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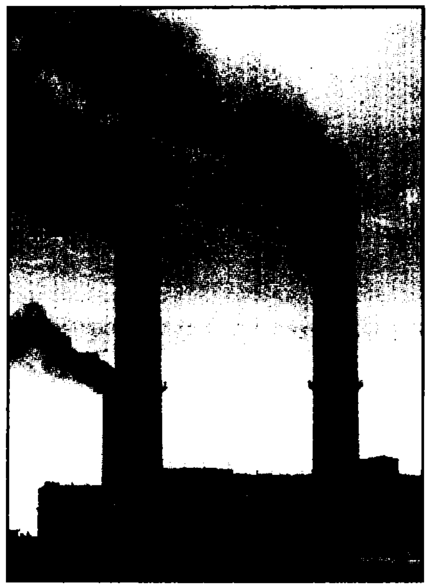
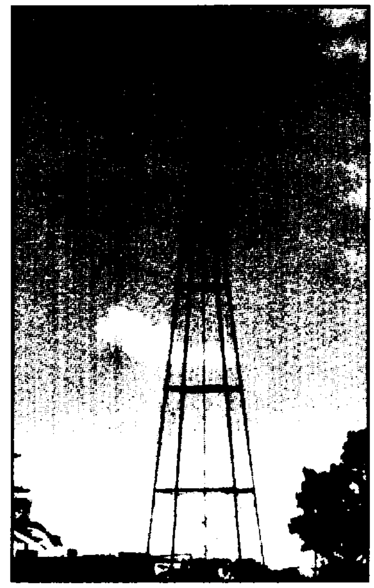
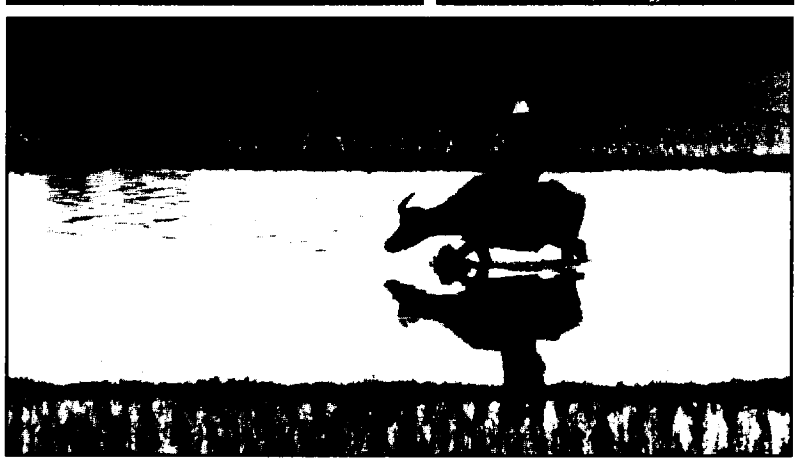
CHINA

Issues and Options in Greenhouse Gas Control







POTENTIAL IMPACTS OF CLIMATE CHANGE ON CHINA

SUBREPORT NUMBER 9

Chinese Research Academy of Environmental Sciences
Beijing, China

September 1994

CHINA

Issues and Options in
Greenhouse Gas Emissions Control

Potential Impacts of Climate Change on China

Report Number 9

by

Chinese Research Academy of Environmental Sciences
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Foreword

This report is one of eleven subreports prepared by Chinese and international experts as inputs to the United Nations Development Programme technical assistance study, China: Issues and Options in Greenhouse Gas Emissions Control.

The Chinese National Environmental Protection Agency (NEPA) was responsible for overall management of this subreport, with the project research organized by the the Chinese Research Academy of Environmental Sciences. A complete list of contributors is provided below.*

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CHINA

POTENTIAL IMPACTS OF CLIMATE CHANGE

October 28, 1994

CURRENCY EQUIVALENTS

(As of January 15, 1994)

Currency Name = Renminbi (RMB)
Currency Unit = Yuan (Y)
\$1.00 = Y 8.70
Y 1.00 = \$0.11

WEIGHTS AND MEASURES

Metric System
1 mu = 1/15 ha

ACRONYMS AND ABBREVIATIONS

C	-	Carbon
CAS	-	Chinese Academy of Science
CH_4	-	Methane
CO_2	-	Carbon dioxide
GCM	-	General circulation model
IPCC	-	Intergovernmental Panel on Climate Change
MSL	-	Mean sea level
NCAR	-	National Center for Atmospheric Research (USA)
N_2O	-	Nitrous oxide
ppm	-	Parts per million

CONTENTS

TABLES IN TEXT

TABLES IN TEXT (cont'd)

TABLES IN TEXT (cont'd)

FIGURES IN TEXT

1. INTRODUCTION

A. Survey of China's Climate

1.1 China is a developing agricultural country with a population of 1.17 billion (1992) and an area of 9.6 million km^2. Bordering the Pacific Ocean to the east, China is located in the eastern portion of the European-Asian continent, from 4°N to 53°N. The length of the coastline is about 18,000 km.

1.2 Climate in China is influenced by varied geographical conditions. The four seasons throughout the year are distinct. The mean temperature is 26°C in July and -5°C in January. The average annual temperature is about 12°C. Precipitation is concentrated mainly in the summer months due to the monsoons. The range of precipitation is large, however, with northwest China receiving less than 50 mm and south China more than 2,500 mm annually. The average annual precipitation in China is about 680 mm (Hulme et al., 1992).

1.3 China not only exhibits great climatic variability, but is also a region sensitive to climate changes. Important agricultural areas such as the northern plain and the northeast plain are in the "fragile climate region," with frequent extreme climatic conditions and severe disasters. Since the People's Republic of China was founded in 1949, there has been on average one severe flood or drought every three years (State Science and Technology Commission, 1990).

1.4 There are several large alluvial plains in coastal areas with lower-level topography such as the Pearl River delta, Yangtze River delta, and Yellow River delta. These are well developed industrial, agricultural, and economic areas with some of the densest population in China. These areas will be greatly affected by future climate warming and sea-level rise. As the climate becomes warmer, socioeconomic development in these areas will be seriously tested.

B. Global Warming and Climate Change Trends in China

1.5 The issue of global warming is of increasing concern around the world. Much uncertainty remains over whether it is the result of greenhouse gas emissions from human activities, natural undulation of climate, or both. However, most scientists in the world now agree that the "greenhouse effect" induced by the large emission of greenhouse gases (such as carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide), deforestation, and great damage to vegetation, is the major cause of global warming.

1.6 China also has an important impact on the global environment. While changes in surface air temperature tend to be similar to those taking place in the Northern Hemisphere, clear differences exist in the process and range of specific changes. According to Chinese scholars, climate change in China can be summarized as follows:

(a) Global climate in the 20th century falls within the rewarming period of the end of the Little Ice Age. In the past 100 years, global temperature has increased by 0.3-0.6°C.

(b) China's climate was coldest during the 17th and 18th centuries and has become warmer in the 20th century. Due to the general warming trend in the past 40 years, the average annual temperature in 1980s was 0.21°C higher than that for the last 30 years, and 0.16°C, 0.22°C and 0.25°C higher than that in 1970s, 1960s and 1950s, respectively.

(c) The annual temperature change in China has a clear regional distribution. The northern region, Tibetan plateau, and the coastal zone to the south of the Five Ridges, belong to a warming area, with the most significant warming taking place in the northern region and at higher latitudes. In contrast, the climate appears colder in the areas to the south of Yellow River, to the north of the Five Ridges, and to the east of Sichuan;

(d) Temperature changes exhibit a significant seasonal feature in China. The climate throughout the year exhibits a warming trend in southeast China, northern China, and the northern part of Xinjiang, especially in the winter. However, the average annual temperature is lower over most areas of the Yangtze River basin in the central part of China, especially in the summer. There has been a trend of warmer winter and colder summer both in the Yellow River valley and in the most areas of northwest China.

(e) Since the 1980s, the average winter temperature in northern areas has been 0.3-1.0°C higher than that for the past 30 years; temperature has also increased by 1.2-2.5°C in most areas of southeast China, Inner Mongolia, and the northern part of Xinjiang.

1.7 Sea-level rise can be divided into global sea-level rise and regional relative sea-level rise. The State Oceanic Administration of China has analyzed several years of monitoring data from more than 1,200 branch stations of 48 long-range tidal gauge stations. The results show that the rate of sea-level rise is 1.4 mm/yr in China, with the maximum rate, 2.19 mm/yr, found in the coastal areas of Guangdong (Tang Yongluan et al., 1993). This is consistent with the average global rate of 1-2 mm/yr estimated for the past 100 years from hundreds of tidal gauges in the world.

C. Potential for Future Climatic Change in China

1.8 Since the industrial revolution, large quantities of greenhouse gases have been emitted into the atmosphere from fossil fuels consumed by human activities. Annually, about 6 billion tons of carbon (C) is emitted into the atmosphere. In addition, methane (CH_4), nitrous oxides (N_2O), and chlorofluoro halocarbons are also emitted into the atmosphere. Therefore, as the concentration of various greenhouse gases has increased, the "greenhouse effect" caused by these gases has had a great impact on global climate, threatening the earth's environment and human subsistence. Changes in surface air temperature, precipitation, soil moisture, and total cloud cover between 1990 and 2050, based on the National Center for Atmospheric Research (NCAR) general circulation model (GCM) predictions (Wang et al., 1992), are shown in Table 1.1.

Table 1.1: The GCM Simulated Changes in Surface Air Temperature (Ts in °C), Precipitation (P in %), Soil Moisture (S in %) and Total Cloud Cover (C in %) between 1990 and 2050

Item	Ts		P		S		C	
Month	12-2	6-8	12-2	6-8	12-2	6-8	12-2	6-8
China	4.8	3.9	12.7	9.3	-2.4	-2.9	-5.1	-2.9

1.9 Because of limitations in knowledge and technological measures, many important factors in predicting climate change have not been fully considered; e.g., the implication of the biosphere, the role of deep-layered oceanic circulation, and so on. Therefore, although current predictions contain many uncertainties, the trend among the results of various GCM predictions is consistent. Due to uncertainties in predicting global climate change and the lower resolution of GCM, regional climate change prediction will be even more difficult. However, these predictions provided a basis for impact studies of climate change. Therefore, climate impact assessments and adaptive strategy studies can be conducted on this basis.

D. Impact studies of climate change in China

1.10 Climate systems are very complex, and the impact of climate change is even more complicated. Impact studies of climate change are at an early stage in China. There is a small amount of research on climate change impact, based on data collection, estimates, and analysis. In this report, the impact assessment of climate change focuses on: (1) important productive sectors including agriculture, fisheries, and animal husbandry; (2) terrestrial ecosystems; and (3) the effect of sea-level rise on economic development in the coastal regions. Adaptive strategies and mitigation measures also are included in this report.

