1997) (appendix 5).

Of the three Barangays surveyed, San Vicente and Talima appear to support more species than Tungasan. Pomacentridae (damselfish) and the Labridae (masses) are the most abundant types of fish.

Species richness and fish density are highest at Barangay San Vicente and lowest at Hilutungan Island (table 12). The seagrass beds, coral reefs and the mangrove forest of Olango are important habitats for several macroinvertebrate species, some of which are economically important as food and as raw materials for the still craft industry.

A total of 63 species of macroinvertebrates have been identified in the sanctuary, representing 33 species of molluscs, 19 species of echinoderms, five species of sponges, four species of crustaceans and two species of cnidarians (SNS & WBS 1996). Brittle stars were most abundant followed by Nerites (appendix 6).

Table 12 Species richness and fish density in five reef sites on Olango Island and adjacent islets (SUML 1997)

Reef sites	Species richness (spp/500m^2)	Fish density (md/500m^2)
Tungasan	26	946
San Vicente	42	2140
Talima	37	1085
Pangan-an Island	27	1170
Hilutungan Island	27	357

In another study in Barangays San Vicente and Talima a total of 105 species of macroinvertebrates were identified representing 20 echinoderms, eight crustaceans and 77 species of molluscs (USC-MBS 1980; appendix 7).

5.2.6 Wildlife and birdlife

The terrestrial vertebrate fauna of Olango consists of one species of snake (*Lycodon aulicus*) four species of lizards including the monitor lizard (*Varanus salvator*) and the sail-tailed fin lizard (*Hydrosaurus postulosus*), a number of unidentified bats, and an estimated population of close to 50 000 shorebirds and seabirds during the peak migration months.

A total of 97 species of birds have been identified in various parts of Olango. The most researched area is the sanctuary where annual monitoring of birds is undertaken (PAWD-EMPAS DENR-7 1993). Of the total species, 48 are migratory, 42 are resident and the rest have uncertain status (Davies et al 1990) (appendix 8).

Olango Island has been considered one of the most important staging areas for migratory shorebirds in the Philippines, and it is for this reason that the southern coastal area of the island has been declared a sanctuary, the first and only Ramsar site in the country.

5.2.7 The wildlife sanctuary: values and benefits

The sanctuary is located in the southern part of Olango Island, bordered in the east by Barangay Sabang, Camungi Islet and Pangan-an Island; in the north by Barangay Santa Rosa, and in the west by Barangay San Vicente and Sulpa Island (figure 6). It has an area of 920 ha with both coralline limestones, and sandy and sand-silt substrates, which extend south where seagrasses, seaweeds and some coral formations are abundant.

The sanctuary consists of natural mangrove forests, vast intertidal flats, narrow and shallow water channels, seagrass beds, a patch of elevated ground planted with coconuts, and the newly established mangrove plantation. DENR-7 constructed a nature centre in the western section of the sanctuary that included a main building for the office and reception functions, and a bamboo boardwalk to the three strategically located observation hides.

There are very shallow areas linking the Sabang side of Olango to the southern islets of Pangan-an, Caohagan, Nalusuan and to Hilutungan. These are being used as foot bridges or trails by the residents of the three islets.

Olango became internationally known in the 1980s when bird surveys were conducted in major wetlands of the Philippines, with financial support from foreign agencies (Magsalay et al 1989, Davies et al 1990). Results show that the island supports a large population of migratory birds. Based on the criteria for listing sites as Wetlands of International Importance (the Ramsar Convention; table 13), Olango is an area of international importance for conservation. Thus, on 14 May 1992, the area was declared a wildlife sanctuary, and eventually, on 8 November 1994, the sanctuary was designated the first Ramsar site in the Philippines (DENR 1995).

Table 13 The Ramsar criteria for which Olango qualifies as a 'wetland of international importance' (DENR 1995)

Ramsar criteria*	Significant feature of Olango Island
Supports more than 1% (at least 100 individuals) of a flyway or biographical population of a species of waterbird.	The area supports more than 1% of the known population in the East Asian flyway, and up to 100 individuals of Chinese Egret.
Supports an appreciable number of rare, vulnerable endangered species.	The Chinese Egret and Asiatic Dowitcher are considered endangered species in the IUCN Red Data Book. A significant population of Chinese Egrets is present in the area.
It is of special value for maintaining the genetic and ecological diversity of a region because of the peculiarity and quality of its flora and fauna.	The area is a rich and diverse coastal habitat, including mangrove forest and supports a wide range of waterbird species.
It is of special value as the habitat of plant and animals at a critical stage of their biological cycle.	Olango is a nursery ground for many species of fish and prawns. It is a key staging and wintering area for migratory birds.
It is a particularly good example of a specific type of wetland characteristic of the region.	The extensive fringing sandy coralline, intertidal flats and the extensive mangroves are features not common in the Philippines. Olango is an intact example of a coastal wetland characteristic of coralline islands in the Indo-Malayan realm

* the criteria for listing sites as internationally important were revised in 1999 and reordered.

In the sanctuary, the mangrove forest confers a number of ecological and economic benefits to the island. During weather disturbance, the mangrove fringe around the island serves as a buffer against waves, strong water currents and winds. It is also a habitat to a number of important marine food items such as crabs, shells and other invertebrates. The elevated mounds and mangrove trees are the high tide roosting sites for many birds. Mangrove poles are used as firewood, fencing materials and house posts. They also serve as forage sources for domestic animals.

The seagrass beds are not only a habitat to many important marine organisms but also serve as an important feeding site for most wader birds. It is also a gleaning site for shells, crabs, sea cucumbers, sea stars, algae and fish.

The nearby coral reefs attract many tourists, skin and SCUBA divers. Corals are harvested in some areas. Fishing, aquarium fish and shell collection and lobster fry gathering are also carried out within the nature reserve.

5.2.8 RAMSAR site in the Philippines

Shorebird counts of up to 10 000 have been recorded on Olango (Davies et al 1990). Since then, the populations of these birds have become the main attraction for tourists on the island.

DENR (1995) and Magsalay et al (1989b) showed that the number of species recorded on Olango has increased from 42 species in 1987 to 97 species in 1995. More than half the species are observed every year. There are a number of species that are considered rare and threatened, and utilise the island either as a staging area, roosting or feeding site. These include the Asiatic Dowitcher (*Limnodromus semipalmatus*), Chinese Egret (*Egretta eulophotes*), Great Knot (*Calidris tenuirostris*), and the Far-eastern Curlew (*Numenius madagascariensis*).

Olango appears to be the most important site for the Asiatic Dowitcher in the Philippines (up to 45 birds).

Due to the importance of the sanctuary to migratory shorebirds, the site has been nominated for the East-Asian Australasian Flyway. Thousands of birds use this route as they migrate from the northern to the southern hemisphere during the winter migration, returning to the northern hemisphere during the summer migration (DENR 1998).

In a recent monitoring activity of DENR-7 in 1996 (A Mapalo, unpublished data), the total population of birds counted in the sanctuary was 18 962 (appendix 9).

5.3 Socio-economic attributes

5.3.1 Demography

In 1996, the island had a total population of about 22 324 distributed in eight Barangays. Santa Rosa with a population of 4787 is the most densely populated, followed by Sabang with a population of 3759 and Talima has a population of 3557. However, population density is highest in Barangay San Vicente with 34.44 individuals/ha, followed by Tingo with a density of 27.54 individuals/ha. Santa Rosa appears to have the least density with only 16.88 individuals/ha (table 14).

Table 14 Demographic data of Olango Island (CRMP 1998)

Barangay	Area (ha)	Population	No. of households	Population density (individuals per ha)
Santa Rosa	283.44	4 787	797	16.88
San Vicente	69.46	2 392	457	34.44
Talima	168.28	3 557	593	21.14
Tungasan	86.16	1 557	260	18.07
Sabang	195.28	3 759	627	19.25
Cao-oy	42.27	1 136	189	26.87
Tingo	96.28	2 652	442	27.54
Baring	91.44	2 484	414	27.16
Total	1029.61	22 324	3 779	

Studies show that the fertility rate of Olango is higher than 0.575 in terms of child/woman ratio (Fleiger 1994). Of the eight Barangays, Tungasan and Talima have the highest fertility rate. However, population growth surveys show that the island does not have a high population growth rate, and this is mainly due to the migration of labour age groups to the urban centres of Mactan and Cebu. Talima and Baring exhibited higher population growth rates of about 30%, because there was no net migration (Fleiger 1994).

Most of the families are the 'so-called' single families where no two families live together. Six appears to be the average family size (Remedio & Olofson 1988). The population of Olango has a very low level of education despite its proximity to the urban centres of Mactan and Cebu. About 70% have had some primary schooling but only 23% finished Grade six, and about 15% attended high school and only 20% tried college. About 1% had vocational training (SUML 1997).

There is one Barangay high school located in Santa Rosa, but elementary schools are found in most of the Barangays. Unfortunately, there is neither a college nor vocational school on the island. Most of those at labour age leave the island to seek employment. Those with some determination and ambition to succeed and the financial capacity, do attend college, either in Mactan or Cebu (Remedio & Olofson 1988).

In a recent interview of some 100 respondents from each Barangay in Olango, it appeared that the level of education of the islands has improved tremendously but a higher percentage of the population need to be encouraged to go to school (CRMP 1998). Generally, the population has attended grade school up to first year high school, but beyond that the numbers decrease dramatically (table 15).

Table 15 Educational profile of some Barangays in Olango Island (CRMP 1998)

	Barangay				
Educational Level	**Sabang**	**Tingo**	**Baring**	**Cao-oy**	**Tungasan**
None	4	3	4	60	50
Grade 1-3	20	17	12	20	50
Grade 4-6	48	22	31	20	0
Elementary Graduate	8	25	27	0	0
1^{st} – 2^{nd} year	12	6	4	0	0
3^{rd} – 4^{th} year	8	8	8	0	0
H.S. graduate	0	8	12	0	0
College level	0	8	4	0	0
College graduate	0	0	0	0	0
Vocational education	0	3	0	0	0
Total	100	100	100	100	100

Family income has been near or below the poverty line of Peso 4000 per annum, and this is far below the salary of those hired in Cebu or Mactan. Most families are generally poor and are used to living without the convenience of running water, bathrooms, and electricity. Most houses are made of bamboo, coconut lumber and nipa, and some are made of concrete with galvanised roofing. There are a few larger houses owned by government officials, aquarium fish financiers, commercial fish operators and those married to foreigners. Very few households have toilets (SUML 1997).

5.3.2 Livelihood

The people of Olango Island engage in a number of activities that provide them the needed income for survival. The main activities of the islanders are fishing, shell-craft, aquarium fish collection, lobster fry collection, rabbit-fish fry collection, seaweed collection, gleaning and shell collection. Some families are engaged in livestock and poultry raising, water selling, tricycle driving and boat hire. In some parts of the island, there are small boats that are loaded with shells, shell-craft, corals and some food items that are sold to tourists that go near the shore.

Fishing and fishing-related activities are major livelihood activities (CRMP 1998). The seagrass beds, coral reefs and waters around the island are the most important fishing grounds. Fishing is done almost daily in nearby areas and at times on the other islands of Mactan, Caubian, Bohol and Camotes. Fishing boats may simply be paddled or motorised and are used to carry fishing gear such as nets, hook and line, cyanide, dynamite, spear gun and hookah equipment. Fishing boats maybe rented or owned. In Cao-oy, about 90% of the fishermen own their boats (CRMP 1998).

Fishermen are classified as either ‘one day trip fishers’ for those who fish for a day or as ‘many day trip fishers’ for those who fish for several days in far away places like Palawan, Samar or Camotes. Studies show that about 83.8% of the fishermen are full time fishers, another 11.1% are part time fishers and fewer still are occasional fishers (SUML 1997). The majority of fishermen use cyanide and gill net fishing techniques, as they can yield more catch than other types of fishing (ie 200 kg/trip and 73.2 kg/trip, respectively). Hookah fishing can yield a gross income of 1.869 pesos/trip without considering the risk that goes with this type of fishing (SUML 1997).

Gleaning, or shellfish collecting, is an activity carried out around the island mostly by women and children while the male members of the family are out fishing. The importance of this activity cannot be overlooked because it provides both food and income for the family (SUML 1997).

Table 16 presents the annual average income in pesos of some respondents in the Barangays in Olango Island. In Barangay Cao-oy fishing appears to be the only livelihood in the community, generating an annual income of only Peso 12 192. In Barangay Baring, the community is engaged in more varied income generating activities including fishing and fishing-related activities, which have a combined annual income of Peso 59 585. In Barangay Sabang, business is the most lucrative occupation, generating an annual income of Peso 53 100. Employment also provided a yearly income of Peso 29 256. Fishing and fishing-related activities generated a combined income of Peso 28 050.

Table 16 Annual average income (pesos) of respondents in three Barangays of Olango Island (SUML 1997)

Livelihood	Baring	Cao-oy	Sabang
Fishing	27 840	12 192	17 940
Fishing-related activities	31 745	–	10 110
Salary	60 000	–	29 256
Business	27 000	–	53 100
Skilled Worker	14 700	–	16 320
Unskilled Worker	26 955	–	–
Farming	7 200	–	–
Others	–	–	2 640

The major fishing methods used in various Barangays in Olango include hook and line, spear fishing, cyanide fishing, blast fishing, bamboo traps and floating cages. Other fishing-related activities include abalone collection, shell collection, coral farming and ecotourism. Several types of fishing methods, and their respective catches, earning and use are outlined in appendix 10. Abalone collection appears the most lucrative form of fishing as it can yield an average daily earning of P100–160 with a catch per unit effort of 6–8 kg/day. This livelihood does not require as much capital from fishermen, simply time and labour. The least lucrative method is probably push net because it generally yields only Peso 14–21/day and an average catch per unit effort of 3–4 kg/day.

Families usually rent cultivated lots no bigger than a hectare. About 73% of the total land area is owned by 23% of the islanders. None of the families in Tingo and Baring own their lot. Three major crops are grown in Olango, namely coconuts, cassava and corn. Some 50% of the islanders are engaged in subsistence livestock and poultry raising (Remedio & Olofson 1988).

Other agricultural crops are cultivated but to a lesser degree and these include camote, banana, horseradish, okra, eggplant, tomatoes, ginger, squash, patola and bitter gourd. Ipil-ipil is also planted as a source of fuelwood and foraging (Remedio & Olofson 1988).

5.3.3 Infrastructure, transportation and communication

No large infrastructure exists on Olango Island, but there are two-storey buildings, churches, a small city hall, an emergency hospital and a jetty (more accurately this is a groyne but is referred to locally as a jetty).

The Santa Rosa Jetty is a very long solid structure with sides made of concrete and coral boulders. The jetty projects seaward from Santa Rosa, extending into the intertidal flat, seagrass bed and the coral reef edge. The jetty is constructed so that only two tricycles can pass at a time. It is a solid structure without provision for tunnels or culverts to allow water current to pass through from the northern to the southern side of the jetty, or vice versa.

The Nature Centre of DENR is constructed on low ground within the sanctuary, but it is elevated more than 1 metre above the ground. The boardwalk leading to the observation hides, though made of light materials, would probably last 5–10 years, but not until the predicted sea level rise of 1 metre by the year 2100. The boardwalk and the observation hide were established in areas with coralline limestone and sandy mud substrate. The prolonged submersion of the bamboo on wooden posts in seawater will lead to rapid decay and result in the weakening of the foundation of these structures.

The high school building in Santa Rosa is located at the very edge of the shoreline and can experience salt spray, particularly during high tides and storms and monsoons.

Olango is accessible by boat from Cebu City or at designated areas in Maribago and Dapdap on Mactan Island. The main jetty is in Santa Rosa, but there are other receiving sites in Baring, Tingo and San Vicente. The main mode of public transportation on the island is tricycle. There are bicycles although rarely are they used for public hire. A network of rough roads (about 21 km) links the various Barangays. Of the total road length, only 4.4 km is sealed.

There is no telephone system and the only communication link to Cebu or Mactan is through radio transceivers in some of the Barangay offices. The more affluent homes have their own cellular phones. About 44% have AM/FM radios, stereos, karaoke cassette players and television sets.

The Mactan Electric Company (MECO) supplies electrical power to the various Barangays of Olango Island, but only about 16% of households are served by the company. Power is made available only from 12 noon to 12 midnight. The power plant is located in Santa Rosa about 1 km from the shoreline. Street lighting is provided for in all Barangays.

In summary, Olango Island is still highly undeveloped in terms of infrastructure.

5.3.4 Freshwater supply

In a geo-hydrological survey conducted on Olango Island there was a general conclusion that the island has sufficient freshwater supply, particularly in the southern part between Sabang and Santa Rosa (Ligterink 1988, Walag et al 1988). This observation was based on the iso-conductivity and iso-potential map proposed for the island (figures 8 & 9). This freshwater lens is located in the Barangays of Tingo, Talima, Baring, Santa Rosa and Sabang. It was postulated by community members during the Olango Island vulnerability assessment workshop that the freshwater supply of Olango will be sufficient for the next 100 years if seawater does not intrude. How true this is remains to be confirmed by scientific studies (Ligterink 1988).