2. IMPACT OF GLOBAL WARMING ON AGRICULTURE, ANIMAL HUSBANDRY, AND FISHERY IN CHINA

A. The Impact of Global Warming on China's Current Agriculture, Animal Husbandry, and Fishery

Planting System

2.1 China's territory ranges from 4°N to 53°30'N and from 74°E to 135°E, extending across the tropic, subtropic, warm-temperate, temperate, and subfrigid zones from south to north; and the humid, semi-humid, semi-arid, arid, and alpine frigid zones from east to west. The planting system is distributed throughout these climate zones. For reasons of climate and topography, the planting system is mostly concentrated in the southeastern part of China, which is divided by the isohyet of 400-mm rainfall. It stretches from the northeast along the Daxinganlin mountains southwest to Lhasa, Tibet, with more than 90 percent of arable land falling southeast of this line.

2.2 There is about 100 million ha of farmland in China, making up only 10.4 percent of the total land area. The total planted area of cash crops is about 3.34 million ha with tea, mulberry, fruit, and rubber plants as typical crops. Grain oil-bearing crops, and cotton are the major crops grown on agricultural land in China. The sown area for all kinds of crops in 1991 is listed in Table 2.1, while the distribution of planting divisions is shown in Figure 2.1.

2.3 Table 2.1 shows that, based on a population of 1.14 billion, China's per capita grain output is only about 387 kg, lower than the established world standards for basic grain production, set at 500 kg per person. China's agriculture has primarily reached the level of providing adequate food and clothing for the people.

2.4 Because of the size of China's population, natural resources per person are extremely limited. Farmland per capita is less than 0.1 ha, only one third of the mean world level. In addition, the country has less than 10 million hectares (ha) of potentially reclaimable idle land. The runoff of water resources is approximately 2,400 m^3 per capita, equal to one fourth of the world average. Most parts of China are influenced by a monsoon climate and almost all the nation's farmland relies on human irrigation to some extent. As a result, climate is a sensitive factor, causing fluctuations in agricultural production and constraining agricultural development.

Table 2.1: SOWN AREA OF ALL KINDS CROPS IN CHINA (1991)

Crops	Sown area /a (10^4 mu)	Total yield (10^4 ton)	Per mu yield (kg)
Total sown area	224,378.7	-	-
Grain crops	168,470.4	44,193.3	262
Summer crops	48,323.8	9,849.6	204
Rice	48,885.1	18,735.1	383
Early rice	13,698.7	4,677.6	341
Wheat	46,421.8	9,663.6	208
Corn	32,361.4	10,082.8	312
Cereal	3,121.4	336.3	108
Sorghum	2,081.6	493.2	237
Potato	13,617.4	2,719.9	200
Soybean	10,561.5	988.7	94
Other grain crops	11,420.2	1,173.7	103
Cash crops	35,207.7	303.1	112
Cotton	9,807.7	-	-
Oil-bearing	17,294.5	-	-
Peanut	4,319.9	-	-
Rape	9,200.0	-	-
Sesame	1,019.3	-	-
Sunflower	1,185.8	-	-
Fiber crops (other than cotton)	678.8	-	-
Jute and dogbane	403.5	-	-
Sugar crops	2,920.8	-	-
Sugarcane	1,745.6	-	-
Beet	1,175.2	-	-
Tobacco	2,706.1	-	-
Medical plants	254.2	-	-
Other cash crops	1,545.6	-	-
Other crops	20,700.6	-	-
Vegetable	9,819.5	-	-
Green manure crops	6,612.6	-	-
Fruit	7,976.7	-	-

/a 1 mu =1/15 ha.

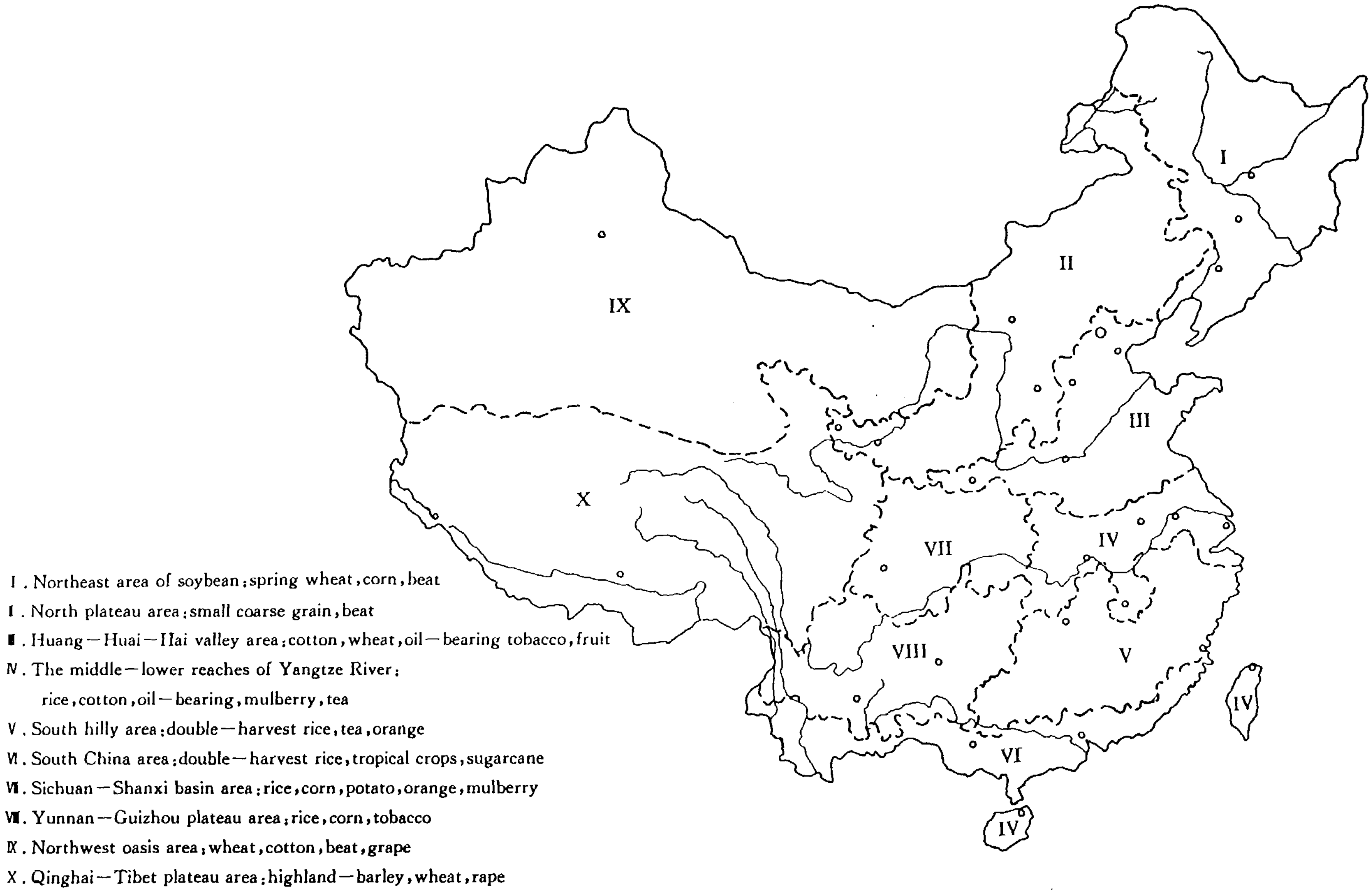

Fig. 2.1 Division map of China planting system.

Animal Husbandry

2.5 At present, China's animal husbandry is divided into three different types: the scattered home-feeding system of broad agricultural regions; the typical animal husbandry system of the grasslands; and the system of large-scale animal farms in city suburbs.

(a) **Scattered Home-Feeding Systems in Broad Agricultural Regions.** Chinese farmers have a tradition of combining agriculture and animal husbandry. Planting plays a major role in the system, with the breeding of draught animals, pigs, sheep, and fowl as a supplementary element. Because of the number of peasant households, domestic animals and fowl are the largest components of this system. For instance, by the end of 1991, the total number of major livestock (cattle, horses, donkeys, mules, and camels) was up to 1.319 billion, with this system accounting for 58-79 percent of the total. The number of pig and fowl was 3.696 billion and 25 billion, respectively, with this system accounting for more than 90 percent of the total.

(b) **Animal Husbandry Systems of the Grasslands.** The total grasslands area (including desert) is about 4 million km^2. Usable grassland covers 221 million ha, which covers 23 percent of the territory of the vast arid and semi-arid regions of the north and northwest of China. Typical animal husbandry areas are found in the three northeastern provinces as well as Inner Mongolia, Ningxia, most parts of Gansu, Qinghai, Xinjiang, northwestern Tibet, and northwestern Sichuan province. In these areas, the major breeding animals are sheep, camels, horses, and cattle.

China's grasslands can be divided into two categories. First is the temperate or desert grasslands in the north and northwest, with arid or semi-arid climate, less than 300 mm of precipitation and, in some areas, less than 4 mm. This area has a very fragile eco-environment, and overgrazing and unchecked reclamation have resulted in the expansion of grassland desertification and reduction of grass yield. Second is the frigid grasslands of the Qinghai-Tibet plateau and northwestern Sichuan. Cold is a restrictive factor in their development, as is reclamation and overgrazing in northwestern Sichuan.

(c) **The System of Large-Scale Suburban Animal Farms.** Since 1980, to supply cities with animal products and promote modernization of animal husbandry, many modern animal farms have been set up in the suburbs of Chinese cities with state, local government, and private investment, while animal husbandry production bases have also been developed. In 1987, for example, 122 animal husbandry product bases were established by the Ministry of Agriculture in cooperation with local governments.

2.6 These farms and bases have provided meat, eggs, and milk for residents of towns and cities, fur and wool for industry, and some other animal husbandry products for export. This development has also stimulated development of the feedstuff industry. By 1991, the feed-processing capability of these farms reached 60 million tons, and the capability to produce mixed feed was about 32 million tons, putting the total yield among the top in the world.

2.7 To sum up, China's animal husbandry system still relies mainly on products produced by numerous farmer-households. The output of products just meets the basic food and clothing needs of the people and the urban areas. The output per person of eggs, for example, is 7 kg (1990), roughly equal to the world average of 6.8 kg; per capita meat (25.3 kg) and milk (4 kg) production are lower than the world averages (which are 33.1 and 101 kg, respectively). The grain and forage yield and the availability of sources of protein greatly restrict further development of animal husbandry. Climate change is another important factor affecting forage production and livestock.