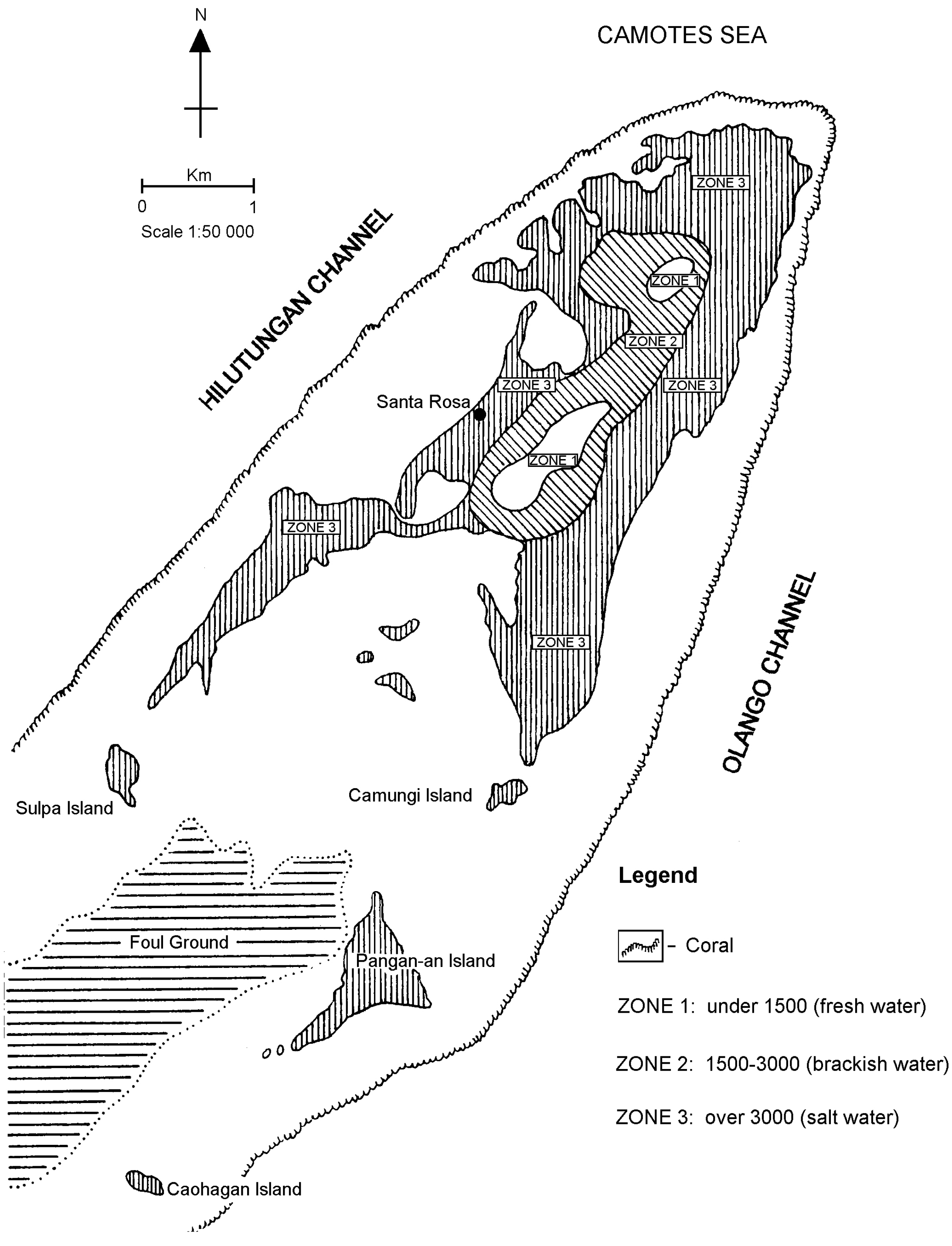

Figure 8 Map of Olango Island showing conductivity isobars (μS/cm) for groundwater based on well surveys (Walag et al 1988)

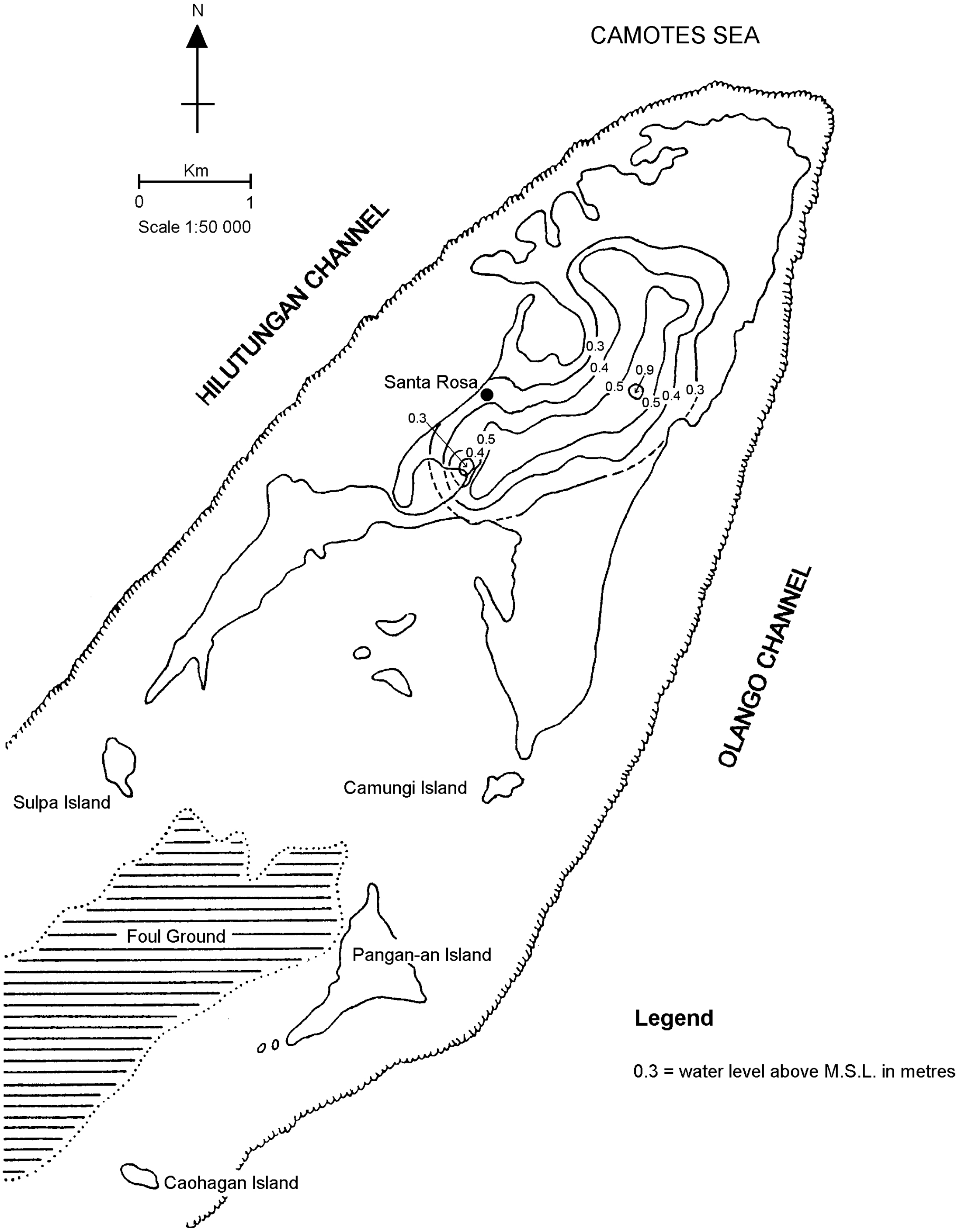

Figure 9 Isopotential map for groundwater on Olango Island (Ligterink 1988)

However, in the area around Sitio Aguho, freshwater over-extraction resulting in brackish water being collected has been observed. Figure 10 shows the location of existing water extraction facilities in Olango Island. At present, there are few settlements in the area directly above the freshwater lens. Maintaining this situation is important, and is discussed further in section 8. There are no streams or rivers on Olango with precipitation simply seeping through to the freshwater lens. However, because of its location and the small size of the island, this lens is threatened by seawater seepage from the nearby bays and wells (CRMP 1998). In a survey of 356 wells, only 31 extracted freshwater, with 54 and 271 extracting brackish and seawater, respectively (Walag et al 1988).

During the dry season, freshwater supply becomes scarce and people may be forced to drink brackish water. For those who have money, they buy freshwater at P3 per container of 20 litres of water. But for many, they have to walk to the source to collect water. To supplement their water supply, many households construct their own rainwater collectors in the forms of concrete or galvanised iron tanks. The scarcity of water supply is also a major constraint to tourism-related development.

5.3.5 Tourism

Olango was proclaimed a tourist zone and marine reserve in 1978, but until now the island still awaits full-scale tourism development. It has beautiful white sandy beaches that are ideal for recreation. A number of beach resorts are now in operation and provide the basic amenities for tourists such as food, freshwater, power and entertainment.

An estimated 2000–4000 tourists, both local and foreign, visit the sanctuary every year and this is expected to increase next year if promotional projects succeed. In addition to bird watching, tourist activities include photography and snorkeling. Eco-tours are being organised in coordination with the Association of Travel Agencies, Department of Tourism, Coastal Research Management Project and the Department of Environment and Natural Resources. A number of tourism establishments exist on Olango, but most are privately owned, including Tingo by the Sea, Malansyang Beach Resort and Baring Beach Resort.

5.4 Political attributes

5.4.1 Local political boundaries

The island is divided into eight component Barangays namely Tingo, Baring, Cao-oy, Tungasan and Talima in the northern half, and Santa Rosa, San Vicente and Sabang in the southern half (figure 11; Lapulapu City 1996). There are other sitios though like Aguho between Santa Rosa and Sabang; sitio Suba south of Sabang; and the sitios of Basdaku and Bascoral south of San Vicente.

5.4.2 Local government structure

A chairman and seven council members head each Barangay. The chairman represents the Barangay at the Association of Barangays Council (ABC) which elects a representative to the city council. The ABC meets on a monthly basis. The city of Lapulapu, which is headed by the mayor, has the political jurisdiction over Olango Island and its eight component Barangays. A city board or Sangguniang Panglungsod has the legislative function under which are various committees, which handle specific legislative concerns. The management of the coastal resource of Olango is under the Committee on Environmental Protection and Sanitation. Lapulapu City also has political jurisdiction over the sanctuary, but the administrative supervision is vested in the DENR-Region 7.

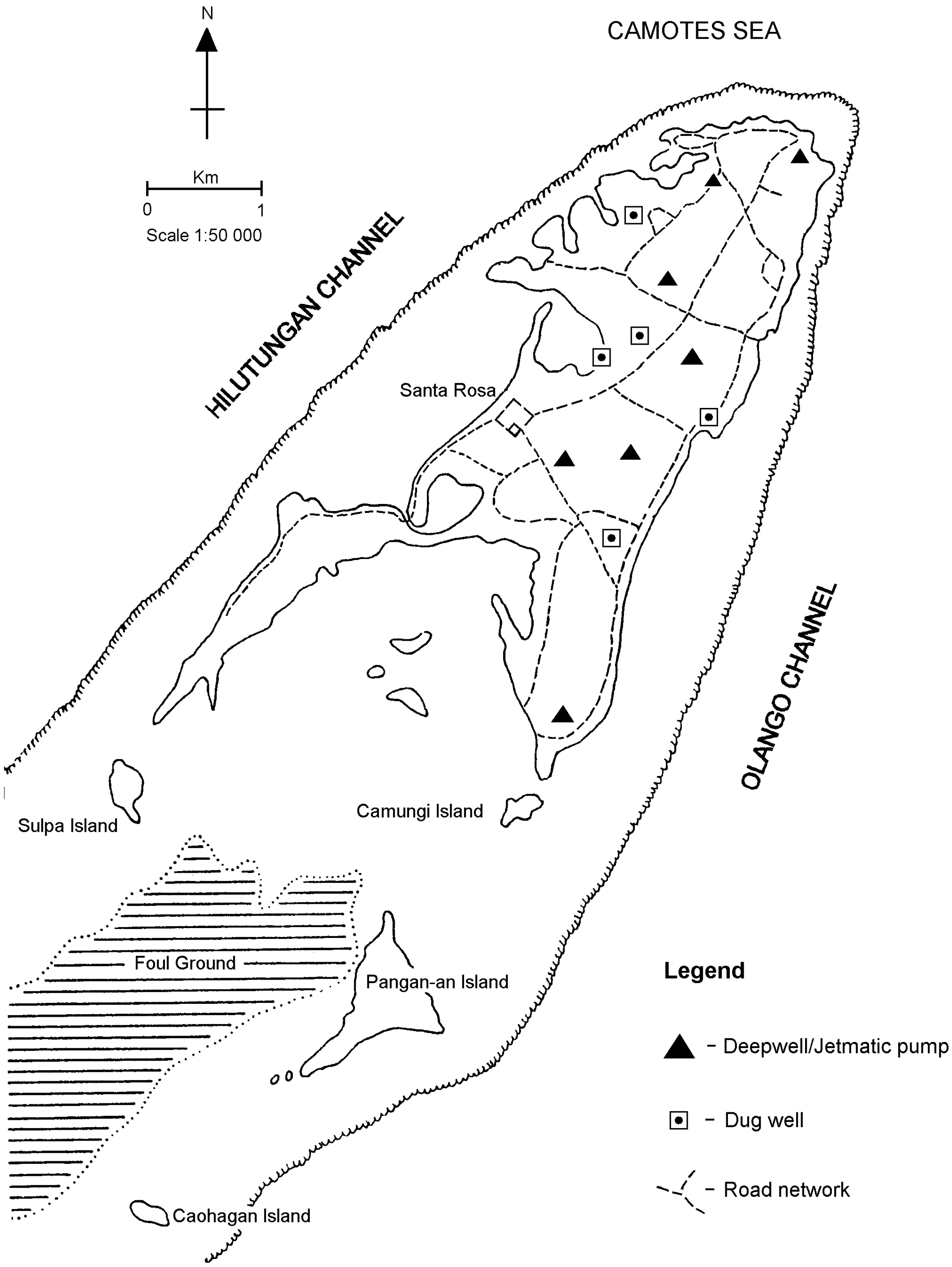

Figure 10 Location of existing water extraction facilities on Olango Island (Lapulapu City 1996)

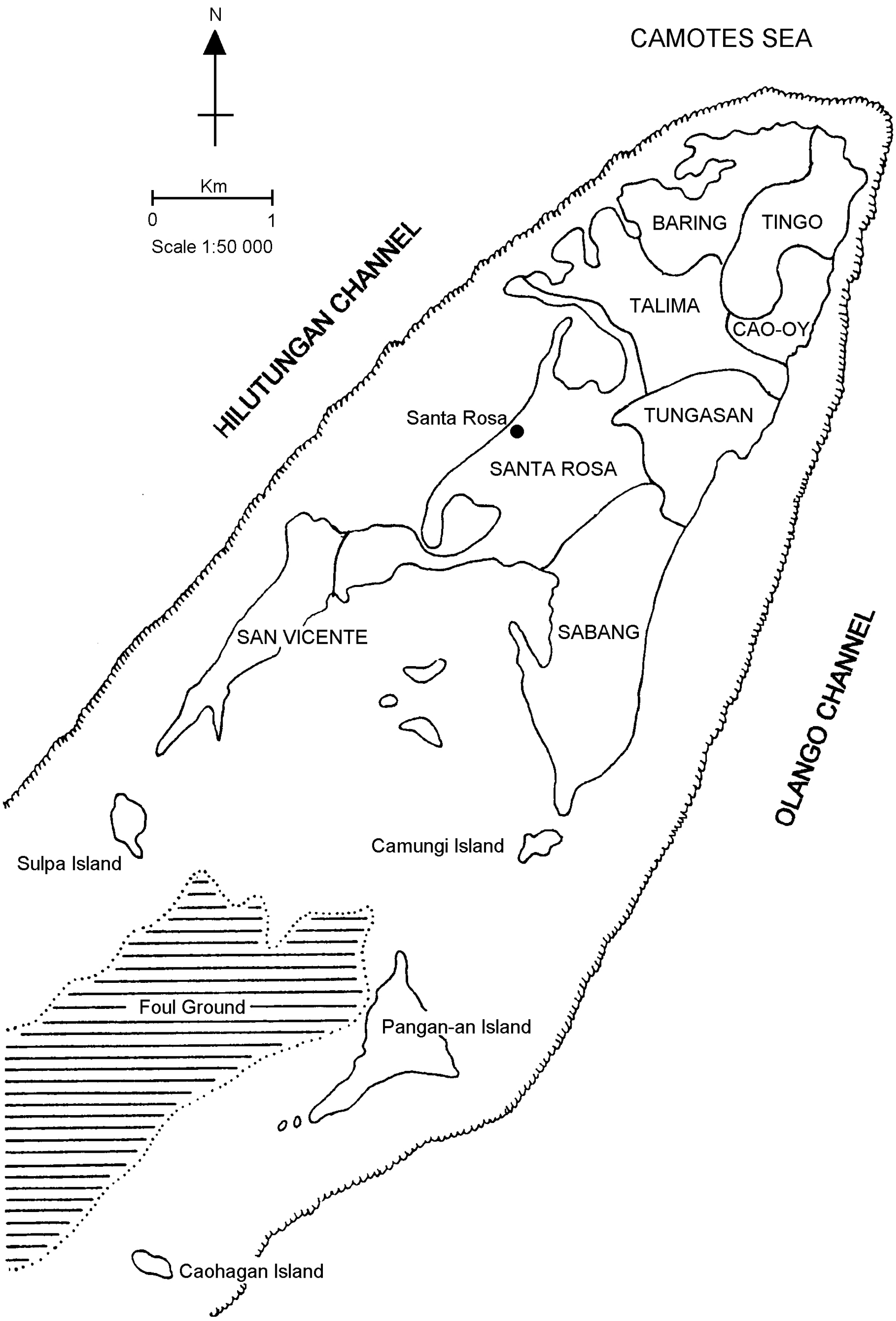

Figure 11 Map showing the Barangay political boundaries of Olango Island (*Mactan Integrated Master Plan* Lapulapu City 1996)

The Protected Area Management Board, with representatives from the various sectors of the island together with the Protected Area Superintendent from the DENR, constitutes the direct management and governing body of the wildlife sanctuary.

The authority to manage, protect and utilise the various coastal resources of Olango and the country at large are vested on several national and local agencies including the Department of Agriculture, Local Government Unit, Philippine Coast Guard, Philippine Navy and the Department of Justice. The health and social welfare needs of the islanders are under the administration of the Department of Health and the Department of Social Services and Development.

5.4.3 Non-governmental and governmental agencies

There are a range of non-governmental organisations (NGOs) that help in the local development of the natural and human resources of Olango. These are described below (CRMP 1998):

- The US-AID funded Coastal Resource Management Project (CRMP) has selected Olango as one of its 'learning sites' where a participatory coastal resource assessment is being implemented to identify strengths and weaknesses that are of importance for the sustainable management of the island. Positive results have been noted since the project started in 1996.
- The International Marine Alliance is involved in the management of collecting live coral fish including the training on the proper and sustainable techniques of collecting aquarium fishes. The same NGO noted the significant reduction of cyanide fishing in the island in its 1996 report.
- The Japan International Cooperation Agency (JICA) and the Wildbird Society of Japan provide funding and technical assistance to the on-going research and monitoring of the flora and fauna of Olango.
- The University of San Carlos–Water Resources Centre is studying the development of the two bays as important water reservoirs for the island. At present, a solar powered water pump supplies water to a cooperative that sells the commodity to the community. Another unit of the university, the Marine Biology Section, studies the marine resources, initiates alternative livelihood projects and conducts an education campaign on the dangers of hookah diving. One volunteer from the US Peace Corps is assisting the campaign.
- The Lihok Filipina Foundation, an NGO for women, trains women and minors in methods of fish and meat processing. This foundation was a recipient of funding assistance from the US Embassy Women's Club.

Other NGOs and people's organisations involved in the future development of Olango include the Save Nature Society, Philippine Wetland and Wildlife Conservation Foundation, Island Ventures Incorporated, Cao-oy Women's Group, Suba Women's Group, Fishermen's Foundation of San Vincente, Cao-oy Fishermen's Association, Cao-oy Consumers Cooperative and the San Vincente Water Association.

Several national agencies are involved in local development of Olango including the sanctuary. These include the Department of Environment and Natural Resources, Department of Tourism, Department of Agriculture, Department of Interior and Local Government, The Bureau of Fisheries and Aquatic Resources, the Philippine Coast Guard and Navy, Department of Health, Department of Social Services and Development, and the Philippine

Atmospheric, Geophysical and Astronomical Services Administration, which monitors climatic disturbances, temperature and rainfall of the country.

5.4 4 Bantay Dagat

Bantay Dagat is a task force whose main function is to protect and guard the coastal waters and resources of Olango against destructive forms of fishing and indiscriminate disposal of garbage. This became inactive a few years after its creation in 1979 but was revived again in 1987. The task force had many loopholes in its implementation, including the lack of police powers in apprehending illegal fishermen. The task force cannot arrest violators, and it is difficult to enforce and manage the confiscation of dynamite and other illegal fishing equipment. At present, Bantay Dagat is recognised as one vital force in the rehabilitation of the already damaged coastal zone of Olango Island.

6 Identification of current forcing factors and their impacts

Forcing factors are those natural and man-made processes, events, activities and even structures that can have negative, harmful or destructive effects on the biological, social, cultural, physical and political attributes of an island, ecosystem or habitat. These factors were identified from the above mentioned reference sources and/or elaborated during the consultation and workshop phases of the project. A summary of the workshop was prepared (Vulnerability assessment of major wetlands in the Asia-Pacific region 1999) and is available as an unpublished report.

6.1 Natural forcing factors

On Olango Island, the most important natural forcing factors are the monsoons, typhoons, storm surges and the El Niño phenomenon, as summarised below and in table 17.

Table 17 Summary of major impacts of existing natural forcing factors on Olango Island

Forcing factor	Impacts
Monsoons	Inundation, flooding, saltwater intrusion, coastal erosion, aquatic and terrestrial habitat damage, property damage
Typhoons	Inundation, flooding, saltwater intrusion, coastal erosion, aquatic and terrestrial habitat damage, property damage, business/livelihood interruption, loss of lives, loss of biodiversity
Storm surge	Inundation, flooding, saltwater intrusion, coastal erosion, aquatic and terrestrial habitat damage, property damage, business/livelihood interruption
El Niño	Property damage, freshwater shortage, loss of crops

6.1.1 Monsoons

Monsoons have both positive and negative effects for Olango. The south-west monsoon with its strong winds and heavy rain can greatly affect the southern and western coasts of Olango. The waters in these parts can become very rough particularly in the area south of the sanctuary and the foul ground, a shallow area with limited water and sediment movement, non-navigable by large boats. If the south-west monsoons coincide with the high spring tides, inundation and flooding may result. The strong winds result in storm surges that can erode the shoreline as the wave retreats back to the sea. The south-west monsoon has caused some coral damage in Carcar (Bagalihog & Redentor 1996).

The north-east monsoon strikes the northern and eastern coast of Olango. The northern coast has a slightly elevated rocky shoreline and impacts are generally limited to the effects of salt spray. At times inundation occurs along the eastern coast. Coral breakage in Bohol has been attributed to the north-east monsoon (Bagalihog & Redentor 1996).

A positive effect of the monsoons is that the rains recharge the groundwater and enable the community to collect rainwater.

6.1.2 Typhoons

Typhoons, with their wind velocities of 60–240 kph can be more devastating than monsoons. The continuous rainfall for several hours that tends to accompany typhoons can inundate and flood low as well as slightly elevated areas. This flooding can cause contamination of the freshwater lens. Tidal surges will result in erosion of the shoreline. The eastern coast of Olango is most often directly hit by typhoons. Property damage is always reported after a typhoon. In rare cases, there will be loss of lives. Super-typhoon Ruping in 1990 destroyed many houses in Talima. In 1960, Typhoon Amy hit Olango Island during high tide and water moved inland for about 15 m from the shoreline.

Strong winds and storm surges may result in the breakage of seagrass blades, seaweed thalii and branches or trunks of mangroves and other trees. This was observed in Baring and Tungasan. In Pangan-an Island, Bohol, and Carcar, Cebu, a high percentage of damaged corals have been attributed to storm surges and typhoons. Although there are no reports of this kind in Olango, it is still probable that typhoons can inflict serious damage to the reef areas of the island.

6.1.3 Storm surge

Storm surge can exert adverse impacts on Olango particularly when coinciding with typhoons. The strong and rushing water current can cause erosion and siltation along water channels in the south of the island (including the sanctuary) and shoreline.

6.1.4 El Niño

The El Niño phenomenon results in lower rainfall on Olango. This adversely affects ground water levels and salinity. This reduction may even allow seawater to intrude into the groundwater. During the El Niño of 1997, some wells dried up, while others produced brackish water. In Sabang most of the cultivated crops died because of a lack of water during the peak of El Niño.

6.2 Anthropogenic forcing factors

A number of anthropogenic forcing factors have been identified for Olango, these being overpopulation, unregulated and destructive forms of natural resource utilisation, infrastructure, tourism and the physical proximity of Olango to the urban centres of Cebu and Mactan. These are outlined below and in table 18.

6.2.1 Over-population

Foremost of these anthropogenic factors is the increasing population of the island, which is exerting extreme pressure. The higher the population the more is the demand for resources and space to meet the survival requirements. This factor has flow-on effects for all other forcing factors.

A corollary to overpopulation is the concentration of population and settlements along the coastal areas that exacerbate the problem of shoreline erosion. Subjecting the sandy shoreline to human activities, vehicles and other heavy objects breaks down the structure of the sand resulting in increased erosion.

Table 18 Summary of major impacts of existing anthropogenic forcing factors on Olango Island

Forcing factors	Impacts
Over-population	Increased demand for resources resulting in depletion (see remaining forcing factors), domestic pollution
Natural resource utilisation:	
Fishing	Loss of biodiversity, habitat destruction
Groundwater extraction	water shortage, saltwater intrusion
Mangrove cutting and forestation	Habitat destruction
Sand and coral extraction	Habitat destruction, erosion, inundation
Infrastructure	Habitat destruction, obstruction of natural water currents
Tourism	Habitat destruction, erosion, bird disturbance
Proximity to Cebu urban centre	Pollution, wildlife disturbance

The higher the population, the greater is the demand for freshwater. As the rate of extraction increases and the ground water is depleted each year so does the number of wells that become brackish.

6.2.2 Natural resource utilisation

Fishing is an activity that should be encouraged to improve the living standard of the people of Olango. However, if it involves illegal methods, and becomes destructive and unsustainable, then it should be stopped. In Olango, the most notorious and destructive fishing methods being practised are cyanide-fishing, blast-fishing and poison-fishing, all of which are illegal.

Cyanide-fishing uses sodium cyanide, a chemical that can disable, stun or kill not only the target fish but also other marine organisms. This method is used particularly for the collection of tropical aquarium fish. Two other chemical extracts, known locally as 'tubli' and 'lagtang', are used for the same purpose, and the destruction these method can cause is great. Coral reefs are particularly susceptible to cyanide poison.

Blast-fishing has occurred around Olango for several decades, with attempts to stop the practice being ineffective. Blast-fishing not only kills non-target marine organisms, but also destroys the habitat provided by the reefs and seagrasses.

Fine-mesh net fishing is another destructive fishing method because it catches almost everything from the bigger, mature fish to the smallest and immature fish. The nets are dragged over reef areas and seagrass beds breaking coral heads and uprooting seagrasses.

The unhealthy condition of the mangroves in Olango, particularly in the sanctuary, is attributed partly to over-cutting and the unsuitable sandy substrate. If over-cutting remains unchecked, mangroves will not be able to recover and may die. The loss of mangroves in Olango would also mean the loss of a buffer zone against strong waves and storm surges. Mangrove forestation in itself is a worthwhile undertaking if it is aimed at rehabilitating a denuded mangrove area, but if it is established on an ecosystem that is entirely distinct from it, the result can be just as devastating and can eventually lead to the loss of another habitat. Such is the case with the mangrove forestation project inside the sanctuary in the middle of a seagrass ecosystem. Should the mangrove plantation survive, the seagrass will die out resulting in the loss of feeding grounds for many bird species.

One of the major viable industries on Olango is shellcraft, because the raw materials are readily available and the demand is very high. However, to meet this demand, over-harvesting may occur and could become a problem. The use of push-nets over intensive areas of seagrass bed to collect shells not only destroys the seagrass, but also indiscriminately collects non-target species.

Coral and sand extraction are human activities that can destroy the stability of the coral reefs and shoreline. The short-term economic benefits are far outweighed by the negative environmental impacts. The coral reef habitat and associated marine organisms may be lost as a result of coral extraction. Sand extraction on the other hand increases the rate of soil erosion and shoreline retreat.

Sand extraction was occurring in Tingo, Baring, Sabang and San Vicente in the mid 1990s but has now stopped. Barangay Tingo has lost its sandy beaches because of sand quarrying, while in San Vicente the shoreline has retreated due to sand extraction.

6.2.3 Infrastructure

The only infrastructure that has a potential to cause some degree of damage to the coastal ecosystem is the 'jetty' in Santa Rosa. This structure is close to 2 km long and nearly 2 m wide and extends across the intertidal flat, seagrass bed and coral reef of Santa Rosa. The jetty has no culverts and completely inhibits the natural water movement along this section of the coast. The construction of housing on the island could also destroy natural habitat, however, there is little of this remaining anyway.

6.2.4 Tourism

Tourists and tourism facilities are recognised as having some negative influences on the coastal resources of Olango. While revenues are generated from tourism it can also cause coral damage, erosion, and habitat destruction and bird disturbance. Mooring of tourist boats more often over coral reef and seagrass bed can be damaging. In addition, some tourists bring air rifles and shoot birds.

6.2.5 Proximity to Cebu urban centre

Olango Island is just a few kilometres from the urban centres of Mactan Island and Cebu City, where human and industrial activities have intensified. These centres have a combined population of about 850 000 people. Tourism facilities, an export processing zone and other industries discharge pollutants into the air and water that may eventually reach Olango Island and degrade its immediate environment and critical habitats.

Mactan is the site of an international airport and a military air base. From time to time aircrafts hover close to the ground over Olango and in some instances land in the intertidal flat inside the sanctuary. The landing of aircraft may not disturb the vegetation but can cause disturbance to the wildlife, particularly the birds.

7 Assessment of vulnerability

In assessing the vulnerability of Olango Island to climate change and sea level rise, it is important to place it within the context of current vulnerability to existing coastal hazards (forcing factors). Thus, the first part of this section examines the current vulnerability of the various attributes of Olango to existing coastal hazards. Following this, the vulnerability to climate change and sea level rise is considered. In addition to using information from existing literature, outcomes arising from the three separate workshop discussion groups for biophysical, biological and socio-economic attributes were used to determine vulnerability (see summary in Vulnerability assessment of major wetlands in the Asia-Pacific region 1999). As a result, the following discussions for each of the above three attributes vary to some extent due to the adoption of slightly different approaches and priorities by the workshop discussion groups.

7.1 Vulnerability to existing forcing factors

7.1.1 Geophysical attributes

Olango Island is in the heart of Central Visayas. In certain months of the year monsoons and typhoons pass over the area with strong winds and large amount of precipitation. A summary of the vulnerability of Olango Island to existing natural and anthropogenic forcing factors is shown in table 19.

Table 19 Summary of the vulnerability of major geophysical attributes of Olango Island to existing forcing factors (- negative impacts, + positive impacts, 0 no impacts)

Attribute	Forcing factor						
	Monsoon	Typhoon	Storm surge	El Niño	Over-population	Coral/sand extraction	Ground-water extraction
Topography	0	–	–	0	0	–	0
Hydrology	+	+	–	–	–	0	–
Geology	0	0	0	0	0	0	0
Water current	0	0	–	0	0	0	0
Tidal regime	0	–	–	0	0	0	0

The north-east and south-west monsoons do not have significant impacts on the topography of the island. The monsoon rains and wind are not strong enough to change the shape and configuration of the island. The magnitude of soil erosion may not be sufficient to affect the topography of Olango. The positive impact of the monsoon and typhoon rains is the increase in the amount of groundwater due to precipitation. It was reported in the Olango Island vulnerability assessment workshop that no soil erosion has been observed in Barangay Baring after the north-east monsoon season.

During the north-east monsoon season from November to April, the northern portion of Olango is the most affected, including the coastal areas of Tingo, Baring, Cao-oy and Santa Rosa. Small-scale erosion may occur in the sandy beaches of Olango because of the onslaught of strong winds and amplified waves that are associated with the monsoons.

During spring tides, the high water level inundates the low-lying coastal areas. The wave surges also increase soil erosion as they break and retreat in the sandy shoreline. At low tide during the south-west monsoon, there is a localised attenuation of waves as they pass the ‘foul-ground’ just south of the sanctuary. At high tide, the monsoon winds may amplify the prevailing wave situation, which can greatly increase the rate of coastal erosion.

Olango is one of the many islands in the region affected by typhoons. Although typhoons occur as short weather disturbances from two to three days over a specific area, the devastation they can inflict can be immense. The winds can have a velocity of up to 160 km/h and are associated with heavy rainfall. Waves and currents generated by cyclonic winds can cause soil erosion particularly in areas with a sandy shoreline. Thus, the major portion of the southern half of Olango is most vulnerable to coastal erosion.