Fisheries

2.8 China's fishery system is divided into freshwater catch and breeding and seawater catch and breeding.

(a) **Freshwater Catch and Breeding**. China's total inland water area is 26.67 million ha, with 12 million ha of rivers, 8 million ha of lakes, and 6.6 million ha of reservoirs and ponds. There are 5,000 rivers with an area of more than 100 km^2 and 2,800 lakes with a watershed area of over 1 km^2. All are important freshwater fishery areas, with a total available breeding area throughout the country of nearly 5.64 million ha. The freshwater catch was 0.91 million tons in 1991 and the fish farm yield was 4.63 million tons. Due to arid climate over the past 30 years and increasing water consumption for industry, agriculture, and daily use, the inland water area has decreased. There were once more than 1,000 lakes in Hubei Province, for instance, but there are only about 300 left. Water pollution is also an important factor behind reductions in the freshwater catch yield. Since the late 1970s, China has greatly developed freshwater fish breeding to meet the needs of towns and cities for various aquatic products. The total amount of fish bred has gradually exceeded that of those caught.

(b) **Seawater Catch and Breeding.** The southeast region of China borders on the Bohai Sea, Yellow Sea, East Sea, and South Sea. The coastline is 18,000 km in length, and rich aquatic resources abound in these four sea districts. But due to overcatching in the coastal areas and water pollution, the catch is declining, especially for such common aquatic products as yellow croaker, hairtail prawn, and crab. In 1991, the seawater-catch yield was up to 6.1 million tons, and the seawater-bred yield was 1.90 million tons. Since the late 1970s, seawater fish breeding has rapidly developed. In 1991, the total area of seawater fish breeding exceeded 0.15 million ha.

In addition, the total output of bred prawn, hairtail, and seashell exceeded that of the seawater catch.

At present (1991), the total output value of agriculture in China is Y 815.7 billion which accounts for 42.9 percent of the rural social output value, and is equal to 28.9 percent of the industrial output value. The proportions of planting, animal husbandry, fishery, forestry, and sidelines in agricultural output value are 57.2, 26.4, 5.9 and 10.5 percent, respectively.

Regional Differences in Climate and Global Warming

2.9 If a direct relationship existed between climate change and the increase of man-made greenhouse-gas emissions, the beginnings of climate change should have coincided with the beginning of the industrial revolution. Actual climate change in various regions of China in the past century could be related to global warming, and provides important background information for estimating future climate changes in the various regions.

2.10 Analysis of meteorological data from various monitoring stations reveals that climate change trends in China during this century were the same as those in the northern hemisphere. Beginning in the early part of this century, temperature increased gradually and peaked in the mid-1940s, then dropped over the following 20-25 years. Since the mid-1960s, the temperature has slowly recovered again; by the early 1990s, it reached and exceeded the peak level of the mid-1940s. Li Kerang and Lin Xianchao (1990) analyzed the temperature change tendency based on reporting from 160 meteorological stations in the past 40 years (1951-88). The results indicate that the temperature still showed an upward trend from the 1950s to the 1980s, with temperature change in the 1980s 0.2°C greater than during the 1950s. As latitude increases, the warming area becomes larger. Temperature increase in the winter was greater than that in the summer. Moreover, in the winter temperatures generally increased in most regions.

2.11 In the last 40 years, precipitation changes also differed between regions. From the 1950s to the 1980s, on the North China Plain, Shandong, and Inner Mongolia, precipitation decreased by 24, 16.8, and 14.7 percent, respectively. In southern Xinjiang, the Weihe River, and Hanshui River areas, South China and the north part of the Northeast, precipitation had an increasing trend. The largest precipitation increase (up to 16.3 percent) is in the southern part of Xinjiang.

2.12 Based on these observations, there were different responses to global warming in different regions. To conform to the estimation pattern of the northern Hemisphere (Wang et al.,1992), we divide China into nine regions based on the present situation (1990) to make the following preliminary estimate of climatic change to 2030 (see Table 2.2). As a middle-period forecast, by the end of the next century, temperature may increase by a factor of one; meanwhile, the intensity of change will be doubled.

Table 2.2: TENDENCIES OF CLIMATE CHANGE IN DIFFERENT AREAS OF CHINA IN 2030

Region		Provinces	Climate change tendency
I.	Northeast	Heilongjiang, Jilin, Liaoning	Temp.: +1.5°C; Rainfall:+7%; Slight waterlogging in the summer
II.	Inner Mongolia	Inner Mongolia	Temp.: +1.2%; Rainfall:+5%; Slight waterlogging in the summer in eastern part
III.	North China Plain	Beijing, Tianjin, Hebei, Henan, Shandong, Shanxi, Northern Jiangsu	Temp.: +1 °C; Rainfall:+6%; Slightly waterlogging in the summer; More evaporation; Severer drought and more hot dry winds
IV.	Xinjiang	Xinjiang	Temp.:+1.2°C; Rainfall:+3%; More evaporation; Severer drought in the winter and spring; More hot dry winds
V.	Loess plateau	Shaanxi, Gansu, Ningxia	Temp.: +1 °C; Rainfall:little change; More evaporating; More hot dry winds; Rainfall: + 5% in South Shaanxi
VI.	Yunnan, Guizhou, Sichuan	Yunnan, Guizhou, Sichuan	Temp.: upward from dropping to present level; Rainfall: unchanged,+ 5% in West Sichuan.
VII.	Qinghai-Tibet plateau	Qinghai-Tibet	Temp.:+1°C; Rainfall:+ 5% in east part.
VIII.	Huaihe River to Nanlin mountain	Hubei, Hunan, Anhui, Jiangxi	Temp.:+0.5°C; Rainfall:+5%; More hot dry winds.
IX.	Coast areas	Guangdong, Guanxi, Zhejiang, Shanghai, South Jiangsu	Temp.:+0.2°C; Rainfall:+10%; Double frequency of typhoon and storm.

2.13 To sum up, there will be different climate changes in different areas by the year 2030. There will be a marked warming tendency in the northern part of China and the Qinghai-Tibet plateau. In contrast, the temperature in the south of China will increase less. In Yunnan, Guizhou and Sichuan provinces there will be a downward trend to reach the present average temperature level. Increasing temperature mainly appears in the winter and is not so obvious as in the summer. Rainfall will markedly increase in the northern warming areas, the south of Shanxi, the eastern hillsides of the Qinghai-Tibet plateau and the coastal areas of the southeast. The frequency of summer floods and waterloggings will increase in the areas of the Yangtze River, the Liaohe River, and the Haihe River. Meanwhile, the frequency of typhoons and storms will increase in the coastal areas of the southeast. In most of the remaining regions, including the greater part of Xinjiang, the central and western part of Inner Mongolia, the Loess plateau, Shandong, northern Jiangsu, Hubei, and Hunan, drought and hot dry winds will increase, as will soil evaporation, especially during the spring to early summer. All these changes will have various effects on agriculture, animal husbandry, and fisheries in the regions.

Impact of Climate Change on Agriculture, Animal Husbandry, and Fisheries

2.14 Future climate changes will greatly affect agriculture, animal husbandry, and fisheries. Some effects will be due to an ecosystem chain-reaction and are therefore difficult to estimate at present. Research on the relevant factors remains inadequate, especially quantitative research on the dose-response relationship between climatic change and productivity. Moreover, limited simulated research that takes place single-factor conditions may differ from the actual situation. It is therefore difficult to quantitatively assess the impact of future climate changes on agriculture, animal husbandry, and fisheries. The following are key prerequisites for such an estimation.

(a) It is necessary to consider future climate changes in different areas, based on direct observation of the present situation in these areas and the major climate change impacts on agriculture, animal husbandry, and fisheries. Based on the estimation for different areas, one can then make an overall estimation for the country. Changes in the isohyet rainfall line and the northward movement of planting zones should also be considered.

(b) It is important to fully utilize the limited data available from research on the dosage-reaction relationship to climate change effects and to choose carefully conformable results as the basis of quantitative estimation. One must also consider empirical statistics on climate change effects in the past time to identify trends in such areas as the frequency of disasters and the quantity of effects as the basis for estimation.

(c) It is necessary to consider those direct and indirect factors related to the effects of global warming, and based on changes in different regions, to estimate their positive and negative effects. These major factors are:

(i) The possible impacts of temperature increase;

(ii) The possible impacts of rainfall increase;

(iii) The possible impacts of an increase in CO_2 concentration. For plants, it is necessary to consider the different responses of C3 and C4 plants;

(iv) The impacts of soil and water evaporation increase;

(v) The impacts of typhoons, storms, and hot dry winds;

(vi) The frequency of pests and disease resulting from changes in temperature and moisture;

(vii) The adaptability of animals and plants in response to climate change.

B. Impact of Climate Change on the Agro-ecological Environment

2.15 Climate changes will effect the agro-ecological environment in many ways, including the level of soil erosion, soil water evaporation, transpiration from crop leaves, soil salinization, marsh formation, vegetation cover, biodiversity, and so on. An analysis of various effects has been made in this report, to better inform decisions on effective measures for preventing or adapting to global warming.

Impact of Climate Change on Soil Erosion

2.16 Climate is an important factor in soil erosion. Soil erosion occurs continuously, and appears to follow a stable and regular pattern over time. But following climate changes, differences in temperature, moisture, and the duration and strength of sunshine may speed up soil erosion.

2.17 Based on Table 2.2 and the classification of soil erosion in China by Xin Shuzhi and Jiang Delin (1982), soil erosion in China can be summarized as shown in Table 2.3. Table 2.3 indicates that climate warming will lead to increased soil erosion no matter what type of zone it takes place in. This will no doubt increase fertilizer loss and losses of farmland, especially in river-mouth areas. Increases in wind speed caused by climate warming will increase water power, freezing, melting, and other soil erosion. Ecological construction projects should be strengthened to prevent wind and erosion damages.

Impact of Climate Change on Soil Evaporation and Plant Transpiration

2.18 Evaporation and transpiration of water in soil and plants will increase as temperature rises and weather becomes increasingly dry. Based on a formula for the earth's heat balance, Budyko estimated that for every 1°C temperature increase, the evaporation rate will increase by 4 percent. Gao Suhua (1991) pointed out that after temperature rises, the increased evaporation rate in the summer is greater than in the winter, and greater in the north than in the south, i.e., the drier the regions, the greater the evaporation rate. Zhang Houxuan (1992) pointed out that when temperature rises 1°C,

Table 2.3: TYPES OF SOIL EROSION AND ITS CHANGES DUE TO CLIMATE WARMING IN CHINA

Type of erosion	Main region	Situation after climate warming
Region with water as main energy	Loess plateau in Northwest, black soil in Northeast, mountains and rolling hills in North, basin and hills in Sichuan, plateau in Yunnan and Guizhou	Precipitation per year in China increases by about 7%,8% and 10% in Yangtze River basin and Yellow River valley, which increases surface water and groundwater and cause more severe soil erosion in these regions.
Regions with wind as main energy	Plain in the North China, Xinjiang,Loess plateau, Inner Mongolia, Huaihe River valley and coastal region	Wind intensity and speed will be more great, and severe weather caused by wind will increase. Precipitation mainly concentrates in July and August, so that it will be drier in other months. Because of dry soil, erosion caused by wind will be more strong, which makes soil erosion more serious.
Regions with freezing and melting as energy	Plateau in Qinghai and Tibet, Tianshan mountain region in Xinjiang, cold regions in Heilongjiang River Valley	Temperature rises,and it will become warmer in the early spring; snow melt earlier and quicker. But because soil thaws slow, the melted snow stream will wash away top soil.
Other regions	Coastal regions, river mouth regions with low latitude	Coastal area will be eroded by water because of sea level rise. In river mouth sea water flows backwards, which leads to erosion, salinization and desertification.