Typhoons are likely to cause destructive effects on the topography and tidal regime of Olango but a positive impact on the water storage capacity of the island. Typhoons are not known to have significant impact on the water current, but can bring about a shifting of sand and large scale erosion. These two processes may lead to changes in the topography of the island.

Monsoon and typhoon winds amplify the waves and render the coastal waters very rough and risky for small fishing boats. High tide waters surge over the intertidal areas reaching as far as the high grounds in the middle of the sanctuary. The south-western sections of the island are also affected by the wave surges over the coral reefs and seagrass bed up to the shoreline. Storm surge can also cause intrusion of saltwater into the freshwater lens.

Of the five geophysical attributes of Olango, the water regime is the most vulnerable to the El Niño phenomenon. The most obvious impact of El Niño of 1997 was the shortage of freshwater supply in almost all of the Barangays. In Baring and Santa Rosa, most of the wells dried up, while others only extracted brackish water. Even in Talima, which is the main source of freshwater, the water from the wells was brackish.

Several of the geophysical attributes of Olango are also vulnerable to a number of anthropogenic forcing factors, and these are summarised below and in table 19. The growing population of Olango is considered a forcing factor that can affect its geophysical attributes. Based on the assessment during the vulnerability workshop, it was concluded that over-population has had, and will continue to have an impact on the topography and particularly the hydrology of Olango. Population settlements and their associated activities cause soil erosion thereby altering the topography of the island, while the over-extraction of fresh groundwater for domestic and agricultural use is well documented. Excessive water extraction resulting from increased population demand can only exacerbate the serious problem of water shortage brought about by the El Niño phenomenon.

Island topography, being influenced by sand displacement and deposition, is highly vulnerable to sand extraction. For example, the sandy beach in Barangay Tingo disappeared many years ago due to large scale, illegal sand extraction. In addition, in Barangay Sabang, a portion of the shoreline retreated because of sand quarrying, while a beach resort in San Vicente experienced significant shoreline retreat because of sand extraction. The intertidal and subtidal topography of the island is vulnerable to coral extraction and blast fishing, with these activities already having significantly damaged the reefs.

7.1.2 Biological attributes

Table 20 presents a summary of the vulnerability of various biological attributes of Olango Island to natural and anthropogenic forcing factors. The anthropogenic forcing factors have been grouped as one general factor, namely *human disturbance*. In addition, the current extent of disturbance of each attribute is indicated.

Table 20 Summary of the vulnerability of major biological attributes of Olango Island to existing forcing factors (- negative impacts, + positive impacts, 0 no impacts)

		Forcing factor				
Attribute	**Extent of disturbance**	**Monsoon**	**Typhoon**	**Storm surge**	**El Niño**	**Human disturbance**
Fishery	very high	–	–	–	0	–
Corals	very high	–	–	–	0	–
Seagrasses	very high	–	–	–	0	–
Mangroves	low	–	–	–	–	0
Land Vegetation	very high	+/–	+/–	0	–	–
Sanctuary	low	–	–	–	0	0/–

Of the six attributes, the mangroves and the sanctuary are the least disturbed, due to their protected status. Unlike fisheries, corals, seagrass and land vegetation that can be direct sources of food and materials for the islanders, a presidential proclamation declares the cutting of mangroves, and any other exploitative activities within the sanctuary, punishable by law. Assessment of the biological attributes indicated that all six are vulnerable to the north-east or south-west monsoons. For instance, in Baring, fishing activities using bamboo traps and hook and line come to a halt during the north-east monsoon and typhoon. Large masses of seagrass washed up onto the beach are evidence that seagrasses are also uprooted during the north-east monsoon. In Cao-oy, fishing is affected only by typhoons. Tungasan also experiences seagrass damage along the coastline after the south-west monsoons.

All biological attributes are adversely affected by typhoons and storm surges. Impacts of typhoons and storm surges on fisheries include loss of biodiversity and destruction of habitats for the fishes. Another possible impact of typhoons is coral destruction, as reported in Bohol and Cebu, where coral rubbles have been attributed to such events.

Some important seagrass areas that were lost due to human disturbance include those that were displaced by the mangrove plantation in the sanctuary, and a part of the jetty site in Santa Rosa. Mooring of boats can also be damaging to seagrass beds. Seagrass beds may also be damaged by inundation with diluted waters as a result of typhoons and storm surges.

The mangroves of Olango particularly those in the eastern and western coasts are growing well compared with those inside the sanctuary where the plants have stunted growth. Natural factors such as typhoons and monsoons appear not to have significantly affected the survival of this type of ecosystem. Overcutting of mangroves in the sanctuary has been checked and the plants are exhibiting remarkable recovery compared with their growth prior to its proclamation as a protected area.

The sanctuary is considered vulnerable to monsoons, typhoons and storm surges. The south-west monsoon is more destructive to the sanctuary than the north-east monsoon, because of its location in the vast open southern coast of Olango. Flooding and longer inundation periods may occur in the sanctuary during storm surges and south-west monsoon. The water channels and their associated seagrass beds may experience longer inundation periods. Dilution of seawater with rain may occur, conferring some advantage to the mangroves. Longer inundation periods for seagrasses also results in the birdlife having reduced access to their feeding areas. Erosion along the channels and sedimentation in the seagrass bed and mangrove plantation may result during storm surges, monsoons and typhoons.

Typhoon and monsoon winds directly affect the activities of the birds in the sanctuary. When the high tide roosting sites are flooded, the roosting birds may have to look for other sites on higher ground, or they may roost on branches of mangrove trees. Normally, during fine weather the birds are seen everywhere, however, when there is a climatic disturbance, the birds respond by roosting in elevated grounds under mangrove trees.

Storm surges can have negative impacts on the fishery, corals, seagrasses, mangroves and sanctuary but not to any great extent on the land vegetation. In contrast, the El Niño phenomenon will affect the mangroves and the land vegetation, but not the fishery, corals, seagrasses or the sanctuary to any great extent. The mangroves of Olango survived the long dry spell brought about by the El Niño phenomenon of 1997–1998. While there were no reports of mangrove trees having died of heat stress, the growth and development of the mangrove plantation was observed to have slowed during the drought, indicating some form of adverse effect.

The terrestrial vegetation of Olango is considered vulnerable to monsoons and typhoons, with impacts ranging from minor structural damage to felling of entire trees. However, the increased precipitation during typhoon and monsoon events can be considered a benefit to the vegetation. The vegetation is also vulnerable to El Niño and the associated shortages of freshwater.

In summarising the vulnerability of the biological attributes of Olango to natural forcing factors such as typhoons, monsoons and storm surges, it should be recognised that in many cases the biology has a capacity to recover and/or adapt to these types of periodic or episodic stresses. In contrast, they are far less likely to be able to recover from long term, continuous exploitation by the population of Olango and surrounding regions. Thus, the vulnerability of the biological attributes to anthropogenic factors is likely to be far greater than to natural factors.

7.1.3 Socio-economic attributes

Table 21 presents a summary of the vulnerability of the major socio-economic attributes of Olango Island to natural and anthropogenic forcing factors.

Table 21 Summary of the vulnerability of major socio-economic attributes of Olango Island to existing forcing factors (- negative impacts, + positive impacts, 0 no impacts)

Attribute	Forcing factor							
	Monsoon	Typhoon	Storm Surge	El Niño	Over-population	Resource utilisation	Infra-structure	Tourism
Population	+/–	–	–	0	–	–	+	+
Livelihood	–	–	–	0	–	–	+	+
Infrastructure	0	–	0	0	–	0	+	+
Transportation	–	–	–	0	–	0	+	+
Tourism	–	–	–	–	–	–	+	+

The monsoons affect the Olango population both negatively and positively. Many aspects of the lives of the islanders are affected when the island is experiencing either north-east or south-west monsoon. Practically all domestic activities, from vending to washing and gleaning cannot be fully undertaken during monsoon rains and winds. However, the increased precipitation associated with the monsoons recharges the island's freshwater supply, offering benefits to the local population. In Barangays Baring and Tingo, fishing activities using traps and hook and line cease during the north-east monsoon. Tungasan is similarly affected by the south-west monsoon, while Santa Rosa can be affected by both north-east and south-west monsoons.

Sea transport is also vulnerable to monsoons. Trips leaving and going to Olango may be cancelled, reduced or postponed depending on the intensity of monsoon. Docking can even be hindered. The coves in Talima become a common docking area for many pumpboats during the north-east monsoon. The jetty in Santa Rosa can provide safe docking sites for many boats during both north-east and south-west monsoons, while the wharf in Tingo has previously been damaged during the north-east monsoon. The difficulties in transport to the island, and the general inclement weather during the monsoons discourages tourists from visiting Olango, which in turn reduces revenue on the island.

All socio-economic attributes are vulnerable to typhoons, with very little escaping from the harsh impacts of strong winds and rains. In Baring, tidal waters during a typhoon can inundate houses located about five metres from the shoreline. In Talima, many houses were reportedly destroyed during the height of super typhoon Ruping in November 1990. During Typhoon Amy, the tidal waters moved inland and inundated an area about 15 metres from the shoreline during low tide. Barangay Tungasan also experiences flooding as the tidal waters rise to about 5 metres from the shoreline during typhoons. Barangay Santa Rosa experiences less flooding as a result of typhoons. Most types of livelihood activities are affected by typhoons. For example, fishing activities in Cao-oy and Sabang cannot be undertaken during typhoons.

Storm surges can also render population, livelihood, transportation and tourism vulnerable. Storm surges can slow down business activities including sea travel to and from Olango, and this has a negative effect on the number of tourists that visit the island. Storm surge can also prevent the people from gleaning, shell collection, and other livelihood activities. Infrastructure, communication and power are not thought to be a risk from storm surges, although houses and other buildings close to the shoreline may be affected.

Human activities also have major impacts on the social and economic structures of Olango (table 21). Over-population of Olango will by far have the greatest impact on the socio-economics of the island. As mentioned above, over-population can result in many negative impacts including habitat loss and an increase in demand for resources. Further pressure on the already over-exploited natural resources could lead to major social conflict within and between the communities of Olango. Over-population will also place stress on, and most likely reduce the sustainability of many livelihood activities. Infrastructure will also be affected. School buildings will be over-crowded, potentially resulting in less efficient education programs. Hospitals may experience similar stresses. The road system, already in poor condition, will deteriorate further. Many of the impacts of over-crowding, including those listed above and others such as increased sewage and garbage disposal issues will have adverse consequences for the development of a profitable tourism industry on Olango.

Destructive resource utilisation practices such as dynamite, cyanide and poison fishing place unnecessary stress on livelihood activities and tourism development on Olango. In addition, these practices are a hazard to individuals, with a number of islanders having been victims of dynamite explosions and hookah diving accidents. While dynamite and cyanide fishing initially yield good catches, this decreases dramatically to the point where the majority of fish life has been caught or destroyed. Similarly, push net fishing has almost depleted the shell resources of Olango, which are used as raw materials for the shellcraft industry. As the coastal resources of Olango are its main tourist attraction, destructive fishing methods are a serious and current threat to tourism development.

Infrastructure and tourism can be seen as forcing factors as well as attributes. As forcing factors they will have mostly positive impacts on the socio-economic status of Olango Island. Population, livelihood, transportation and tourism will generally benefit from existing and future infrastructure and tourism activities.

7.1.4 Summary

It is clear that Olango Island is already under significant stress from a number of natural and anthropogenic forcing factors. First and foremost among these is the increasing population and the associated over-exploitation of the island's natural resources. In terms of biological resources, legal and illegal fishing and fishing-related activities have greatly diminished the fish life in the waters surrounding the island. This is demonstrated by the increased distances travelled by the local fishermen in recent years in order to ensure sufficient catch. The limited freshwater supply also appears to represent a constraint on the further development of Olango. However, current recommendations for the management of groundwater extraction and freshwater supply should assist in ensuring the long-term sustainability of this resource (see section 8). With regards to natural forcing factors, Olango is particularly vulnerable to typhoons and storm surges, given its low elevation above sea level, and poorly constructed infrastructure.

7.2 Vulnerability to climate change and sea level rise

The geophysical, biological and socio-economic attributes of Olango are constantly interacting with each other and will be constantly responding to regional climate change and sea level fluctuations. The impact may be categorised as either negative if the response elicited is harmful or damaging to a particular attribute, or positive if it confers some advantage or benefit. Alternatively, no impact may be observed or perceived at all. However, it is generally considered that predicted climate change and sea level rise will result more often in adverse than beneficial impacts.

The underlying rationale for these types of assessment are that ecosystems and human development activities located in low lying, coastal regions will be vulnerable to climate change and sea level rise. An understanding of the extent of vulnerability will depend on knowledge of the predicted changes in climate and sea level at the site of interest. Since information on climate variation for Olango is lacking, data from various sources including the IPCC (Houghton et al 1990) and CSIRO (1994) were used as points of reference for discussion of the assessment.

Two predicted scenarios of sea level rise were used for the assessment of Olango Island, one for the year 2030, being a sea level rise between 8–30 cm, and another for 2100, being a sea level rise between 15–95 cm. In assessing vulnerability, a sea level rise of 30 cm by 2030 and 95 cm by 2100 were assumed.

The predicted climate change scenario for Olango included a 20% increase in the intensity of typhoons with an associated increase in wind velocity, rain intensity and storm surge. In addition, average precipitation is predicted to increase in the form of more precipitation events or an increase in the intensity of precipitation (Fowler & Hennessy 1995).

7.2.1 Geophysical attributes

Sea level rise constitutes the most important manifestation of climate change that can significantly affect the coastal attributes of an island, and in the case of Olango it is a major concern that can have substantial implications on its natural and social resources. The potential impacts on Olango are varied and may include the physical processes of inundation, flooding, erosion, change in the salinity of groundwater through saltwater intrusion, biological effects such as habitat loss, wildlife displacement and population dislocation. Table 22 presents a summary of the vulnerability of the major geophysical attributes of Olango Island to predicted climate change and sea level rise.

Table 22 Summary of the vulnerability of major geophysical attributes of Olango Island to predicted climate change and sea level rise (- negative impacts, + positive impacts, 0 no impacts)

		Sea level rise	
Attributes	**Climate change**	**80 cm by 2030**	**95 cm by 2100**
Topography	–	–	–
Geology	0	0	0
Hydrology	+	–	–
Water Current	–	–	–
Tidal regime	–	–	–
Soil	–	–	–

Olango Island's low topographic relief and elevation render the island vulnerable to climate change and sea level rise. Intense typhoon winds will increase the intensity of storm surges resulting in greater erosion and displacement of sand and sand bars on the shoreline along Tungasan, Sabang, Santa Rosa and San Vicente. Erosion may result in shoreline retreat and widening of water channels in Sabang and San Vicente. As there are no rivers on Olango to augment sedimentation during intense rain and storm surge, accretion will most likey not be sufficient to counteract the changes in the topography of the shoreline resulting from erosion.

The low relief of Olango makes the island relatively vulnerable to the predicted sea level rise of 30 cm by the year 2030, and extremely so for a rise of 95 cm by 2100. A rise of this magnitude could inundate a significant portion of the island's land area. Slightly elevated areas in the north and central parts, western isthmus and the southern coast near the sanctuary will be slightly above the water. All the outlying areas of Tungasan, Sabang, Santa Rosa and San Vicente will be vulnerable to inundation. As the sea level rises, the seaward portion of the intertidal area will be partly inundated even during low tides, and the inner low-lying area will become a part of a new inland intertidal zone that is inundated only during high tide. Unfortunately, as there exists no adequate topographical map of Olango Island, it is difficult to quantify the area of land that will be inundated by the above predicted scenarios. Given the island's mostly low topographical relief and a maximum height above mean sea level of around 9 m, it is estimated that more than 10% of the island's current land mass would be lost in the event of a 95 cm rise in mean sea level.

The rate of erosion and sedimentation along the shoreline will most likely increase as sea level rises, however, this may take some time before a change in topography at this scale could be detected.

The water regime of the island may be affected by climate change, but it is likely to be a positive impact. An increase in rainfall intensity and frequency will increase the rate of groundwater recharge and also probably the size of the groundwater lens. In addition, if the two bays are closed at their entrances to the Hilutungan Channel as proposed, the freshwater resource will be further enlarged. An expected increase in the use of rainwater collectors will also increase the freshwater supply. Thus, it is more likely that the yearly freshwater supply will increase, and that it will be available for longer periods.

However, predicted sea level rise and storm surge associated with monsoons and typhoons may offset some of the benefits bestowed on the freshwater supply by increased rainfall. Sea level rise and increased storm surge will combine to increase the interaction between the fresh groundwater and saltwater, particularly during high tides. As reported above, water from a number of the wells on Olango currently turns brackish during high tides during the dry season, suggesting this problem will only worsen with increased sea level and storm surge. In addition, the bays, with a height above sea level of 0–0.75 m, if closed off, may experience significant saltwater intrusion, rendering them ineffective for freshwater storage. This is so for the predicted sea level rise scenarios for both 2030 and 2100. Thus, the net effect of climate change and sea level rise on the hydrology/freshwater supply of Olango remains somewhat uncertain.

Water current will likely be enhanced by sea level rise as well as stronger winds associated with typhoons and monsoons. Predictions reveal an increase in the current velocity as monsoon and typhoon winds and waves amplify. Consequently, erosion along water channels and the sandy shoreline will also likely worsen. As sea level rises, more landward areas will be subjected to the impacts of intensified water current.

Tidal inundation will be greater during intense storms, monsoons and typhoons, with the associated storm surge potentially resulting in increased erosion and flooding. The degree of tidal inundation can also be exacerbated by intense precipitation during typhoons. In addition, major inundation and flooding would be likely to occur at night, when spring tides occur during the wet season. In 1951, Typhoon Amy hit Olango Island during high tide, resulting in storm surges that flooded the coastal area up to 15 metres from the shoreline. A similar event happened during Typhoon Pepang in 26 October 1995, when storm surge during high tide resulted in the flooding of several coastal areas in Cebu including Olango Island. Sea level rise will also have an impact on the tidal regime. The prevailing tidal range of Olango, which is about 1 m, will increase as the sea level rises. In addition, the mean high water level will also increase, resulting in longer or permanent inundation of some areas that are currently exposed during low tide.

Olango has a very thin layer of topsoil and this can be very vulnerable to impacts such as erosion, flooding and storm surge. The predicted intense rain will result in increased run-off in slightly elevated areas, but in areas that are flat runoff maybe minimal because water will simply seep through the aquifer. Erosion brought about by runoff is only a minor problem in slightly elevated areas. Sea level rise will result in inundation of previously dry land, and subsequent erosion of topsoil as tidal waters recede, bringing along with them silt and other debris that can settle down in seagrasses and coral reefs.

The impact of sea level rise and the associated wave action on the elevated rocky cliffs in Tingo, Baring, Cao-oy and San Vicente will most likely be minimal. Perhaps an increase in salt spray and slight inundation, to a level that can be considered not damaging, will occur. Thus, this particular attribute of Olango is not expected to be vulnerable to sea level rise.

Evidence of sea level rise affecting the geology of Olango over a period of 30 years is unlikely as the geological processes require time scales that are much longer than 30 or 100 years. Therefore, the geology of Olango was not considered vulnerable to sea level rise by the year 2030.

7.2.2 Biological attributes

Assessment of the major biological attributes of Olango indicated that all are vulnerable to climate change, but only four are vulnerable to sea level rise (table 23). This is discussed below.

Table 23 Summary of the vulnerability of major biological attributes of Olango Island to predicted climate change and sea level rise (- negative impacts, + positive impacts, 0 no impacts)

		Sea level rise	
Attributes	**Climate change**	**30 cm by 2030**	**95 cm by 2100**
Mangrove Forest	–	–	–
Seagrass bed	–	0	0
Terrestrial vegetation	–	–	–
Coral reef	–	0	0
Aquatic fauna	–	0	0
Wildlife	–	–	–
Sanctuary	–	–	–

Mangrove forests

The mangrove forests were considered vulnerable to climate change because their survival and distribution are determined in part by climate. Thus, any change in climate will potentially influence their health and survival. The predicted increase in precipitation will dilute the seawater, which favours mangrove growth. Predicted intensification of typhoons, strong winds and heavy rain is likely to cause more damage to the plants. Mangroves are highly specialised plants that prefer stable, warm and calm conditions. If the site cannot provide these because of change in climate, extreme inundation, typhoons, storm surges, strong winds and waves, the mangrove forest will have difficulty establishing itself, resulting in less dense stands with stunted growth. The adverse weather conditions will not favour seedling establishment and growth. The predicted increase in air temperature will most likely slow down mangrove growth. This is more likely to happen as El Niño is predicted to become more severe.

A rise in sea level of either 30 or 95 cm will also have a major impact on the mangrove forests. Mangroves are able to tolerate partial inundation during high tide and emergence during low tide. They do not grow well in permanently flooded areas and they require air above the water for at least three hours; any shorter than this can retard their growth. For example, in Carcar, Cebu, where the mangrove plantation has been established in subtidal areas, the mortality of the mangrove was very high and the growth very slow. The current mangrove stands are not likely to be able to withstand a sea level rise of 95 cm. The mangroves in the eastern and western sections of the island may die out or they may spread inland if the rate of suitable substrate formation is sufficiently rapid. Such establishment would take some time, but if the community sustains its mangrove forestation program inland, then some mangroves might yet survive in Olango. Landward mangrove colonisation due to sea level rise may be restricted by infrastructure along the shoreline. The mangrove stand planted in the seagrass bed in the wildlife sanctuary will eventually die out due to longer inundation period. It cannot move inward because the shoreline is too far away, with a limestone flat and outcropping further restricting its landward movement.

An important implication of the decline in mangrove habitat is the loss of roosting sites for migratory birds and also a source of fuelwood and forage.

Seagrasses

Seagrasses are affected by various environmental factors including temperature, salinity, substrate, water depth, waves, currents and turbidity. Edwards (1995) suggested that intertidal and shallow seagrass beds (<5 m depth) are most likely to be impacted by freshwater run-off from land and elevated sea surface temperature. This was considered to be the case for the seagrass beds surrounding Olango Island. An increase in precipitation could dilute the salinity of the shallow waters surrounding the island, potentially altering the distribution and abundance of seagrass species. With decreased salinity, new species may emerge replacing the previously dominant species. For example, *Enhalus* sp. can tolerate low salinities and may become dominant, replacing *Cymodocea* and *Thalassia*, both of which are halophylic.

Associated with seagrasses are some species of seaweeds or algae that are sensitive to changes in water temperature. *Enteromorpha*, a species of seaweed that given appropriate environmental conditions can rapidly proliferate (bloom), is abundant in the waters surrounding Olango. With the predicted increase in sea surface temperature by 2100 of 1–2°C (Watson et al 1996), algal blooms will most likely be a common occurrence in the waters surrounding the island. Thus, increased water temperature could also have major impacts on the abundance, distribution and community structure of the seagrass beds. Another response of seaweeds to increased water temperature is discolouration. This can cause heavy economic losses to some highly desirable seaweeds such as *Eucheuma.* Other reactions of algae to enhanced changes in salinity, water current and temperature include growth rate reduction, tissue softening and death. Other effects of climate change on seagrass beds include breakage of individual plants and destruction of whole natural stands due to intense typhoon winds, waves and storm surge. Seaweed farms are at risk from damage and destruction, as occurred on Hingutanan, Bohol, and Hilutungan, Cebu.

Terrestrial vegetation

The terrestrial vegetation of Olango will also probably be impacted by climate change and sea level rise. The predicted increase in air temperature and the intensification of El Niño will result in more extreme droughts that will most likely cause mortality of many of the terrestrial plants. While coconut palms may survive El Niño events, they will not yield good harvest. Terrestrial vegetation close to the shoreline may also be vulnerable to flooding and erosion due to sea level rise and increased storminess. Intense typhoon winds will result in more plant damage, breakage and felling.

Coral reefs

It is thought that coral reefs are particularly sensitive to increases in seawater temperature and increased irradiance (Watson et al 1996). In addition, an increase in the intensity and frequency of typhoons and monsoons is also considered to pose a significant hazard to coral reefs around Olango Island. As observed elsewhere, the most important response of corals to increased seawater temperature is bleaching (Watson et al 1996). Given that predicted increases in sea surface temperature are realised, effects such as bleaching, reduced growth and reproductive impairment may occur. Coral bleaching was observed in the early half of 1998 as a result of increased sea temperature due to the El Niño phenomenon (Chou 1998).

If present day typhoons and monsoons can break coral heads, then it is likely that predicted intensified typhoons will result in greater damage to coral reefs. With the predicted increase in frequency of typhoons, coral reefs will also be subjected more regularly to typhoons and consequently may have less time to recover. Furthermore, intense typhoons may hit Olango during low tide, resulting in storm surges damaging exposed and shallow coral reefs.

There are several other potential impacts of climate change and sea level rise on coral reefs, however, their significance for Olango Island may not be great. Dilution of seawater below 35 ‰ due to predicted intense precipitation may result in adverse effects on the distribution and survival of coral reefs (Engemen & Hegner 1981). Storm surges and amplified local wave climates can increase soil erosion and sub-tidal sediment disturbance, resulting in sedimentation on reefs and subsequent adverse effects on coral growth, reproduction and survival (Panutakul 1973, Sudara et al 1991). Sedimentation due to run-off from the regions of Mactan Island and Cebu is not considered a problem due to the spatial separation. These impacts are anticipated to be minor because of the small size of the island.

Aquatic fauna

Mean seawater temperatures around the reefs of Olango, including Danajon reef in Northern Bohol, range from 26–31°C, this being favourable for growth and development of most marine organism in the region. With the predicted increase in sea surface temperature, there is a possibility that the abundance, composition and distribution of marine species will be altered. Such community changes will most likely be a result of physiological and behavioural changes on individual organisms due to factors such as an increase in sea surface temperature or decreased salinity. Responses to such factors could include changes in egg incubation times (eg the fish, *Siganus*; Duray et al 1986), osmotic stress, impaired swimming/feeding ability, and even avoidance.

Wildlife

Wildlife, particularly the birds of Olango will most likely be affected both directly and indirectly by climate change and sea level rise. The birdlife is not thought to be vulnerable to predicted increase in air or sea surface temperature, but they are vulnerable to the predicted increase in storminess, intense typhoons and monsoons. Strong winds and rains during extreme events can force them to cease feeding and seek shelter and refuge. Storm surges may inundate and damage feeding grounds, thereby affecting bird feeding habits. In addition, strong winds are capable of causing injury to the birds especially during flight. A rise in sea level, even of 30 cm by 2030, could adversely affect birdlife by decreasing the exposed area of the major feeding grounds, the intertidal mud flats and seagrass beds. In addition, the mangrove, which provide roosting sites for the birdlife may also be greatly reduced. Such effects may result in many of the bird species not using the island as a stop-over site during migration.

Wildlife sanctuary

Given the above, it is obvious that the wildlife sanctuary as a whole is also vulnerable to the impacts of climate change and sea level rise. Impacts will include erosion, inundation, flooding, changes in habitat distribution or even habitat destruction, and changes to animal and plant species abundance, diversity and distribution. In addition, intense typhoons and storm surges may damage or destroy the nature centre, boardwalk and observation hides. Sea level rise will have a major impact. For example, a 95 cm rise in sea level by the year 2100 will result in long-term inundation of more than 50% of the sanctuary, particularly during high tide.

7.2.3 Socio-economic attributes

Impacts on the geophysical and biological attributes of Olango Island will ultimately impact upon the local people and their lifestyles. Given this, it is obvious that the socio-economic attributes of Olango will be vulnerable to climate change and sea level rise. In addition, direct impacts to socio-economic attributes would also be observed. The expected vulnerability of the major socio-economic attributes of Olango to climate change and sea level rise is shown in table 24.

Table 24 Summary of the vulnerability of major socio-economic attributes of Olango Island to predicted climate change and sea level rise (- negative impacts, + positive impacts, 0 no impacts)

		Sea level rise	
Attributes	**Climate change**	**30 cm by 2030**	**95 cm by 2100**
Population	–	–	–
Livelihood	–	–	–
Fishing	–	0	0
Aquaculture	–	–	–
Infrastructure	–	–	–
Communication	0	0	0
Power	–	0	–
Transportation	–	–	–
Tourism	–	–	–

Population

In the densely populated areas of Malabon and Navotas in Metro Manila, it is predicted that the population may survive the increase in sea level rise but not the increased intensity of storm surges, and even typhoons and monsoons. The population centres of Olango are situated in coastal locations making them extremely vulnerable to climate change and sea level rise. Inundation and flooding due to storm surge and sea level rise may inundate and damage human dwellings and other property, while lives may also be lost. Those families which cannot move to higher grounds may be forced to migrate either to Mactan, Cebu or elsewhere.

Livelihood

Livelihood, fishing and agriculture will also be affected. Increased storminess, intense typhoons, monsoons and storm surges will result in interruptions to, and even cessation of business operations, such as small stores, fishing and plant cultivation. Gleaning in the seagrass beds and collection of fry and edible seaweeds will also be hindered. Sea transportation to and from Olango will be more restricted, and this will have flow-on effects on tourism and other business activities. Tourism will most likely suffer from climate change and sea level rise, particularly if the rich biological resources such as the coral reefs and other marine life are damaged. In addition, the erosion of sandy beaches due to storm surge and sea level rise will also adversely affect the tourism industry. Damage to agriculture will most likely result from intense typhoons as more coconut trees, kalamungay, breadfruit trees and other cultivated plants are damaged or destroyed. In addition, the intensification of El Niño may also cause damage to agricultural crops during these periods, through water shortage and heat stress. In contrast, increased rainfall and CO_2 levels could serve to increase plant productivity. The extent to which such factors counteract each other, and the ultimate extent of impacts on crops and other plants remains uncertain and needs to be assessed.

Inundation of the seagrass beds, mangroves and reefs due to sea level rise will reduce their accessibility for livelihood activities, such as shellfish collection (gleaning), coral collection, and mangrove and seagrass harvesting. Small businesses close to the shoreline will need to relocate to higher ground, or alternatively to Mactan or Cebu. Fishing and fishing-related activities will be adversely affected by sea level rise. Fishing methods will become less efficient with the rise in sea level, and will need to be adapted. Fishing is usually done during low tide when the water is shallower and fish are easier to catch. Thus, unless fishing methods can be adapted, reef fish and other reef-associated catch, such as lobster fry, are likely to decrease. On a positive note, illegal fishing methods such as cyanide-fishing and blast-fishing might be reduced due to increased water depth and the migration of fishermen to other regions. In addition, inundation and possible loss of mangroves in the sanctuary may have adverse effects on rabbitfish recruitment, resulting in subsequent decreases in rabbitfish fry catch.

The effect of climate change and sea level rise on local water supply is uncertain. Increased rainfall due to increased intensity of storms and monsoons will most likely result in an increased supply of freshwater for domestic uses. However, the effects of sea level rise may result in increased saltwater intrusion into the fresh groundwater lens, rendering the water less suitable for domestic use. Again, the extent to which these factors will counteract each other is yet to be understood.

Infrastructure

Increased intensity of typhoons, monsoons and associated wind, rain and storm surges, and sea level rise will greatly affect the infrastructure on Olango Island. Some of the major infrastructure at risk includes the churches, school buildings, the emergency hospital, the power plant and associated electricity poles, the beach resorts and the jetty in Santa Rosa. The 'jetty' could be extremely vulnerable to sea level rise during the south-west monsoon, when strong winds, currents and high tides combine to increase the wave action on the 'jetty'. Similarly, the nature centre, observation hides and boardwalk will also be particularly affected by sea level rise during the south-west monsoon, when strong winds, tidal currents and high tides combine to produce storm surges that can be destructive to these facilities. The church building in San Vicente, which is located near the shoreline will likewise be inundated. In addition, some segments of road, such as that along the coastal sections of Santa Rosa, San Vincente and Sabang may be damaged by sea level rise and storm surge. Consequently, transport mechanisms will be impaired, unless new roads are constructed. Disruption of the infrastructure will have flow-on effects on transport links and tourism on the island.

7.2.4 Significance of vulnerability

Previously, it was emphasised that in order to evaluate vulnerability of Olango Island to climate change and sea level rise, an understanding of the vulnerability to existing forcing factors, or coastal hazards, was required. The degree of vulnerability to each of these will depend on a number of factors, including the proximity to the coastline, elevation and the degree of human exploitation.

Attributes which are located along or very near the coastline, and have a higher degree of human exploitation, are vulnerable to existing and future anthropogenic forcing factors. Their degree of vulnerability to climate change and sea level rise will be greater than their vulnerability to existing natural forcing factors since it is predicted that there may be increases in the intensity and even frequency of present day typhoons, monsoons, storm surges, El Niño and La Niña. As a result of predicted climate change, the magnitudes of impacts and their effects on the various attributes will likewise intensify.

Therefore, the degree of vulnerability to current natural forcing factors will increase with the intensification of the physical factors related to climate change and sea level rise. Higher vulnerability will mean greater damage that the impact can inflict on the resource. Knowing which attributes will be vulnerable to climate change and sea level rise, and their effects on the resources, is very important in determining what mitigating responses and preventative measures should be developed and implemented so that damage may be avoided or minimised.

8 Current responses to coastal hazards

8.1 Planning and policy

Appropriate management of the resources on Olango requires a concerted effort, not only by the barangays, but also provincial, regional and national agencies. The coastal hazards facing Olango are substantial and they are taking their toll on the condition of its resources. Being an island of international importance for biodiversity, Olango needs to be proactive in addressing the various sustainable management issues so that the rate of resource degradation can be arrested and hopefully reversed.