Note: The first three types are classified by Xin Shuzhi et al., while the "other regions" are defined by writers.

soil evaporation will increase by 5-10 percent. In the future, soil evaporation will increase by 7.5-15 percent which will lead to drier soil and more severe disasters. Increased evaporation poses a threat to arid and semi-arid regions of north China.

2.19 Li Yue et al. (1991) calculate the effect on farmland planted with wheat and corn in northern China that would be caused by doubled levels of CO_2, and found that this would increase latent evaporation in the region by 4.1-6.2 percent. This is equivalent to a loss of 40-60 mm effective water.

2.20 Using the CERES model, Jin Zhiqing et al. (1992) calculated the effect of doubled CO_2 levels on farmland evaporation in southern China, where rice is grown. They pointed out that on the one hand, night temperature increases evaporation, while on the other hand, increased levels of CO_2 cause the stomas on leaves to open less, thereby decreasing transpiration. On balance, the amount of water lost due to evaporation and transpiration in such areas appears to decline. Evaporation levels in rainfed rice fields are obviously less than those in irrigated fields.

2.21 Using the NCAR model, the "climate change and crop yield" research group (1992) has analyzed and predicted soil evaporation when CO_2 is doubled, as shown in Table 2.4.

Table 2.4: EVAPORATION SITUATION IN CHINA WHEN CO_2 IS DOUBLED

Regions with increase in evaporation	Xinjiang, most parts of Qinghai, parts of Gansu and Tibet: 30 mm increase; Coastal regions: 10 mm increase
Regions with decrease in evaporation	East and northeast of the North: 10 mm decrease Yunnan, Sichuan and Guizhou: 20 mm decrease Central China: 0-10 mm decrease

2.22 Regions with increased soil evaporation are located in arid or semi-arid areas and coastal areas, while northeast and central China may belong to the region of decrease. Therefore, with the exception of Yunnan, Guizhou, and Sichuan provinces, soil evaporation will increase in most parts of China because of climate changes, and soil will become much drier.

2.23 Wang et al. (1993) also point out that, although precipitation in China will increase, it is possible for some areas to become drier because rising temperatures will simultaneously increase evaporation. Annual changes in the moisture content of soil and the aridity index in China will be -11.5 percent and 0.19 percent, respectively; -12.9 percent and 0.05 percent in the Yangtze River basin; -9.7 percent and 0.05 percent in the Yellow River valley.

2.24 Transpiration of crop leaves will be heightened in regions of temperature increase. Since temperature increases in the winter are more obvious, the effects on the wheat crop will be more obvious. Besides, because transpiration of spring-sown crops and wheat during the spring and early summer is much larger due to drought, crops will die if they do not get enough water. In short, if the climate becomes warmer, evaporation of soil water in the regions with increased temperature will be greater, and plant transpiration will increase. This will harm crop growth and reduce output.

Impact of Climate Change on Soil Salinization and Swampiness

2.25 Soil salinization and swampiness are formed by natural conditions and internal soil factors. As mentioned above, climate changes may lead to more concentrated precipitation in many areas of China. The dry period will extend, leading to more serious soil erosion and soil salinization. Drought development will lead to more demand for farm irrigation. In those regions where evaporation is greater than precipitation, and where irrigation methods are not suitable or irrigation installations are imperfect, irrigation will increase the threat of secondary soil salinization.

2.26 Thus, it can be seen that climate change will lead to soil salinization. In regions that already have soil salinization problems, serious drought will make salinization worse.

2.27 In order to prevent soil salinization caused by climate change, drip irrigation or spray irrigation should be used, and drainage and irrigation installations should be coordinated. Before channeling water for irrigation, pH values must be tested, especially in saline-alkaline soil areas. For the precipitation distribution, after climate zones move north, soil salinization will mainly appear in the northern part of central China and the northeast, north, and northwest.

2.28 Soil swampiness results from precipitation increases, from sea water re-irrigation caused by sea-level rise, from drainage obstacles on low-lying farmland, and from elevation of groundwater levels.

2.29 If climate changes occur in China during the next 30-40 years, the main problems thus are likely to be more serious drought and subsequently greater soil salinization. In the northeast, the eastern part of Inner Mongolia, the eastern part of the Qinghai-Tibet plateau, and the coastal regions in the southeast, there may be floods for a brief period (as well as in low-lying areas and regions with difficult drainage). Especially in the northeast plain and coastal regions of the southeast, swampiness may become more serious.

Integrated Assessment of the Impact of Climate Change on the Agricultural and Ecological Environment

2.30 The preceding analysis reveals both advantages and disadvantages to the ecological environment and agriculture as the climate becomes warmer. Results will be reflected in good or bad cycles within the agricultural ecological environment, as well as production increases or decreases involving agriculture, animal husbandry, and fisheries.

2.31 Just as Wang et al. (1993) pointed out, if the rate of greenhouse gas emissions remains constant, by the middle of the 21st century the temperature zones in China will move 4° latitude to the north. By then, the frigid-temperate and moderate-temperate zones will largely disappear, while the size of the subtropic zone will increase greatly. If this happens, it will be favorable to agriculture because of (a) an increase in the multi-planting index (equivalent to the increase in planting area); (b) mitigation of low temperature for crops in the spring in the southeast, and cold damage to crops in the early summer in the northeast; and (c) increasing CO_2 concentration and strengthening photosynthesis. In some areas, increases in green vegetation will also improve the local agro-ecological environment, benefitting agricultural production. These are the positive effects.

2.32 There are also many negative effects. *First*, because of increased evaporation, although precipitation will increase a little, soil moisture will decrease by 11.5 percent and lead to the threat of drought. Because precipitation increases mainly in the summer, the possibility of storms in July or August will increase, which will make agricultural development unstable and production more dependent on the natural environment. *Second*, northward-moving temperature zones will force some species to move or become extinct, leading to a large readjustment of the whole ecosystem that may threaten agriculture systems. *Third*, increases in temperature and evaporation levels will lead to serious drought throughout the country. Water shortages will become more conspicuous. The northwest climate will be more dry, and desertification will become more serious. Desertification in northern, central, and northeastern China will develop further. *Fourth*, rising sea-levels will inundate some coastal areas; low-lying fields will be flooded; storm surges will occur more frequently; and drainage will be more difficult in inland areas of low elevation. In delta areas, incoming sea water will degrade or flood farmland; groundwater will be more salty; and salinization, swampiness, and erosion will be aggravated. Farmland will undoubtedly be degraded or destroyed on a large scale. *Fifth*, because temperature will increase mainly in the winter, pests will not die of cold. In the spring, plant diseases and insect pests will appear earlier. In the autumn, the havoc period will last longer and cause more damage to agricultural production. Luxuriant weeds due to temperature increases will also increase agricultural costs and decrease harvests. *Sixth* is damage to the grasslands. Soil desertification and drying will decrease grass production, which will further affect animal husbandry. *Seventh* is damage to the aquatic ecological environment, which will decrease fishery production. Because of the fast pace of climate change, some rare and endangered aquatic animals will become extinct. *Eighth* is erosion of farmland due to a concentration of rainfall, which will lead to loss of fertilizer components. Floods will cause large losses of aquatic production.

2.33 Thus, looking at the overall effect of climate change, the disadvantages clearly outweigh the advantages. The potential effect on agriculture, animal husbandry, and fishery will be discussed below.

C. Impacts of Climate Change on the Planting System

Impacts of CO_2 Concentration Change

Positive Effect of CO_2 Concentration Multiplier

2.34 In the form of fertilizer, CO_2 could help increase the carbohydrate level of plants. Moreover, photosynthesis is the most important way that CO_2 is absorbed from the atmosphere. Numerous studies have shown that high concentrations of CO_2 could enhance the rate of photosynthesis and subsequent plant growth by reducing water losses from the plant interior.

2.35 Plants respond differently to increases in the concentration of CO_2, however, because their photosynthesis pathway may be either a C3 or C4 type. The CO_2 photo-saturated concentration of C3 plants is 1,500-2,000 ppm, while for C4 plants it is 500 ppm (Qu Xiangzhong, 1983). Therefore, as the concentration of CO_2 increases, the potential for increasing production of C3 plants (such as rice, wheat, potatoes, barley, and legumes) is greater than that for C4 plants (such as sorghum, corn, millet, and sugarcane). According to a 1989 report (Wang Shaowu, 1989), if the level of CO_2 concentration doubles, the fixed rate of CO_2 increases by 50 percent for C3 plants. At the same time, the dry matter and yield increases by about 10-50 percent. C4 plants are less sensitive to percent increases in CO_2 concentration, and yields would only increase by about 0-10 percent. Table 2.5 represents changes in crop yield as CO_2 concentration is doubled.

2.36 Although many experiments in controlled greenhouse or growth chambers have shown that enhanced CO_2 concentrations could increase plant productivity by up to 50 percent, this may not be true under normal agricultural conditions. Often, crops growing under enhanced CO_2 conditions initially show a large response, but with time this response declines and approaches that of crops growing under current CO_2 levels. In contrast, crop growth may be more strongly affected by soil fertility and water availability. Competition for other scarce resources could conceivably restrain the response of plants to higher levels of CO_2. The direct effects of enhanced CO_2 levels should therefore be smaller than those measured under controlled conditions. The main gain could occur in those regions where plants are under water stress, either now or in the future, and where any increase in water-use efficiency will enhance crop productivity.

Indirect Effect of CO_2 Concentration Multiplier

2.37 The previous discussion takes only CO_2 levels into consideration. But CO_2 effects could actually have a disadvantageous impact on China's agricultural production. Along with CO_2 concentration increases, a series of climate changes, (such as temperature and rainfall increases and frequent occurrences of extreme climate) have complex effects on China's planting system, as discussed below.