Some of the best approaches in the control and management of the resources of Olango are to formulate policies, regulations and management plans that can address the various issues that confront Olango today. Several resolutions and ordinances have already been passed at the barangay level, which provide for the proper development of the coastal resources of Olango (table 25). Both at the regional and national levels, a number of Republic Acts, Presidential Decrees, Executive Order Memorandum of Agreement, and other policies have been passed and approved that govern the control and utilisation of the coastal resources of the country, including the island of Olango (table 26).

The management of the coastal attributes of Olango, particularly water, wildlife, mangroves, seagrass beds and coral reefs, will need the concerted effort of the barangay leaders and the community, technical experts and decision makers from the city, provincial governments, national agencies and non-governmental organisations. However, one thing that should be recognised is that these agencies, government and non-government, have concerns other than coastal development, so that it is important to re-channel some resources toward this end. It is therefore proper in perspective to review some policies and regulations pertinent to the development of the coastal environment of the island in particular and the country in general.

Table 25 Barangay resolutions and ordinances related to coastal resource management of Olango Island (CRMP 1998)

Barangay	Ordinance #	Date	Description
Santa Rosa	Ord. # 03-97	09-Sep-97	Levying wharfage fee to all boat owners/operators docking in causeway port for business transaction.
	Ord. # 34-96	02-Jun-96	Interposing vehement objection against application of foreshore lease on Mr. Antonio Dy, along the shore of Santa Rosa wharf.
	Res. # 17-93	10-Oct-93	Favourably endorsing the application of Mr Samuel Regual to the Office of Provincial Governor of Cebu to extract sand from seawater of Santa Rosa.
San Vicente	Ord. # 06-95/	06-Sep-95	Declaring the fishing ground of San Vicente as Fish Sanctuary and Marine Reserve and imposing penal sanctions for violation prohibitive acts thereof. 1st offense – P50, 2nd offense – P1000 and 3rd offense – P1500 or 1 mos. Imprisonment or both.
Sabang	Res. # ?	Oct. 1995	Imposing no objection on the foreshore lease application of Alenter Resort Hotel Corporation over a 200 Ha. Foreshore area situated between Sulpa Is. and Hilutungan Is. and within territorial waters of San Vicente, Lapu-lapu City.
Tungasan	Ord. # 24	18-Apr-95	Enforcement of Bantay Dagat to implement rules.
	Ord. # 28	Jul. 1995	Landing fee. Selling of colon –P5, nipa – P10, fruits – P5 and wood – P5.
	Ord. # 27	27-Jun-95	Planting of coastal trees for environmental concerns.
	Ord. # 10-96	Mar. 1996	Prohibiting any illegal fishing activities.
	Ord. # 12	02-Aug-97	Prohibiting other barangays to glean in the intertidal waters of Tungasan.
Cao-oy	Ord. # 02	10-Aug-97	Prohibiting all residents in throwing garbage inside the territorial seawater and seashore of Barangay. Cao-oy. Penalty P200.
Baring	Res. # 1	07-May-89	Prohibiting the transport of sand to another Barangay. Penalty of P100 per violator.
	Res. # 3	07-May-89	Prohibiting the weeding of seaweeds 'lumot' at the seashore of Barangay. Baring. Penalty of P30 plus confiscation of seaweed.
	Res. # 07-95	09-Oct-95	Obstructing the application for preliminary approval and location clearance of Alenter resorts and Hotel Corporation. Relative to their offshore lease application on the shoreline belonging to Barangay. San Vicente.
	Res. # 09-95	29-Oct-95	Imposing no objection on the foreshore lease application of Alenter Resort Hotel Corporation over a 200 ha foreshore area situated between Sulpa Is. and Hilutungan Is. and within territorial waters of San Vicente, Lapulapu City.
Pangan-an	Res. # 5	20-Oct-95	Imposing no objection on the foreshore lease application of Alenter Resort Hotel Corporation over a 200 ha foreshore area situated between Sulpa Is. and Hilutungan Is. and within territorial waters of San Vicente, Lapulapu City.
	Res. # 30-94	09-Sep-94	Authorising the Barangay. Chairman to execute contract with Pangan-an constituents for the deepening of the passage boundary of the Olango Channel near Sulpa Is. towards the extending 'Awo' within the jurisdiction of Barangay. Pangan-an and for other purposes.
Caohagan	Res. #?	21-Oct-95	Imposing no objection on the foreshore lease application of Alenter Resort Hotel Corporation over a 200 ha foreshore area situated between Sulpa Is. and Hilutungan Is. and within territorial waters of San Vicente, Lapulapu City.

Table 26 Laws, proclamations and policies relevant to the control and use of coastal resources in the Philippines

Republic Act 6541 – An act regulating the use of electric fishing.
P.D. 704 as amended by P.D. 1058 – A decree banning the use of dynamite and cyanide fishing.
Fishery Administrative Order 155 – Regulates the use of fine mesh nets.
P.D. 1219 – regulates the gathering of corals.
Local Government Code – Authorises the local governments to enact ordinances pertaining to the utilisation of the coastal resources.
Executive 240 – mandates the creation of fisheries and aquatic resources management councils.
Conservation on the International Trade of Endangered species.
DA-DENR Joint General Memorandum of Agreement Order No. 3, series of 1991 – prescribes the guidelines to the reversion of fishpond lease agreements into mangrove forestlands.
DA-DAR Administrative Order November 18, series of 1991 – prescribes the guidelines in the redistribution of cancelled and/or expired FLAs to agrarian reform beneficiaries.
R.A. 7586 – The National Integrated Protected Areas System Act provides for the proclamation of marine protected areas.
DENR Administrative Order No. 54 – provides for the established of a National Bird Banding System.
Department Administrative Order No. 03, 1991 – provides for the guidelines for the award and administration of the mangrove stewardship agreement.
DENR Administrative Order No. 15, 1990 – provides for the regulation governing the utilisation, development and management of mangrove resources.
Memorandum Circular No. 15, 1989 – prioritises the reforestation of mangrove areas.
Fishery Administrative Order 163, 1996 – regulates the use of Moro-ami and shoreline fishing.
FAO 156. 1986 – provides for the guidelines in the use of trawls and purse seine within 7 km from shoreline of all provinces.
Presidential Decree 1081 – decree designating Olango as a tourism zone.
Republic Act 8550 – provides for the policies pertaining to fisheries and fisheries related activities.
Ordinance No. 8 – passed in Lapulapu City regulating the hunting of birds in Lapulapu City, Olango Island, Calubian, Pangan-an and Caugan Island.
ABC Resolution No. 1 – 1998 – resolving that Olango is protected from any form of hunting, collecting and exploitation that would endanger the wildlife.

The provisions are not presented in detail, but rather a general statement is presented to describe briefly the policy. However, many policies do not have provisions on what measures to take should there be any rise in sea level, and how it should be addressed. If there is no provision that can fully or even partly address sea level rise, in what condition will the coastal environment find itself? The community cannot deal with it alone. Thus, it requires interaction and cooperation between the local community, the city government, the Philippine Tourism Authority and the DENR. It is imperative that a multi-sectoral planning effort be organised to deal with the problem holistically, not piecemeal.

A number of management plans have been proposed for Olango by concerned agencies including the Lapulapu City Government, the Department of Environment and Natural Resources, and the Coastal Resource Management Project. It is only a matter of time before these plans are literally translated into some visible and realistic structures together with financial resources and committed leadership.

The proposed land use plan for Olango Island lists four major items (Mactan Integrated Master Plan, Vol. 1 1996):

- Establishment of a commercial district in Santa Rosa to expand later to the northern and southern parts of Olango.

- Establishment of a tourism area in the eastern part of the island to promote ecotourism for the sanctuary.
- Establishment of high level and low-level residential areas in the centre of the island.
- Some areas in Olango shall be declared protected including the Olango wildlife sanctuary. This will remain as such ‘to keep the natural character of the island’.

The residential area in the proposed land use plan is located at the site where the freshwater lens is situated (figure 12). This might not be compatible with the proposed plan to protect the freshwater lens and its major catchment area.

A total of four reclamation projects have been proposed for Mactan and Cebu City. It is anticipated that these development activities may directly or indirectly affect the various attributes of Olango Island. The projects are:

- *South Mactan Reclamation Project:* This area is about 1600 ha in size. A part of this will be converted into a container port for domestic and international vessels. The western coast will be the site of the proposed industrial zone.
- *North Mactan Reclamation Project:* This is a 120 ha project site for the expansion of the Mactan Export Processing Zone.
- *East Mactan Reclamation Project:* A strip of land 200 metres wide and six kilometres long where some 170 hotels and resorts will rise.
- *Cebu City South Reclamation Project:* This will cover an area of about 400 ha to accommodate the proposed coastal road.

One of the participating agencies in the vulnerability workshop conducted in December 1998 was the Coastal Resource Management Project (CRMP), a USAID funded project that is being implemented in Olango Island. Five interventions have been proposed for Olango as follows:

- Develop various alternative enterprises – ecotourism, seaweed farming, fish-cage culture, handicrafts
- Create an island-wide Coastal Resource Management Council
- Designate zones for specific uses
- Intensify information, education and communication campaign.
- Intensify law and policy enforcement.

In a workshop conducted by the Department of Environment and Natural Resources – Region 7 in October 1998, ten proposed management activities for the sanctuary were drafted and will be prepared for implementation. Their aim was to achieve a better environment and sustainable development of the island’s coastal resources. The proposed activities are as follows:

- Widen and elevate the jetty and consider impacts of sea level rise.
- Require jetty contractor to turnover the jetty to the Lapulapu City Government for repair, rehabilitation and improvement.
- The Department of Public Works and Highway may introduce measures to improve the usefulness of the jetty.
- Implement provision of Presidential Proclamation 1081.
- Formulate a better water distribution system in Olango.

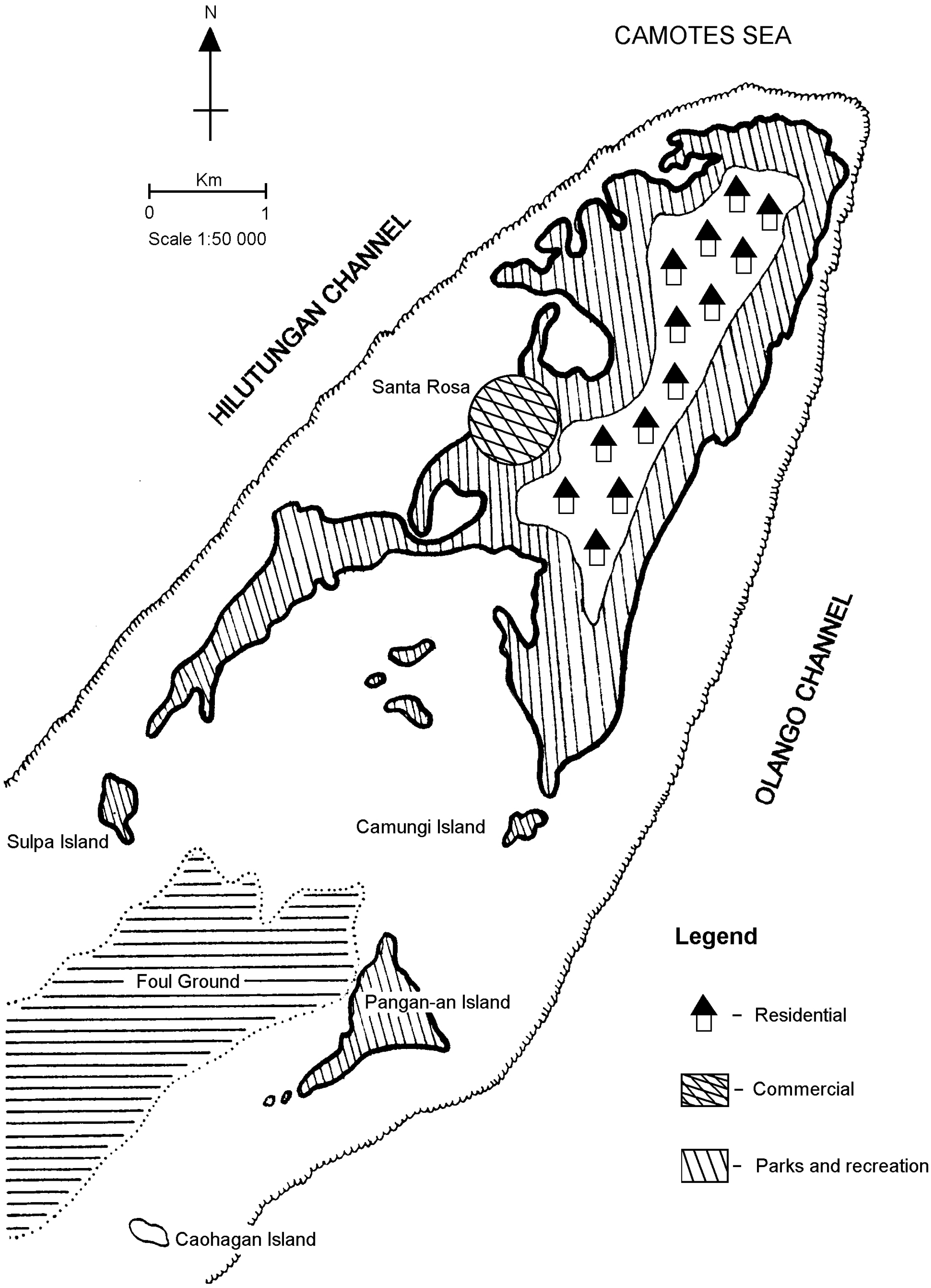

Figure 12 Proposed land use plan for Olango Island (Lapulapu City 1996)

- Avoid installing water pumps close to the sea to prevent seawater intrusion.
- Ban of construction/dwellings in areas above the freshwater lens.
- Create a people's organisation to protect the freshwater lens area.
- Plant ipil-ipil to facilitate water usage and as fuelwood source.
- Require small voluntary monitoring donation from water users.

Included in the policy action plan for the Philippines are eleven policy options that have been proposed for adoption by the coastal resource sector. These are as follows:

- Formulation of guidelines and legislation for the implementation of an integrated coastal zone management for all coastal zones in the Philippines. Land use planning in coastal zones will help reduce vulnerability to a rise in sea level. Mechanisms for coastal zone management must include: requirement of setbacks, allocation of low-lying vulnerable land to lower value use such as parks rather than housing, requirement of compliance with construction standards or post-storm reconstruction standards. These policies reduce the risk of living in coastal areas from current climatic variability and protected against potential sea-level rise.
- Formulation of guidelines and legislation for the implementation of an integrated coastal zone management for all coastal zones in the Philippines.
- Mangrove resources development should be institutionalised through the formulation of additional policies and regulations (like DAO No. 15, S1990) or amending existing policies and regulations to allow effective and sustainable mangrove management highlighting the massive reforestation of degraded mangrove systems through a community based approach.
- Public easements and buffer strips should be treated as separate lots during land surveys. These should be excluded from tilling or private ownership. However, to avoid large losses, flexible land-use policies maybe opted such as presumed mobility which do not completely prohibit development but allows markets to avail of climate change information to determine whether development is economically feasible. Variation of this policy include: requiring property owner to remove threatened coastal structures if sea level rise is observed, provision to adjust land ownership on the basis of tidal regimes according to the changes in the tides and/or, provision in coastal land deeds that revert the land back to public ownership if in so many years if the sea level rises to a specified amount.
- LGUs should be required to reserve foreshore areas, which are critical for recreation/tourism purposes, and other public uses and are excluded from disposition.
- Inclusion of wetlands/swamps/marshes in the NIPAS with a category of wildlife sanctuary or unique ecosystem. Preservation efforts should be made to maintain wetlands/swamps/marshes that are more likely to withstand a sea-level rise. Wetlands/swamps/marshes are valuable natural areas that are difficult to recreate; therefore, current and future efforts are warranted to protect the area. Protecting these areas will also improve water quality, flood control and habitat under current climate conditions. Concerning these, guidelines for the proper use and management of wetlands/swamps/marshes must be drawn up and funds provided for their implementation.
- A multi-hazard mitigation/protection plan for natural coastal hazards must be developed with priority on the maximum reduction in threat to life, structures and economic production. This must include the provision of or improvement of and/or increase of

existing networks of collecting/observing platforms for monitoring these hazards, prediction, warning and system of communication to disseminate such warning. Funds for disaster relief could be tied up to the implementation of long-term hazard reduction policies. Benefits are independent of climate change as risks from current disasters are likewise reduced.

- Formulation and strict implementation of mining laws, reforestation of denuded watersheds to reduce river/coastal erosion.
- Requirement of geological, hydro-meteorological and structural engineering evaluation as part of the environmental impact assessment prior to coastal development. This will allow also to redirect growth away from sensitive lands and move towards less vulnerable area to reduce the risks of sea-level rise as well as from severe coastal hazards that occur in the present climatic conditions. Engineering standards may provide the incorporation of marginal increases in the height of coastal infrastructures, such as bridges, ports, sewage outflow treatment plants or sea walls, to offset a sea level rise. Such provisions are less expensive to make while construction is in progress rather than after initial work has been completed.
- Limitation of government subsidies or tax incentives to develop land sensitive to sea-level rise, such as barrier islands, coastal wetlands, estuarine shorelines and critical wildlife habitats. Additionally, insurance and banking industries maybe encouraged to factor risks of climatic variability into investment decisions, thereby, reducing reliance on government subsidised insurance and disaster relief.
- Climate change impacts on coastal zone systems are not well understood by the public or decision makers, promotion of awareness about erosion sea level rise, flooding risks and storm/earthquake standard building code, could be a cost effective means of reducing future expenditures.

8.2 Infrastructure

Olango Island lacks infrastructure that is solely for providing shelter and protection against coastal hazards. There were concrete rock structures in what used to be Santa Rosa Bay. In addition, there is a sea resort in south-west Olango but this has been abandoned and damaged.

In the south-west, toward the north and northwest, the rocky coast has been reinforced with concrete structures primarily to prevent damage on the shoreline.

It is not likely that the existing infrastructure in Olango has been designed and constructed with some consideration on the rise of sea level in the future. In most instances government infrastructure is made to last 20–25 years but other structures do not last that long. Most structures collapse and are destroyed even before they outlast their usefulness. The Santa Rosa 'jetty' was continually extended until the seaward edge of the coral reef was reached. The end portion has been damaged with the concrete structure cracking due to impact from the wave action. Its height is just within the reach of salt spray and this has produced giant potholes on its platform.

8.3 Monitoring

In 1996, the Save Nature Society, with financial assistance from the Wildbird Society of Japan, monitored the population of the birds, the rate of soil deposition and displacement, mangrove growth, the zoobenthos, and water quality in the sanctuary. Unfortunately, the monitoring activities ceased because of some changes in the DENR Policy regarding the conduct of monitoring status within a protected area.

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) regularly monitors the rate of precipitation, temperature, and humidity and the direction and velocity of typhoons and other weather disturbances. The National Mapping of Resources Information Agency (NAMRIA) through its tide station in Cebu City monitors and predicts tidal currents, levels and time of occurrence.

The Department of Environment and Natural Resources Region 7 conducts monitoring of bird populations and sea level in the sanctuary.

The City Disaster Coordinating Council and the Department of Social Welfare and Development are given the authority to conduct assessment and evaluation of the extent of damage the typhoons, monsoons, and other climatic distribution can inflict on Olango. A team is normally sent to typhoon damaged areas to determine the kind and cost of the damage after each typhoon. The result of the visit is used to determine the allocation of emergency goods and services that will be provided to typhoon victims. In general, they are given canned goods and a few kilos of rice and used clothing.

9 Future monitoring requirements and management strategies

Monitoring is a valuable tool in effective coastal management because without it departures from normal or average conditions cannot be detected. The sea level for instance may be suspected to remain at a certain point imperceptibly, but if there is a scientific means of measuring any fluctuation in the sea level, one may be able to conclude that sea level indeed is rising. Following is a list of major parameters that need to be monitored in the future to be able to support or reject the predictions of climate change and sea level rise, and also to further understand the processes of change on Olango Island:

Geophysical Attributes: Soil deposition/displacement rate, sand bar shifting, mean sea level fluctuations, storm surge, water current, shoreline erosion, water and air temperature, groundwater salinity, rate of groundwater extraction, capacity of freshwater lens, transmissibility, limestone porosity.

Biological Attributes: Bird populations, mangrove growth and distribution, seagrass cover, impact of mangrove plantation on seagrass beds, zoobenthos population, substrate temperature in the mangrove forest, location and type of roosting sites, coral cover, reef fish biomass, fish catch/shell catch.

Socio-Economic Attributes: Population structure, standard of living, health condition, educational attainment, number of resorts/tourists, number and type of infrastructure.

Management strategies to help achieve sustainable development of Olango and also to effectively manage for the effects of climate change and sea level rise have been proposed previously by DENR as well as the CRMP and other organisations/agencies involved in the management of Olango. In particular, proposed management activities for the wildlife sanctuary include:

- Habitat maintenance for bird protection
- Zoning of the wildlife sanctuary
- Identification of allowable activities

- Education of local communities on natural resource management
- Maintenance of buffer zone
- Provision of livelihood projects
- Endorsement of ecotourism
- Creation of job opportunities
- Provision of additional income for local government
- Community development
- Institutional linkages

In addition, the workshop on the vulnerability assessment of Olango Island proposed a number of other management strategies and monitoring requirements for some of the major attributes of Olango Island. The proposed measures are aimed at managing to mitigate impacts of climate change and sea level rise, and are summarised in table 27.

10 Links to regional and national policy

The impacts of the anthropogenic forcing factors may be specific for Olango but those due to natural forcing factors, and regional climate change and sea level rise will be broader ranging, affecting the surrounding islands and the Philippines as a whole. While Olango does not contribute significantly to the elevation of greenhouse gases compared with the urbanised cities of Mandaue, Cebu and Manila, the island will still experience the consequences, being increased sea level due to global warming and the associated impacts.

It is important to integrate the concept of sea level rise in the management plans of all agencies concerned at the local, regional and national levels. The more important aspects of the plan should incorporate strategies on the sustainable use of the resources, 'disaster preparedness and emergency responses'.

In the country, the management of coastal resources of low-lying islands is not only governed by policies legislated at the barangay level, but also by laws and regulations approved at the national levels. Whatever national legislation there is can be promulgated at the local level.

11 Identification of information and research gaps

Although Olango Island has been very well studied compared to other islands in Central Visayas, further information on the coastal and social attributes needs to be gathered. A review of the literature pertaining to Olango showed that many studies have been undertaken by various agencies, covering a wide spectrum of subjects from salinity measurements to bird species monitoring. Even the coastal profile of the island, which could be the most comprehensive publication on Olango, is not as comprehensive as it should be. In the course of preparing this assessment, it was discovered that much information could not be incorporated in this report because it is either incomplete or missing. The following are information and research gaps that need to be addressed in order to make the data for Olango as complete as possible to give future researchers the advantage of access to a more comprehensive literature survey:

- Storm surge data
- Volume and location of sand and corals extracted

Table 27 Proposed management measures to mitigate impacts of climate change and sea level rise on Olango Island

Attribute	Management measures
Geophysical:	
Topography	Construction of wave breakers
	Review policies on mangrove establishment
	Ban the harvesting of erosion resistant vegetation
	Ban the extraction of soil along shoreline
	Intensify information and education campaign
Hydrology	Regulate groundwater extraction
	Intensify information and education campaign
	Review proposal to close the bays
	Installation of rain collectors
	Declare area over freshwater lens as protected
Biological:	
Fishery	Shift to other livelihood
	Intensify law enforcement
	Intensity information and education campaign
	Establish fish sanctuaries
	Install fish attraction devices
Coral Reefs	Implement proper solid waste disposal
	Intensify law enforcement
	Intensify information and education campaign
	Encourage 'reef tourism'
	Identify more recreational dive sites
Seagrass Beds	Intensify information and education campaign
	Try seagrass planting
Mangroves	Enrichment planting in natural stands
	Intensify information and education campaign
Land Vegetation	Enhance planting of salt tolerant species
	Encourage planting of fruit trees
	Intensify information campaign
	Revegetate water catchment area
Wildlife Sanctuary	Intensify mangrove cluster planting around nature centre
	Intensify information campaign
	Update management plan
	Develop community-based ecotourism and livelihood options
Socio-economic:	
Coastal Population	Retreat for about 10 m from the highest tide level
	Toilets must be installed away from freshwater source
Agriculture/Livelihood	Protect and accommodate
	Shift to other alternatives
Transportation/Roads	Protect and elevate road level
	Retreat for about 10 m from highest tide level
Freshwater distribution system	Protect, implement Water Resources Centre recommendations

- Typhoon damage on property, lives, coral reefs, seagrass beds
- Biology and ecology of endangered species in the island
- Water current studies
- Substrate deposition and displacement data
- Groundwater salinity and transmissibility data
- Limestone porosity to water seepage studies
- Water pollution pathway from urban pollution sources
- Duration of inundation of seagrass beds
- Economics of the tricycle industry
- Cost of dynamite, cyanide and poison destruction
- Impacts of mangrove forestation on the seagrass beds in the sanctuary
- Detailed topographical information for Olango Island.

12 Conclusions

The island of Olango with its limited coastal and terrestrial resources is in a critical period of its development, survival and progress. Its future does not depend so much on the industrial investment that the concerned agencies may put into the island, but on how well the islanders are able to sustainably develop their natural resources. Should the rate of exploitation remain unregulated and uncontrolled, the time will come when all that is left are mangrove trees, seagrasses and coral skeletons. The overall poor condition of the island is lamentable and is compounded by the harsh impacts of some natural disturbances and the predicted impacts of climate change and sea level rise. Being a small and low lying island, its vulnerability to both anthropogenic and natural forcing factors is realistically high. Therefore, any imbalance that is imposed on the resources can severely affect and deplete them. The higher the degree of depletion the greater is the vulnerability to the impacts of forcing factors, including climate change and sea level rise. Recognising that Olango is indeed vulnerable, it is imperative that existing policies and regulations are enforced and new ones formulated to mitigate possible impacts on both natural and man-made interventions. As a strategy to help minimise the rate of resource degradation, agencies have devised their respective management plans for the island. These plans integrate proposed land use, infrastructure, tourism and livelihood opportunities, but one component that has not been considered in these plans is the aspect of climate change and sea level rise. It is therefore important to integrate climate change and sea level rise in the management plans on both local and national levels.

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Appendices

Appendix 1 List of mangrove species found on Olango Island

Species	Local name	Poo[2]	Talima[2]	Tungasan[2]	Sabang[2]	San Vincente[2]	San Isidro[1]	Suba Basbas[1]	Sta Rosa[1]	Lumayag Pt.[1]	Remarks/ usage
Acanthus ebracteatus	n. d.										
Acanthus ilicifolius	n. d.					2					n. d
Aegiceras corniculatum	Sagin-saging				2						n. d
Aegiceras floridum	n. d.									1	
Avicennia alba	Piape laki	3			1		1	1		1	firewood
Avicennia lanata	Piape laki				2				1		firewood
Avicennia marina	Piape baye	2			2	2		1	1	1	firewood
Avicennia officinalis	Piape laki	1			3		1	1		1	firewood
Bamngtonia asiatica	Bito-bitoon		2								n. d.
Bruguiera cylindrica	n. d.									1	
Bruguiera gymnorrhiza	n. d.	1								1	
Ceriops decandra	n. d.	1			1					1	
Ceriops tagal	n. d.	1					1		1	1	
Dolichandrone spathecea	Tui		2		1						n. d.
Excoecana agallocha	Alipata; Buta-buta	1	2	2	3		1	1	1	1	n. d.
Lumnitzera littorea	Mayoro	3	2		1		1	1		1	n. d.
Lumnitzera racemosa	n. d.	1					1	1	1	1	
Osbornia octodonta	n. d.	1							1	1	
Pandanus sp.	Pandan										n. d.
Pempis acidula	Bantigi		2	2	2						n. d.
Pongamia pinnata	n. d.		2		2	2					n. d.

1 Magsalay 1989a; 2 SUML 1997; nd – no data

(Appendix 1 continued)

Species	Local name	Poo[2]	Talima[2]	Tungasan[2]	Sabang[2]	San Vincente[2]	San Isidro[1]	Suba Basbas[1]	Sta Rosa[1]	Lumayag Pt.[1]	Remarks/ usage
Prosopis vidaliana	n. d.	2									n. d.
Rhizophora apiculata	Bakhaw laki	1	2		1		1	1	1	1	reforestation & decor
Rhizophora mucronata	Bakhaw baye	3	2	2	3	2	1	1	1	1	reforestation & decor
Rhizophora stylosa	Bakhaw tigre		2	2	1		1	1	1		reforestation & decor
Scaevola frutescens	Aroma		2	2	2						n. d.
Scyphiphora hydrophyllacea	n. d.	1									
Sesuvium portulacastrum	n. d.	1							1	1	
Sonneratia alba	Pagatpat; pedada	2	2		2						fencing and decor
Sonneratia caseolaris	n. d.	1			1		1	1	1	1	
Terminalia catappa	n. d.									1	
Thespesia populnea	n. d.									1	
Xylocarpus moluccensis	n. d.	1			1				1	1	

1 Magsalay 1989a; 2 SUML 1997; nd – no data

Appendix 2 Number of seaweed and seagrass species per genus on Olango Island (SUML 1997)

Genus	Poo	Talima	Tungasan	Sabang	San Vincente
Algae					
Rhodophyta					
Actinotrichia	1	1	1	1	1
Galaxaura	2			1	1
Gelidiella	1	1	1	1	1
Gelidium				1	
Pterocladia		1			
Amphiroa	2	2		1	1
Jania	2	1	1	1	
Mastophora		1		1	1
Psedolithophyllum			1		
Gracilaria	2	2	3	2	2
Gelidiopsis	1		1		
Hypnea	1		1	2	1
Champia	1	1	1	1	
Acanthophora	1		1	2	
Amansia	1	1		1	1
Bostrychia	1	1	1		
Laurencia	2	2	1	1	2
Phaeophyta					
Colpomenia	1		1		
Hydroclathrus	1	1		1	1
Dictyota	3	3		1	1
Padina	2	2	1	1	1
Lobophora	1	1	1	1	
Sargassum	2	2	2	2	3
Turbinaria	3	3	2	2	2
Chlorophyta					
Monostroma	1	1			
Ulva	2	2	2	1	1
Chaetomorpha	1	1	1	1	1
Cladophora	1	1			
Anadyomene	1	1	1	1	
Microdictyon				1	
Boergesenia		1	1	1	
Boodlea	1	1	1	1	
Dictyosphaerea	1	1	1	1	1
Valonia	1	1			
Ventricaria	1			1	
Caulerpa	2	1	2	1	2

(Appendix 2 continued)

Genus	Poo	Talima	Tungasan	Sabang	San Vincente
Codium	1			1	1
Halimeda	1	2	1	1	2
Avrainvillea	1				
Udotea	1	1			
Bornetella	1	2		2	1
Halicoryne		1			1
TOTAL	**48**	**43**	**30**	**37**	**29**
Seagrasses					
Cymodocea	2	1			
Halodule	2	1	1	2	2
Syringodium	1	1	1		1
Enhalus	1	1	1	1	
Halophila	1		1	1	1
Thalassia	1	1	1	1	1
TOTAL	**8**	**5**	**5**	**5**	**5**

Appendix 3 Terrestrial plants used as fuel wood on Olango Island (from Remedio & Olofson 1998)

Visayan Term	Scientific name	English name
Biatilis, ipil-ipil	*Leucaena leucocephala*	Leadwood
Bakhaw, tungki	*Rhizophora spp.*	Mangrove
Kamoteng kahoy & tungdan	*Manihot utilissima*	Cassava stems, dried cassava
Puno-an sa lubi	*Cocos nucifera*	Coconut palm trunks
Anasil	*Unidentified*	–
Bantigi	*Pemphis acidula*	None
Madre de cacao	*Gliricidia sepium*	None
Kanding-kanding	*Lantana camara*	None
Bayabas	*Psidium guajava*	Guava
Bungaw	*Astrocalyx calycina**	None
O-on	*Ixora**	None
Gapas-gapas	*Camptostemon philippinense**	Mangrove
An-an	*Buchanania arborescens**	None
Hamomi-aw	*Unidentified*	–
Tugas	*Vitex parviflora*	Molave
Kamunggay	*Moringa oleifera*	Horse radish tree

* Identification uncertain

Appendix 4 Number of coral species per genus at three sampling sites on Olango Island (SUML 1997)

Genus	Poo	Talima	Tungasan
Reef building corals			
Acropora	2	5	5
Astreopora		1	
Montipora	1	1	1
Coeloseris	1		
Gardineroseris			
Leptoseris	1		
Pavona		1	2
Pachyseris	1	1	1
Euphyllia	1	1	1
Physogyra			1
Plerogyra	1		
Tubastrea	1	1	
Turbinaria	2	1	
Cyphastrea	2	2	2
Diploastrea	1		1
Echinopora	1	1	1
Favia	3	3	2
Favites	2	1	2
Goniastrea	2	2	1
Leptastrea	1	1	
Leptoria			
Montastrea	1	2	1
Platygyra	3	1	2
Cycloseris			
Diaseris			
Fungia	1	1	4
Halomitra			
Herpolitha	1		1
Sandalolitha	1		
Hydnophora	2	1	1
Merulina	1		
Lobophylla	1	1	1
Scolymia		1	
Symphyllia	1	1	
Galaxea	1	1	1
Echinophyllia	1	1	
Mycedium	1	1	1
Oxypora	1		
Pectinia	2		1