Table 2.5: IMPACTS OF DOUBLED CO_2 ON CROP YIELD

Type of crop		Increase of biomass for immature crop (%)	Increase of yield for mature crop (%)
C3 plant	cotton	124	104
	cucumber, eggplant, okra, sesame, tomato	40	21
	barley, rice, sunflower, wheat	26	36
	broccoli, white-lucerne, lettuce	37	19
	kidney bean, pea, soybean	43	17
	sweet turnip, nave	49	-
C4 plant	pasture-plant	34	-
	sorghum	5	7
	corn	1.7	2
	millet	9	8
	sugarcane	4	-

Impact of Rising Temperature

Positive Effects of Temperature Increase

2.38 If other factors such as rainfall and evaporation are ignored, and only the heat needs of crop growth are considered, temperature increases would have an advantageous impact on China's planting system. As CO_2 concentration is doubled, the active accumulated temperature above 10°C and its sustained days would increase. In addition, as the average annual temperature increases, the period of no frost increase. As a result, crop planting boundaries would shift greatly to the north.

2.39 Based on the cropping pattern in China between 1951-80, changes in cropping patterns as Table 2.6 estimate temperature increases. The potential changes in cropping systems projected by the composite GCM scenarios in the year 2030 for China are also given in Table 2.6. This indicates that, except for the southwest part of the Qinghai-Tibet plateau and the northern part of the northeast, large changes would occur almost everywhere in China. The most significant changes occur in east China, which is currently the most important agricultural area. The warmer climate will cause a large part of the present double-cropping area to be replaced by different triple-cropping systems, while the current double-cropping area will shift northward to the central part of the current single-cropping area. More explicitly, the northern boundary of the triple-cropping area will shift more than 500 km from its current border at the Yangtze River toward the

Table 2.6: PERCENTAGE OF AREA UNDER DIFFERENT CROPPING SYSTEMS PREDICTED BY THE CROPPING SYSTEM MODEL FOR CURRENT (1951-80) CLIMATE AND FOR THE YEAR OF 2030
(From Hulme et al.,1992)

Cropping system		Current climate	Best estimate in 2030	Low estimate in 2030	High estimate in 2030
I.	Single cropping	62	39	31	56
II.	Double cropping	24	25	21	29
III.	Triple cropping	12	29	19	29
IV.	Heat triple cropping	1	7	3	11

Yellow River, and shifts in multiple-cropping systems will significantly decrease the extent of single-cropping regions (Hulme et al., 1992).

Negative Effects of Temperature Increase

2.40 To a certain extent it seems that climate warming should be favorable to agricultural production in China, increasing yields due to diversification of cropping systems. Unfortunately, as climate changes, the balance between water and heat is often not suitable. Temperature increase is accompanied by less rainfall increase, but evapotranspiration also increases. According to direct observation, as the average annual temperature increases by 1°C, evapotranspiration increases by 32 mm, which is equal to 4 percent of total evapotranspiration (Zhang Houxuan, 1992). Based on statistical data, if temperature increases by 1°C, evapotranspiration increases by 5-10 percent. This indicates that, as climate becomes warmer in China, future evapotranspiration will be 5-15 percent greater than at present. This will seriously affect agricultural production in northwestern and northern China, which are already areas of drought. Other reports indicate that, as CO_2 concentration is doubled, the effect of rising temperatures on evapotranspiration is greater in summer than in winter, and greater in the north than in the south. The more dry areas, the greater the change. In January, evapotranspiration will increase by 1 percent in the north and 4 percent in the south; in the summer, it will increase 18 percent in the north and about 10 percent in the south.

2.41 In China, the major crop cultivated in multiple-cropping systems is paddy rice, and its normal growth requires a great amount of water. Because the net balance of precipitation and evapotranspiration would be negative, less water will be available, making the future climate less suitable for rice cultivation. In other words, the area of triple-cropping suitable for rice cultivation will increase, but average yields will decrease due to decreased water availability.

2.42 Wheat is the staple crop in double-cropping regions where water demands cannot be met at present. So the wheat crop would also be seriously affected by slight changes in the water balance. But in some regions, crop yields would almost certainly increase. At the cold margins of cereal production zones, where conditions tend to be sub-optimal because low temperature often prevents crop maturation and/or early frosts result in harvest failure, a warmer climate may increase yields significantly. This is most likely to occur in northeast China and the Qinghai-Tibet plateau, currently one of the coldest agricultural areas in China.

2.43 The effect of temperature alone on crop growth is very complex. Figure 2.2 indicates that crop yields (rice, wheat, and corn from north to south) decreased as temperature increased in China in 1987. When temperature increases by 1°C, the per unit area yield of rice, corn, and wheat decrease respectively by 14 kg, 17 kg, and 28 kg. This phenomenon occurred due to the effect of all factors, including sunshine.

2.44 But as temperature increases, precipitation, sunshine, and other climate factors will change as well, just as photothermal conditions in the northern area change into those of the southern area. As a result, as temperature increases, per-unit yields will decrease on the whole. In a few intersect-areas, spring wheat may be replaced by winter wheat and double-cropped rice may take the place of single-cropped rice, thus increasing annual yield.

Negative Effects due to Increases in Diseases and Pests

2.45 Climate warming will aggravate the threat of diseases and pests. The damage caused by pests is more serious because, as CO_2 concentration increases, crop growth speeds up, decreasing the crop's nutritional elements and protein contents. As a result, pests have to consume greater amounts to survive. According to biological studies from the University of South Carolina in the United States, the Lepidoptera larva, which feeds on potatoes, eats more when potatoes are grown under rich CO_2 conditions. As CO_2 concentration is doubled, the larvae's consumption capacity increases 80 percent. Because climate warming lengthens the period of crop growth, many pests are able to breed an additional 1-3 generations per year. The final result is that the index number increases. In addition, temperature increase is favorable for pest survival through the winter, which will increase damage done by diseases and pests in the coming year. Moreover, as CO_2 concentration is doubled, some weeds flourish. This increases competition between weeds and crops for sunshine, water, and nutrition, thereby reducing crop production.

Impact of Climate Warming on Crop Adaptability

2.46 The crop variety planted in certain areas has undergone the process of adaptability selection for a very long time. As climate becomes warmer, crops will lose their original adaptability so that crop yields could rapidly decrease. For example, when the average temperature increases by 1°C, the possible reduction of winter wheat production is 166-750 kg per hectare.

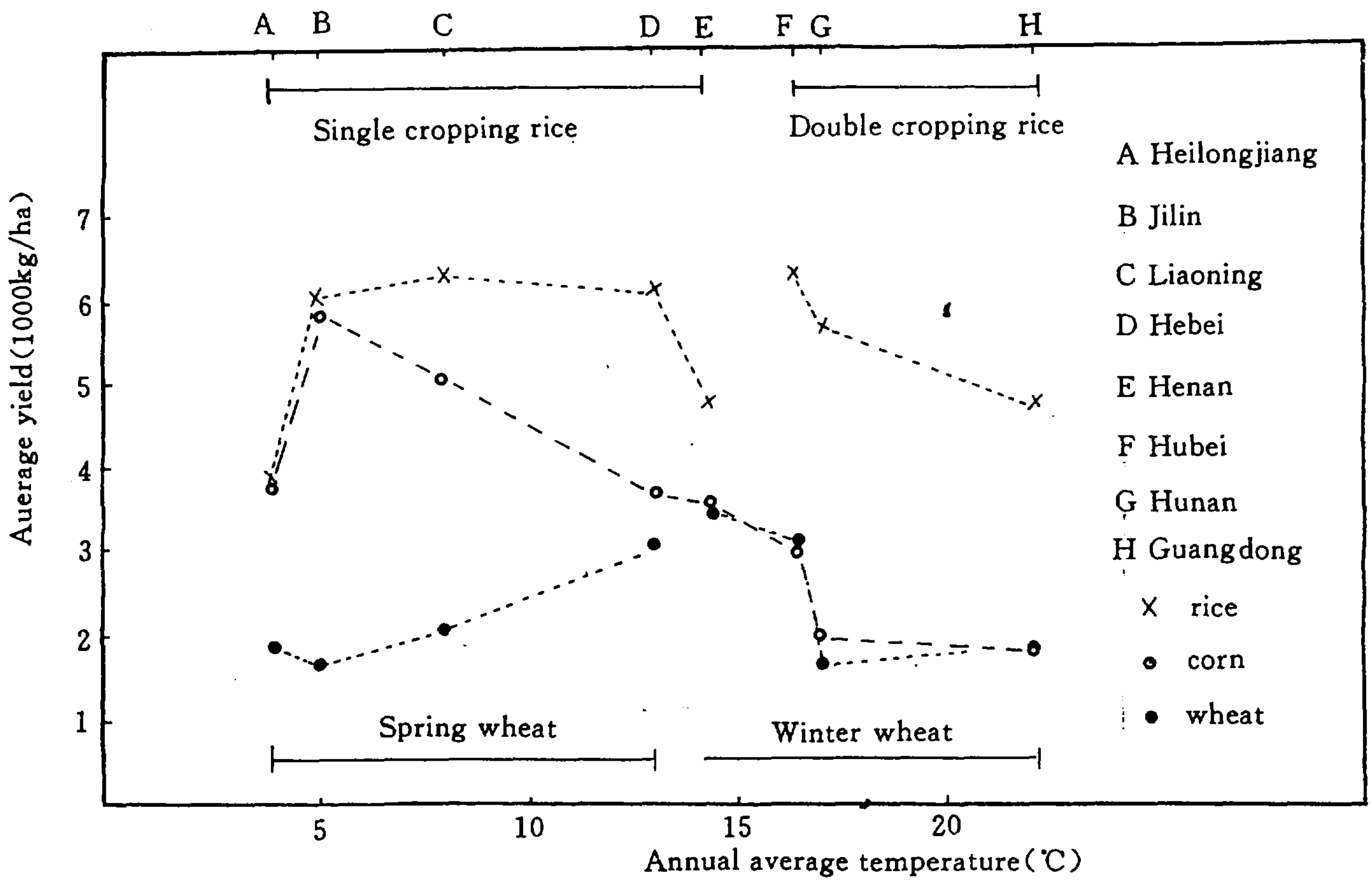

Fig 2. 2 Relationship between temperature and yield.

Impact of Extreme Climate

2.47 A disadvantageous climate can seriously harm agricultural production by restraining the growth and development of crops, hindering the metabolic process, injuring plant tissue, killing crops, and destroying agricultural installations. Many kinds of extreme climate can cause huge disasters. According to the Ministry of Civil Administration, approximately 33 million ha per year of total land area was affected by natural disasters between 1949 and 1988, including drought, waterlogging, wind, frost, and freezing. The area of reduced production was 14 million ha and the loss of grain was more than 5 billion kg due to disasters. In the past 40 years, there were 11 years in which disasters damaged more than 40 million ha. In 1988, the area affected by disaster was 51 million ha, with reduced production on 35 million ha and 49 million ha of no harvest. It caused 0.2 billion kg of grain loss as well as the deaths of 7,300 persons and 2.5 million livestock (Cheng Chunshu, 1991).

Negative Impact of Drought and Flooding

2.48 Among the various climatic factors at work, China is threatened most by drought. China's climate is controlled by the inland monsoon, which easily causes spring drought in the north, summer drought in the south, and sustained drought in the northwest. Serious droughts lead to crop death and destroys the harvest. Sustained periods without rain can cause lakes to dry up, surface water levels to drop, and the irrigation areas to decrease. Sustained drought leads to drinking water shortages for humans and livestock. In 1972, for example, when it rained less than usual in most parts of China, the area of reduced production was 13.6 million ha. Some rivers dropped to their lowest water level in history. Similarly, in 1978, spring drought in the north and summer drought in the south affected 40 million ha and led to the loss of 100 kg of grain.

2.49 In contrast, periods of heavy precipitation cause serious floods and waterlogging. Huge storms cause mountain torrents to erupt and rivers to flood, harming crops, destroying farmhouses and agricultural installations, and even causing the deaths of people and livestock. In 1954, vast areas of the Yangtze River basin were waterlogged. There were 0.17 million ha of farms flooded, 18 million persons affected, and 13,000 deaths (Liu Deren, 1987). The waterlogging of the Yangtze River basin in 1980 reduced grain production by 7.1 billion kg in Hubei, Anhui, Jiangsu, and Zhejiang provinces. In 1985, Jilin and Liaoning experienced grain losses of 5 billion kg due to waterlogging.

2.50 In 1991, disastrous flooding occurred in many areas of southern China. In Anhui and Jiangsu provinces alone, direct economic losses reached Y 40 billion. National statistics reveal an obvious trend of increasing waterlogging disasters over the past 40 years. In the first 20 years after the founding of the People's Republic of China in 1949, waterlogging disasters occurred on average once every three years. This frequency has increased to twice every two years in the last 20 years. As CO_2 concentration increases, waterlogging is forecasted to occur 1.4 times more frequently than it does at present.

Negative Impact of Increasing Typhoons and Hot Dry Winds

2.51 Typhoons cause extreme problems for agricultural production in China's coastal areas. In 1988 and 1989, 10 typhoons hit each year, affecting an average of 1 million ha of farmland. In the areas hit hardest, crop yield was reduced 50 percent and even wiped out in some areas. Studies indicate that if precipitation increases 10 percent in southeastern coastal areas, typhoon damages will increase 5 percent.

2.52 Hot dry wind, which results from climate changes, is also disadvantageous for agricultural production. It reduces production levels as it aggravates transpiration; reduces activity in the root system; worsens water conditions inside plants; weakens photosynthesis; destroys the permeability of cell membranes; reduces the transportation of organic matter; injures flower organs; and results in small and shrivelled seeds. According to 1982 statistics, in the 13 northern provinces, wheat production dropped 10 percent as a result of hot dry winds. During serious disaster years, wheat yields dropped about 10-20 percent.

Integrated Assessment of Climate Change Impact on Planting Systems

Analysis of Effect Factors

2.53 Due to the complexity of the impact of climate change, we will here consider only the most important factors. Taking Δy as the rate of change in yield of the main crop, the equation is listed as:

$$\Delta y=[f(T)+f(R)+f(CO_2]-[f(E)+f(W)+f(F)+f(P)+f(S)]$$

where

$f(T)$: the positive effect of temperature increase
$f(R)$: the positive effect of precipitation increase
$f(CO_2)$: the positive effect of increases in CO_2 concentration
$f(E)$: the negative effect of an increasing evaporation rate
$f(W)$: the negative effect of increasing storms and hot dry winds
$f(F)$: the negative effect of increased floods and waterlogging
$f(P)$: the negative effect of increases in diseases and pests
$f(S)$: the negative effect of changes in crop adaptability.

Both $f(T)$ and $f(R)$ have been evaluated by the Chinese Academy of Meteorological Science based on the following equations:

$$y_1 = 728.7693 + 23.5469x_1 + 36.7934x_2 - 0.0238x_3 - 0.0601x_4$$

$$y_2 = 588.7440 + 18.7619x_1 + 5.4757x_5 - 0.0259x_3 - 0.2695x_4$$

y_1: and y_2: meteorological yield
x_1: summer temperature
x_2: average annual precipitation
x_3: cube average annual temperature
x_4: cube of three times average annual precipitation
x_5: square of average annual precipitation

As CO_2 concentration is doubled, under conditions of 1°C of temperature increase and 5-10 percent precipitation increase, the estimated crop yield increases 3.2 percent (i.e., in the range of 1-7 percent). Studies of other factors have not been realized quantitatively so some empirical observation data are used in the assessment.

$f(CO_2)$: According to some experimental data, 2í┴CO_2 does not lead to oversaturation for C3 crops and may lead to a 20 percent production yield increase for them, while there is no obvious yield increase for C4 plants.

f(E): The precipitation increase mainly affects those areas north of 35°N and the dry index is >1. Based on observations, an increase of 1°C in average annual temperature will cause soil evaporation to increase by 32 mm.

f(W): Because of climate warming in the summer, high pressure areas may form in some inland areas. In the coastal areas of the southeast, precipitation increases by 10 percent, increasing losses due to typhoons by 5 percent. There are an average of nine typhoons each year, four of which are considered relatively strong typhoon hits. In recent years, an average of 1 million ha of farmland has been affected by such disasters each year and production drops up to about 50 percent in some of the hardest-hit areas. From south to north, tornados will randomly hit some regions, without following any regular pattern. Hot dry winds in the summer also affect various regions, including the northeast, Inner Mongolia, Xinjiang, the North China plain, and the middle-lower reaches of the Yangtze River. This reduces production of wheat and rice by about 10-50 percent.

f(F): At present, about 1 million ha is affected by floods and waterlogging annually, reducing yields 10-50 percent in the stricken areas.

f(P): Currently, the application of agricultural chemicals recovers 21 million tons of grain (equal to 5 percent of the total output) and about 50 thousand tons of cotton (equal to 13 percent of the total output).

f(S): Temperature increases would affect crop adaptability, especially for wheat, as previously discussed in para. 2.46.

Selection of the Standard Year

2.54 The year 1987 has been selected as the standard year because in the past 10 years, 1987 approximates the average year for natural disasters.

Crop Selection

2.55 Seven major crops in China have been selected for evaluation. They are wheat, rice, corn, potatoes, fruit, oil-bearing crops, and cotton. Together, these crops represent 92 percent of the total output of the planting system.

Results of Integrated Assessment

2.56 Climate change tendencies in different regions in China by 2030 are summarized in Table 2.2. The estimated yield changes are summarized in Table 2.7. Outlined below are the conclusions drawn from this evaluation.

(a) **The Response of Different Regions to Climate Change**

In remote areas of northern China, including the northeast, Inner Mongolia, northern Xinjiang, and the Qinghai-Tibet plateau, there will be a tendency for crop yields to increase. The maximum increase of 3~5 percent is in the northeast. But in Xinjiang, the production yield of wheat and oil-bearing crops is reduced about 2-3 percent due to the impact of the spring drought and hot dry wind.

In Sichuan, Yunnan, and Guizhou, no significant change in agricultural production will take place compared with the present. In other regions, the impact differs based on the extent of climate warming. The greatest impact will be felt in the North China plain, the Loess plateau, and the middle-lower reaches of Yangtze River.

(b) **Crop Responses to Climate Change**

Wheat and rice are affected most, with their total yields reduced by 8 percent and 6 percent, respectively. The reduction in wheat yields mainly results from the increase in spring-winter drought. There are also some effects of hot dry wind, diseases, pests, and changes in crop adaptability. The greatest impact appears to be in the North China plain and the Loess plateau, where total crop yields are reduced by 10-12 percent. The reduction in rice yields is a result of drought in the initial growth period, the advent of hot dry winds at the early-rice stage, and increases in diseases and pests.

On balance, the corn yield increases slightly, by 0.6 percent. This is due to the fact that corn planting areas are mainly distributed in the northeast

Table 2.7: Estimated Yield Change

Regions	Yield (10^5mt/yr) and change rate (%)						
	Rice	Wheat	Corn	Potato	Cotton	Oil-beaning	Fruit
I	7.860 (4)	3.120 (5)	25.490 (5)	1.109 (5)	0.003 (5)	0.671 (5)	1.060 (3)
II	0.080 (2)	1.257 (4)	2.733 (4)	0.337 (5)	0 0	0.540 (5)	0.065 (2)
III	12.100 (-10)	46.300 (-12)	30.854 (-2)	9.731 (-2)	2.756 (-5)	5.396 (-5)	5.890 (-5)
IV	0.362 (2)	3.537 (-2)	1.751 (2)	0.037 (3)	0.280 (2)	0.423 (-3)	0.590 (2)
V	1.410 (-6)	7.600 (-10)	4.436 (-5)	1.070 (-2)	0.061 (-5)	0.654 (-5)	0.800 (-6)
VI	27.700 (0)	7.645 (0)	9.679 (0)	6.941 (0)	0.102 (0)	2.214 (0)	1.520 (0)
VII	0.002 (3)	0.783 (2)	0.007 (3)	0.090 (3)	0 (0)	0.116 (3)	0.260 (3)
VIII	67.070 (-10)	11.749 (-5)	2.413 (-2)	4.868 (0)	0.740 (-5)	3.153 (2)	0.900 (-3)
IX	57.740 (-5)	5.716 (-3)	2.457 (-2)	4.041 (2)	0.303 (-3)	2.112 (2)	5.620 (-2)
Total	174.20 (-6)	87.770 (-8)	79.820 (0.6)	28.220 (-0.2)	4.245 (-4)	15.278 (-1)	16.680 (-2.6)

China plain, where climate is suitable for corn growth. But as climate changes further, the corn yield will be reduced in most parts of China.

The yield of other crops would drop by between 0.2 percent (for potatoes) to 4 percent (for cotton). Cotton yields would drop mainly from drought and pests.

> In short, the overall yield for the seven major crops will be reduced by about 4.4 percent. If other crops are included, the total crop yield would drop 5 percent or more due to climate change.

The impacts of climate change on agriculture are very complex, and many factors have not been considered in this research. Studies on the quantitative relationship between these relevant factors and global climate change should be conducted in the future.