(Appendix 4 continued)

Genus	Poo	Talima	Tungasan
Pocillopora	1	2	1
Seriatopora	1		1
Stylophora	1	1	
Goniopora			1
Porites	3	1	1
Psammocora	1	1	3
Trachyphyllia			
TOTAL	**48**	**38**	**40**
Non-reef building corals			
Heliophora	1	1	
Millepora	1	1	1
TOTAL	**2**	**2**	**1**
Soft Corals			
Nephthea		1	
Sarcophyton		1	
Sinularia	1	1	1
Xenia			1
TOTAL	**1**	**3**	**2**

Appendix 5 The number of fish species per family identified in some selected sites in Olango Island (SUML 1997)

Family	Tungasan	San Vincente	Talima
Acanthuridae	3	3	4
Apogonidae	2		2
Balistidae	1	3	2
Blenniidae		2	1
Caesionidae		1	
Centriscidae		1	
Chaetodontidae		2	1
Cirrhitidae	1	1	1
Holocentridae			
Labridae	12	15	16
Lethrinidae			1
Lutjanidae		2	1
Mullidae	2	2	2
Nemipteridae		1	1
Pinguipedidae	1	1	2
Pomacanthidae	3	1	1
Pomacentridae	9	15	14
Scaridae	3	5	4
Scorpaenidae		1	1
Serranidae			1
Siganidae	1	1	
Syndontidae	1		1
Tetraodontidae	2	2	2
TOTAL	**41**	**59**	**58**

Appendix 6 Population density and wet biomass of zoobenthic organisms collected in the seagrass bed south of Olango Island (SNS & WBS 1996)

Species	Number of individuals	Number of core samples with individuals	Total area of core samples (m^2)	Estimated density	Wet biomass (g)
Slugs	12	4	0.2500	48	3.25
Sponges	22	17	1.0625	21	471.5
Polychaetes	8	8	0.5000	16	0.56
Hermit crabs	14	10	0.6250	22	3.32
Isopods	2	2	0.1250	16	0.17
Crayfish	1	1	0.2500	16	0.09
Annelids	7	2	2.0625	56	0.32
Holothuria sp.	4	4	0.1250	16	1.11
Ophiocoma sp.	98	33	0.2500	47	180.91
Echinotrix sp.	2	2	2.0625	16	26.80
Littorina sp.	6	5	0.1250	19	0.88
Phacoides sp.	4	4	0.3125	16	0.50
Strombus sp.	1	2	0.2500	16	0.65
Tectus sp.	1	2	0.0625	16	0.25
Cynatium sp.	1	2	0.0625	16	0.10
Terebralia sp.	1	2	0.0625	16	0.05
Nerita sp.	31	10	0.6250	50	6.13
Nassarius sp.	3	2	0.1250	24	8.10
Niotta sp.	2	1	0.0625	32	2.18
Cerithium sp.	4	2	0.1250	32	4.10

Appendix 7 Echinoderms, crustaceans, and molluscs recorded in San Vicente and Talima on Olango Island (from USC-MBS 1980)

Echinoderms	**Crustaceans**	**Molluscs**			
Holothuria sp.	*Squilla* sp.	*Terebralia sulcata*	*Lambis millepeda*	*Bursa bufo*	*Rapana* sp.
Synapta sp.	*Thalamita* sp.	*Terebralia* sp.	*Lambis lambis*	*Bursa* sp. 1	*Buccinum* sp.
Holothuria atra	*Uca* sp.	*Terebralia telescopi*	*Strombus aurisdiane*	*Bursa* sp. 2	*Trochus niloticus*
Bohadschia sp.	*Portunus pelagicus*	*Dolabella* sp.	*Strombus lentiginosus*	*Conus literatus*	*Trochus pyramis*
Thelenota ananae	*Pagurus* sp.	*Littorina scabra*	*Strombus luhuanus*	*Conus mustelinus*	*Angaria delphinula*
Stichopuz sp.	*Periclemnes* sp.	*Littorina fascilanara*	*Strombus sinuatus*	*Conus chaldeus*	*Astrea* sp.
Diadema setosum	*Coenobita* sp.	*Littorina* sp.	*Strombus urceus*	*Conus marmoreus*	*Tubo marmoratus*
Echinotrix calamaria	*Calappa* sp.	*Cerithium panlevi*	*Strombus labiatus labiatus*	*Conus planorbis*	*Turbo petholatus*
Toxopneustes sp.		*Cerithium* sp.	*Strombus gibberulus albus*	*Conus rattus*	*Turbo* sp.
Tripneustes gratilla		*Cerithium carbonarium*	*Strombus mutabilis*	*Conus poblianus*	*Ovula ovum*
Prionocidaris sp.		*Cerithium vertagus*	*Strombus* sp. 1	*Thais schinata*	*Oliva annulata*
Salmacis sphaeroides		*Cypraea moneta*	*Strombus* sp. 2	*Thais bufo*	*Ischnochiton* sp.
Echinometra oblongata		*Cypraea annulus*	*Strombus* sp. 3	*Polinices tumilus*	*Cardium* sp.
Protoreaster sp.		*Cypraea tigris*	*Strombus* sp. 4	*Polinices flemingiana*	*Tridacna crocea*
Linkia laevigata		*Cypraea olivacea*	*Strombus* sp. 5	*Nassarius bicolor*	*Spondylus spodgylus*
Archaster typicus		*Cypraea isabella*	*Strombus* sp. 6	*Nassarius subspinosum*	*Spondylus* sp. 1
Mastiphiotrix sp.		*Cypraea poivigi*	*Strombus* sp. 7	*Bulla ampula*	*Spondylus* sp. 2
Ophiomastrix sp.		*Telescopium telescopium*	*Strombus* sp. 8	*Nerita undata*	*Malleus malleus*
Ophiorachna incressata		*Cypraea labrolineata*	*Dostorsio anus*	*Nerita exuvia*	*Anadara maculosa*

Appendix 8 Birds found in Olango Island Wildlife Sanctuary (from PAWD-EMPAS DENR-7 1993)

Common name	Scientific name	Status	Abundance
Yellow Bittern	*Ixobrychus sinensis*	R	2
Chinese Egret	*Egretta eulophotes*	P/N/E	3
Little Egret	*Egretta garzetta*	P/N	3
Intermediate Egret	*Egretta intermedia*	R	1
Reef Egret	*Egretta sacra*	R/V	1
Cattle Egret	*Bubulcus ibis*	R/V	1
Green-backed Heron	*Butorides striatus*	R	3
Grey Heron	*Ardea cinerea*	N/V	1
Purple Heron	*Ardea purpurea*	R/V	1
Northern Shoveler	*Anas clypeata*	N/V	1
Garganey	*Anas querquedula*	N/P	1
Buff-banded Rail	*Rallus philippensis*	R	2
Barred Rail	*Rallus torquatos*	R	2
Lesser Frigate-bird	*Freagata ariel*	P/V	1
Common Black-headed Gull	*Larus ridibundus*	P/N	3
Japanese Gull	*Larus crassirostris*	P/V	1
Common Tern	*Sterna hirundo*	P/N	3
Little Tern	*Sterna albifrons*	R/P	3
Black-naped Tern	*Sterna sumatrana*	R/V	1
Gull-billed Tern	*Gelochelidon nilotica*	P/N	3
Whiskered Tern	*Chlidonias hybrida*	P/N	3
White-winged Black-Tern	*Chlidonias leucoptera*	P/N	2
Paleartic Oyster-catcher	*Haematopus ostralegus*	L/V	1
Pacific Golden Plover	*Pluvialis fulva*	P/N	3
Grey Plover	*Pluvialis squatarola*	P/N	3
Lesser Sand Plover	*Charadrius mongolus*	P/N	3
Greater Sand-Plover	*Charadrius leschenaultii*	P/N	3
Little Ringed Plover	*Charadrius dubius*	P/N/V	1
Kentish Plover	*Charadrius alexandrinus*	P/N	3
Black-tailed Godwit	*Limosa limosa*	P/N	2
Bar-tailed Godwit	*Limosa lapponica*	P/N	3
Little Curlew	*Numenius minutus*	N/V	1
Whimbrel	*Numenius phaeopus*	P/N	2
Western Curlew	*Numenius arquata*	P/N	3
Far-eastern Curlew	*Numenius madagascariensis*	P/N	3
Common Redshank	*Tringa totanus*	P/N	3
Common Greenshank	*Tringa nebularia*	P/N	3
Wood Sandpiper	*Tringa glareola*	P/N/V	1
Marsh Sandpiper	*Tringa stagnatilis*	P/N/V	1

(Appendix 8 continued)

Common name	Scientific name	Status	Abundance
Common Sandpiper	*Actitis hypoleucus*	P/N	3
Grey-tailed Tattler	*Heteroscelus brevipes*	P/N	3
Terek Sandpiper	*Xenus cinereus*	P/N	3
Sharp-tailed Sandpiper	*Calidris acuminata*	P/N	1
Curlew Sandpiper	*Calidris ferruginea*	P/N	3
Red Knot	*Calidris canutus*	P/N	3
Great Knot	*Calidris tenuirostris*	P/N	3
Rufous-necked Stint	*Calidris ruficollis*	P/N	3
Sanderling	*Calidris alba*	P/N	2
Broad-billed Sandpiper	*Limicola falcinellus*	P/N/V	1
Ruddy Turnstone	*Arenaria interpres*	P/N	3
Asiatic Dowitcher	*Limnodromus semipalmatus*	P/N	3
Swinhoe's Snipe	*Gallinago megala*	P/N/V	1
Red-necked Phalarope	*Phalaropus lobatus*	P/N/V	1
Peregrine Falcon	*Falco peregrinus*	R/V	1
Blue-breasted Quail	*Coturnix chinensis*	R	1
Emerald Dove	*Chalcophaps indica*	R	2
Island Collared-Dove	*Streptopelia bitorquata*	R	2
Spotted Dove	*Streptopelia chinensis*	R	3
White-eared Brown Fruit Dove	*Phapitreron leucotis*	R	2
Zebra Dove	*Geopelia striata*	R	3
Colasisi	*Loriculus philippensis*	R	1
Greater Coucal	*Centropus sinensis*	R	2
Lesser Coucal	*Centropus bengalensis*	R	2
Philippine Coucal	*Centropus viridis*	R	2
Oriental Cuckoo	*Cuculus saturatus*	P	2
Koel	*Eudynamys scolopacea*	R	2
Short-eared Owl	*Asio flammeus*	R	1
Common Kingfisher	*Alcedo atthis*	R	1
Variable Dwarf-Kingfisher	*Ceyx lepidus*	R	1
White-collared Kingfisher	*Halcyon chloris*	R	3
Barn Swallow	*Hirundo rustica*	P	3
Red-rumped Swallow	*Hirundo daurica*	R/P	2
Pacific Swallow	*Hirundo tahitica*	R/P	3
Richard's Pipit	*Anthus novaeseelandiae*	R	3
Pechora Pipit	*Anthus gustavi*	R/P	3
Grey Wagtail	*Motacilla cinerea*	R/P	2
Pied Triller	*Lalage nigra*	R	3
Philippine Bulbul	*Hypsipetes philippinus*	R	3
Yellow-vented Bulbul	*Pycnonotus goiavier*	R	3
Brown Shrike	*Lanius cristatus*	P	3

(Appendix 8 continued)

Common name	Scientific name	Status	Abundance
Long-tailed Shrike	*Lanius schach*	R	2
Asian Glossy Starling	*Aplonis panayensis*	R	3
Pied Buschat	*Saxicola caprata*	R	3
Oriental Magpie-Robin	*Copsychus saularis*	R	3
Bright-capped Cisticola	*Cisticola exilis*	R	2
Lemon-throated Leaf-Warbler	*Phylloscopus cebuensis*	R	2
Great Reed Warbler	*Acrocephalus arundinaceus*	R	3
Oriental Bush Warbler	*Cettia diphone*	R/P	2
Golden-billied Flycatcher	*Greygone sulphurea*	R	2
Pied Fantail	*Rhipidura javanica*	R	3
Grey-streaked Flycatcher	*Muscicapa griseisticta*	R/P	2
Large-billed Crow	*Corvus macrorhynchos*	R	2
Olive-backed Sunbird	*Nectarinia jugularis*	R	3
Eurasian Tree Sparrow	*Passer montanus*	R	3
Chestnut Munia	*Lonchura malacca*	R	3
Malaysian Sand Plover	*Charadrius peronii*	P/N	1
Blue Rocktrush	*Monticola solitarius*	P	1

R = resident, present all year

P = passage migrant, regularly passes through the country on its migration between its breeding and non-breeding areas

N = non-breeding winter visitor, presumed not to breed but remains in the country for several months and breed elsewhere

L = little known, status is little known, but is recorded regularly in the country

V = vagrant, accidental visitor in the sanctuary

E = endangered;

Abundance: 1 = very scarce, fewer than 5 records, 2 = uncommon resident or annual visitor, seen fairly regularly; 3 = fairly common to abundant

Appendix 9 Populations of birds monitored in Olango Wildlife Sanctuary in 1996 (A Mapalo unpublished data)

	Month												
Species	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Total**
Butorides striatus	2	14	17	14	8	7	4	9	6	10	4	6	101
Egretta eulophotes	94	48	153		41	3	–	21	–	–	6	1	367
Egretta garzetta	14	11	14	11	2	–	–	–	9	8	3	2	74
Bubulcus ibis	–	–	–	–	–	–	–	–	6	–	3		9
Egretta intermedia	–	–	–	15	–	–	8	–	–	–	–		23
Charadrius alexandrinus	12	57	23	27	–	–	–	–	–	–	5	29	153
Charadrius leschenaultii	13	–	88	15	21	12	3	5	29	4	26	71	287
Charadrius mongolus	30	383	377	117	5	3	5	4	27	10	9	17	987
Charadrius peronii	–	–	44										44
Pluvialis fulva	–	–	3	1					37				41
Pluvialis squatarola	55	801	184		9	11		5	33	11	25	12	1146
Actitis hypoleucus	19	3	8				10	2	6		5	7	60
Arenaria interpres	32	30	40	94	9			4			1	15	225
Calidris canutus		30	35					5		4			74
Calidris ferruginea	6	46	12					4	1	4			73
Calidris minuta								23					23
Calidris ruficollis		1049	1304	114	15	5			91	550	208	569	3905
Calidris tenuirostris	128	87	144					3		5	3	8	378
Heteroscelus brevipes	9	184	17	14	7				5			1	237
Limnodromus semipalmatus	39	9	7		2			19	3	5	2		86
Crocethia alba												1	1
Limosa limosa	6	17	25	4	2				9	30	43	9	145

(Appendix 9 continued)

Limosa lapponica	95	209	84	12	36			2	47	25	5	9	524
Numenius minutus	3			49	3		1	4	4	4	2		70
Numenius arquata	2	6	2					2		1	3	2	18
Numenius madagascariensis		8	6		5								19
Numenius phaeopus	21	19	28	59	25	4	4	19	5	13	23	12	232
Tringa totanus	25	386	419	303	54	4		13	44	4	30	6	1280
Tringa nebularia	27	34	9	7		2		23	4	1	7	5	119
Xenus cinereus	2	13	4				10	2		1	6	11	49
Sterna nilotica		47	52								1	11	111
Sterna hirundo		1812	1639	27	19	7		12	500	324	593	272	7660
Larus ridibundus	37	194	61					2		19		36	349
Chlidonias leucoptera			1	2	3				4		51		61
Chlidonias hybrida		8											8
Sterna albifrons		7		1							1		9
Halcyon chloris			5					1					6
TOTAL	671	5512	4805	886	266	58	45	184	870	1033	1065	3567	18962

Appendix 10 Fishing equipment and income yielded on Olango Island (CRMP 1998)

	Fishing type					
	Fish trap (pangal)	**Multiple hook & line**	**Push net (sud-sud)**	**Tropical aquarium trade**	**Abalone trade**	**Shell trade (Pandayo)**
Barangays involved	Cao-oy, San Vincente	Sabang	Sabang, Talima, San Vincente	Santa Rosa, San Vincente, Sabang	Tungasan, Sabang, Baring, Tingo	Talima, Baring, Tingo
Average catch per unit effort (kg/day)	4–8	3–4	2.4–3.6	3–5	6–8	5–6
Fishing area	Between Bohol & Cebu	Between Bohol & Cebu	Seagrass beds around Olango Is	Visayas Islands, Palawan	Olango Is., Bohol, Palawan	Palawan, Mindoro
Average earning per day (Peso)	245	90–120	14–21	100–160	120–150	–
Target species	Droversal fishes	Pelagic fishes	Cowries, *Nassa* shells	Aquarium fishes	Abalone	Shells, octopus, sea cucumber
Number of fishermen involved	150–200	90–120	150–200	600	110–150	400–800