D. Impacts of Climate Change on Animal Husbandry

Impacts of CO_2 Concentration on Grass Growth

Table 2.8: Grass Resources in China

Grass resources	Distribution	Area (10^7 ha)
Natural grassland	North and west China	31.7 (total) 22.5 (utilizable)
Grass hills and hillsides	Southeast, southwest	6.67 (total) 4.47 (utilizable)
Marginal grassland	Scattered in planting areas	1.33
Artificial meadow		0.24
See beach and shallows		0.0238 (utilizable)

2.57 Feedstuff is the material basis for animal husbandry, and grass is the most important component. Grass is the basis for the husbandry business on vast grasslands and some farmland areas. China's grass resources are summarized in Table 2.8.

Positive Effects of Doubled CO_2

2.58 CO_2 concentration-doubling in the atmosphere is good for C3 plants, as described in paras. 2.34-23.6. C3 plant growth may increase by 20-45 percent under doubled CO_2 concentration conditions if other conditions, such as light, water, and nutrition are satisfactory (Wang Shaowu, 1989). Another positive effect of CO_2 increase is to promote the efficiency of water use by plants, because the number of the open stoma decreases, for absorption of CO_2 from the atmosphere during photosynthesis decreases, less water will be lost through transpiration.

Changes in Grass Output due to Doubled CO_2

2.59 The positive effects of doubled CO_2 on C3 plants will possibly increase grass output in China. Most grasses in China are C3 plants, and in north China, the largest constraint on grass-growing levels is insufficient water supply. We can therefore express the output change under the doubled CO_2 conditions as follows:

where $\Delta P_2 \times CO_2$ means the change of output of grasses under doubled CO_2; P_0 means the grass output at present CO_2 levels; a_1 means the direct-affect index of CO_2 and a_2 means the indirect-affect index of CO_2

$$\Delta P_2 \times CO_2 = (a_1 \times P_0) + (a_2 \times P_0)$$

From the test results mentioned above, it is estimated that a_1 = 8-20 percent and a_2=5-16 percent. A preliminary prediction can then be made for 2 x CO_2. The output of grasses in China may increase by 8-20 percent due to the positive effect of a CO_2 increase under different geography and soil conditions.

Impact of Temperature and Rainfall on Grass Output

2.60 The quantity and coordination between water and heat factors affect both the output and the quality of grasses.

Impacts of Planting System Change on Grass Output

2.61 The planting system in China will change drastically due to global warming as described in Section 2.2. This will have a major impact on animal husbandry as well. As planting zones move northward, they will encroach upon natural grassland areas, especially in northeast China, central and western Inner Mongolia, and Xinjiang. This will force the total grassland area to shrink.

Impact of Temperature and Rainfall Change on Grass Growth

2.62 Overall, changes in temperature and rainfall are estimated to be unfavorable to grass growth. On the surface, warmer temperatures and increased rainfall should be good for the growth of grasses. But except for increased grass yields possibly in the northeast, eastern Inner Mongolia, and northern Xinjiang, the yield of grasses will decrease to varying degrees in other parts of China. The main reason is that the balance of rainfall and evaporation in 2030 is expected to be negative and the amount of water available will decrease greatly.

Effect of Temperature and Rainfall on Grass Growth

2.63 Pasture in China can be classified into three types on the basis of climate characteristics (Xue Deyuan, 1989): northern pasture, western pasture, and Qinghai-Tibet frigid pasture. The distribution is given in Table 2.9.

Table 2.9: DISTRIBUTION OF PASTURE IN CHINA

Grassland	Distribution
Northern pasture	Temperate semi-humid meadow pasture: Northern Hulunbeier, Northeastern Xilinguole; Semi-arid pasture: Most of Songnun Plain, Southeastern Xilingguole, North Shaanxi,South Ningxia,Southern Gansu, Bashang area in Hebei; Temperate arid and semi-desert grassland: Central and northern Inner Mongolia,Central and western Eldorsi plateau, Central Ningxia, Southeastern Qilian Mountains; Arid desert pasture: Alashan plateau, Northern Ningxia, Gansu, Central and western Qilian Mountains
Western pasture	Most Xinjiang, Northern Gansu
Frigid pasture	Qinghai and Tibet plateau

2.64 **Northern Pasture.** At present the yield of grasses is nearly parallel to the isohyet of precipitation, i.e., 100 mm of precipitation produces 50 kg of fresh grass per mu. The annual precipitation in meadow pastures is now 400-600 mm and is expected to increase by 5-8 percent by the year 2030. The temperature will increase by 1.5-2.0°C. The fact that temperature and rainfall increase simultaneously will greatly add to the potential yield increase of grasses, possibly up to 10 percent.

Table 2.10: YIELD CHANGE OF NORTHERN PASTURE IN 2030 (kg/mu)

Pasture	Yield of grasses (kg/mu)		Variation
	Now yield	Yield in 2030	
Meadow pasture	200-300	220-330	+10%
Arid pasture	100-200	90-180	-10%
Desert pasture	50-100	40-80	-20%
Desert	10-50	0-30	-40%

2.65 Conditions in the semi-arid, arid, and desert pastures are more complex because water is the main constraint in these areas, and the available water supply will decrease greatly with the climate changes described above. The yield of grasses will be affected to different degrees, especially in the desert zones (see Table 2.10).

2.66 **Western Pasture.** Variations in the basin and mountainous grasslands, sub-alpine and alpine meadows, are different. The amount of evaporation in most basin and mountainous grasslands greatly exceeds the minor increase in precipitation. The amount of water available will also decrease greatly. The yield of grasses will thereby drop by at least 5 percent. However the temperature in sub-alpine meadows and alpine meadows is very low, which is the main constraint on grass yields in these areas.

2.67 With the temperature increase and a slight increase in rainfall by 2030, the yield of grasses in sub-alpine and alpine meadows is expected to increase to some extent (see Table 2.11).

Table 2.11: THE CHANGE OF THE GRASS OUTPUT OF WESTERN PASTURE IN 2030

Western pasture	Output of herbage (kg/mu)		Variation
	Present	2030	
Basin pasture	200-400	190-380	-5%
Mountainous pasture	200-300	190-285	5%
Alpine subalpine Meadows	50-150	55-165	-10%

2.68 **Frigid Pasture.** Because heat is the main limiting factor for grasses in this zone, the yield of grasses has a close relationship with heat but not with water. The output of grasses in Tibet's frigid pastures will increase by 2030.

2.69 Finally, because summer temperatures in most southern pastures of China are expected to increase slightly ($<1°C$) by 2030, and because precipitation is concentrated in the summer, both the output and quality of grasses will be adversely affected.

Impact of Severe Weather on Grasses due to Climate Change

2.70 Severe weather in 2030 is expected to occur 1.4 times more frequently than it does at present. The severe weather which affects development of grasses includes drought, strong storms, and sandstorms.

2.71 Drought reduces the germination of grasses in the early spring. Water shortages make it is difficult for grasses to turn green, and even if they do, their growth will be short and sparse, thus greatly reducing output. Although the increase in rainfall will be good for grass growth, strong rainstorms may lead to soil erosion or flooding in the lowlands. Therefore the area of pasture and output of grasses will be greatly reduced. Heavy sandstorms may shift the dunes and cover large areas of pasture and village. Thus, sandstorms can devour a large area of pasture, and thereby reduce grass yields.

Table 2.12: THE ESTIMATION OF EFFECTS OF RAINFALL AND TEMPERATURE CHANGE ON ANIMAL HUSBANDRY

Type of pasture	Components	Proportion to pastures of China (%)	Estimated variation of grass output (%)	Effects on animal husbandry of China (%)
Northern pasture	Meadows	11	8	0.88
	Arid and desert pasture	9	15	1.8
	Desert	4	25	1.6
Western pasture	Basins and mountains	10	20	2
	Alpine and subalpine meadows	6	6	0.36
Qinghai-Tibet pasture	Frigid meadows	10	-5	0.5
Southern pasture	Warm and wet grassland	45	-15	-6.8
Total		95/a		-10.6

/a The remained 5% is the estimated proportion for the animal husbandry in suburbs without consideration here.

Estimation of the Integrated Impact of Climate Change on Animal Husbandry

2.72 It is complex to estimate the impact of climate change on animal husbandry. Considering the main factors, we divide the Δy (which is rate of variation in grass output caused by climate change) into direct and indirect factors.

$$\Delta y = f(Z) + f(J) \quad (5)$$

where:

$$f(Z) = f(2 \times CO_2) \quad (6)$$

$$f(J) = f(R) + f(T) + f(D) + f(P) + f(W) + f(O) \quad (7)$$

$f(Z)$: the direct factor
$f(J)$: the indirect factor
$f(2 \times CO_2)$: the direct effect of doubled CO_2
$f(R)$: the effect of rainfall
$f(T)$: the effect of temperature

Table 2.13: THE ESTIMATION OF EFFECTS OF SEVERE WEATHER ON YIELD OF GRASSES IN PASTURE

Effect factor	Loss of grasses of China at present (%)	Increase frequency in 2030 (%)	Loss of grass of China in 2030 (%)
Draught	5.0	40	7
Sandstorm	1.5	40	2.1
Rainstorm	1.5	40	2.1
Pest and disease	1.0	40	1.4
Other	1.0	40	1.4
Total	10.0		14.0

Table 2.14: DIVISION OF THE FISHERY DISTRICTS IN CHINA

Fishery districts	Subdistricts
Inland fishing district	Northeast region, South China region; North China region; Southwest region; the middle-lower reaches of the Yangtze River region; Inner Mongolia-Xinjiang region; Qinghai-Tibet region.
Shallows and shoals fish-breeding district	Bohai Sea; Yangtze River Estuary; northern Yellow Sea; southern Yellow Sea; northern. The western coast of East Sea; The northern coast of South Sea; The islands of South Sea.
Sea fishery district	Bohai Sea; Yellow Sea; East Sea; South Sea

f(D): the effect of drought
f(P): the effect of diseases and pests
f(W): the effect of rainfall
f(O): the effect of other factors

substituting (6) and (7) for (5)

$$\Delta y = f(2 \text{ x } CO_2) + f(R) + f(T) + f(D) + f(P) + f(W) + f(O) \quad (8)$$

$$\Delta y = \Delta y_1 + \Delta y_2 + \Delta y_3 \quad (9)$$

where:

$$\Delta y_1 = f(2 \text{ x } CO_2)$$

$$\Delta y_2 = f(R) + f(T)$$

$$\Delta y_3 = f(D) + f(P) + f(W) + f(O)$$

As mentioned above, Δy_1, the amount of increase, is 8-20 percent, making the average, Δy_1 = 1.4 percent

Δy_2 is very complex, and the data are given in Table 2.12.

According to the calculation above:

$$\Delta y = \Delta y_1 + \Delta y_2 + \Delta y_3 = 14 \text{ percent} - 10.6 \text{ percent} - 14 \text{ percent} = -10.6 \text{ percent}$$

This means that the grass yield in 2030 may be reduced about 10.0 percent due to global climate change.

E. Impacts of Climate Change on Fishery

2.73 China's inland freshwater areas occupy approximately 17.6 million ha, including 5.64 million ha of usable fish raising area. Beaches and shallows (within 10 m isobath) cover 9.66 million ha, of which 0.13 million ha is usable for fish-breeding. The total area of the four sea districts is 4.83 million km^2, of which 1.50 million km^2 is the continental shelf.

2.74 According to 1989 statistics, the proportion of fishery in the value of agricultural production is 5.3 percent. The prosperity of the fishery sector relates directly to improvements in living standards, so the impact of climate change on fishery is of considerable concern.

Impact of CO_2 Concentration Changes on Feeding Organisms

2.75 Water containing CO_2 has a major effect on feeding-organisms in the following three areas: it exercises a buffering function on the change of water pH; it is the major carbon source for autotrophic organisms; and it directly affects the life of aquatic animals. However, the major sources of water containing CO_2 are the respiration of aquatic organisms and the oxidization-decomposition of organic substances. As oxygen is dissolved in water, small quantities of CO_2 from the atmosphere dissolve into the water. The effect of a CO_2 concentration increase in the atmosphere on the dissolution of CO_2 into the water is therefore very slight. The consumption of water CO_2 is mainly due to photosynthesis in aquatic plants (in other words, feeding-organisms). Under special climatic conditions, such as strong winds, a small amount of CO_2 could be dissolved by wind disturbance. But because of weak dissolubility, this is not a major source of atmospheric CO_2 for aquatic plants.

2.76 The major aquatic plant is water grass, found on the banks of rivers, lakes, and ponds. Most of these plants belong to C3 varieties. An increase in CO_2 concentration will have a significant effect on these aquatic plants, increasing production up to 50 percent if there are sufficient nutrients.

Impact of Temperature and Rainfall Change on Fishery Regions

Changes in Temperature and Rainfall in Fishery Districts

2.77 Located in various geographic-climatic zones of China, the climate of fishery districts in China have obvious differences. According to IPCC reports and the analysis of special climates in China, we estimated the possible changes in temperature and rainfall in fishery districts by the year 2030. The fishery regions range from the South Sea (at about 4°N) to the Heilongjiang fishery district (58°N), as shown in Table 2.15.

Table 2.15: TEMPERATURE AND RAINFALL CHANGES IN THE FISHERY DISTRICTS OF CHINA IN THE YEAR OF 2030

	Regions	Temperature increase (°C)	Rainfall increase (%)
Inland fishery districts	The Northeast region	1.5-2.0	>7
	North China region	1.0-1.5	5-8
	The Middle-Lower reaches	0.5-1.0	5
	of Yangtze River region	<1.0	5
	South China region	<1.0	10
	The Southwest region	1.0-1.5	>5
	Inner Mongolia-Xinjiang region		
	Qinghai-Tibet region		
Sea fishery districts	Bohai Sea	1.5-2.0	10
	Yellow Sea	>1.0	5-8
	East Sea	<1.0	10
	South Sea	<1.0	10

Analysis of the Impact of Temperature and Rainfall Change on Fisheries

2.78 Temperature is the most essential and important factor in aquatic organism survival. On the one hand, temperature directly and indirectly affects the metabolic intensity of organisms, and thus controls their growth, development, living conditions, output, and distribution. On the other hand, temperature changes affect food abundance and the dynamic state of physical and chemical factors, and these changes also indirectly affect the survival of organisms.

2.79 For many years, Chinese and foreign scholars have done statistical analyses on the relationship between air temperature and water temperature in various water areas and have come up with similar results. There is a close linear—correlation between water temperature and atmospheric temperature. For example, the relationship between river temperature and atmospheric temperature in Hunan Province is as follows: $y=3.47 + 0.87x$, in which y is river temperature; x is atmospheric temperature; and the correlation coefficient $r=0.91$.

2.80 For reservoir areas, the Wuhan Water Conservancy and Electric Power College researched the reservoir of the Dan River port and obtained the relationship between the surface water temperature and atmospheric temperature as follows: $y=6.1 +0.76x$ (correlation coefficient $r=0.90$).

2.81 Changes in rainfall could affect the environment of water areas, and then, indirectly, affect the growth, development, and distribution of aquatic organisms. First, as rainfall increases, the water region will expand. Meanwhile, the exchange capacity of nutrients also increases and nutrients accumulate in the water, yielding advantages to fishery production. Second, the increase in rainfall has an indirect effect on fish spawning. In spawning season, rainfall increases cause the flow-speed in natural river spawning sites to increase, which stimulates the spawning of parent fish. For sea organisms, increasing rainfall directly affects the salt concentration of seawater, and thus affects the distribution of sea organisms. In addition, increasing rainfall affects the dissolution, turbidity, and transparency of bodies of water, with certain effects on the living conditions of aquatic organisms.

Estimation of the Effects of Temperature and Rainfall Change on Fisheries

Inland Freshwater Fisheries

2.82 There are two kinds of fishery production: man-made and natural. Man-made fish breeding is the dominant form of fishery production in China. In 1989, fish breeding production accounted for 85 percent of the total output of inland aquatic products (China Agriculture Yearbook, 1990).

(a) Southern tropic and subtropic fishery regions in China

This region is China's most important base for freshwater fish production. By 2030, the average temperature will increase by less than 1°C, while temperature in the winter will drop, with negative effects on winter fish breeding and survival. Because of an approximately 5 percent drop in rainfall and the increased frequency of bad weather such as typhoons and storms, nutrition in the water and even some fish will be more easily washed away and lost. This will lead to significant losses in fishery production (see Table 2.16).

Table 2.16: Impacts of Climate Change on Fisheries in the South Sea Region in 2030

Fishery region	Distribution	Temperature change	Rainfall change	Impact on fishbreeding
South China fishery region	South of the Nanlin and Wuyi mountains; Some parts of Guangdong, Guanxi and Fujian; Taiwan; South of Yunnan	<1°C Lower temp. in the winter	10% Waterlogging induced by more typhoons and storms	-10%

(b) The Southwest region (lakes, reservoirs, and rice fields of the middle and southern Yunnan-Guizhou plateau in the subtropic zone)

In this region, low latitudes and high elevation lead to a varied climate. Because summer temperatures are high and fish lack a vigorous growing period, the production of fish has been constrained. Temperature in the region is expected to increase insignificantly through the year 2030, while rainfall will increase 5-10 percent at the same time, thereby increasing the output of fishery production (see Table 2.17).

Table 2.17: Impacts of Climate Change on Fisheries in the Southwest Region in 2030

Fishery region	Distribution	Temperature change	Rainfall change	Impact on fishbreeding
Southwest fishery region	Most part of Yunnan; Guizhou; Sichuan; the Great and small Liang mountain area (in the southwest of Sichuan)	0	5-10	+2%

(c) The middle-lower reaches of the Yangtze River (northern and central subtropical rivers, lakes, ponds and reservoirs)

This region has large rivers and many lakes, scattered reservoirs, and ponds. It is also where China's most concentrated rice fields are located.

The freshwater area is the largest in the country, and its total area accounts for 50 percent of the national inland water area. By 2030, climate change is expected to have a negative impact on fishery production. Temperature and rainfall will increase slightly, the frequency of drought and waterlogging will increase, and storm disasters will occur frequently.

As a result of these changes, the water area will be reduced due to drought, and there will be a loss of fish due to waterlogging. Second, frequent storms, mountain torrents, and loss of water and soil, will result in increasing turbidity, reduction of the transparency of bodies of water, weaker photosynthesis, and decreasing amounts of plankton. These changes will seriously affect overall fishery production (see Table 2.18).

Table 2.18: IMPACTS OF CLIMATE CHANGE ON FISHERIES IN THE MIDDLE-LOWER REACHES OF YANGTZE RIVER REGION IN 2030

Fishery region	Distribution	Temperature change	Rainfall change	Impact on fishbreeding
The middle-lower reaches of Yangtze River	South of the Qinling mountain and Huaihe River; North of the Nanling mountains	0.5-1°C Lower temp. in the winter	5% High frequency of drought and waterlogging	-10%

(d) The north China region (lakes and reservoirs on the middle-lower reaches of the Yellow River in the temperate zone)

In this region, water is unevenly distributed, with many areas of water in the east and few in the west. Large reservoirs and shallow-water lakes make up the main water resources. Up to the year 2030, climate changes will have a negative impact on fishery production in the region. Despite increasing rainfall, the range of temperature increase will be greater, and evaporation will increase. This will lead to more serious shortages of water. Some lakes will dry up throughout the year or during the dry season, which will seriously constrain the development of fishery production (see Table 2.19).

(e) The northeast region (rivers and lakes of the middle and northern parts of the northeast in the temperate zone)

This area of rivers, lakes, and reservoirs accounts for 90 percent of the too much water area of this region. **(not clear)** Many kinds of cold-water fish

Table 2.19: IMPACTS OF CLIMATE CHANGE ON FISHERIES IN THE NORTH CHINA REGION IN 2030

Fishery region	Distribution	Temperature change	Rainfall change	Impact on fishbreeding
North China fishery region	North of the Qinling mountain and Huai River; East of the Qinghai-Tibet plateau; South of the Inner Mongolia-Xinjiang plateau	1.0-1.5°C Higher temp. in the winter; dry and hot in the summer	5-8% More rainfall in the winter	-10%

live in the region. The cold temperatures in the winter and spring greatly restrain fishery production. In 2030, climate changes will have made a positive impact. Rapidly increasing temperatures, especially in the winter, will have an advantageous effect on the growth and development of fish, which will promote fishery production in this region (see Table 2.20).

(f) The Inner Mongolia-Xinjiang plateau (arid lakes and reservoirs in the temperate zone)

Table 2.20: IMPACTS OF CLIMATE CHANGE ON FISHERIES IN THE NORTHEAST REGION IN 2030

Fishery region	Distribution	Temperature change	Rainfall change	Impact on fishbreeding
Northeast region	East of the Inner Mongolia-Xinjiang plateau; North of the middle-lower reaches of Yellow River; Almost all parts of the Northeast area	1.5-2.0°C	>7%	+5%

This region lies in arid and semi-arid areas where water shortages constrain the development of freshwater fisheries. Lakes in this region account for 15.6 percent of the nation's total lake area. Most are shallow saltwater and alkaline-water lakes.

By 2030, climate changes are expected to have a negative impact on fishery production in the region. Although rainfall will increase by more than 10 percent, temperatures will also be higher. As a result, evaporation will

Table 2.21: IMPACTS OF CLIMATE CHANGE ON FISHERIES IN THE INNER MONGOLIA-XINJIANG REGION IN 2030

Fishery region	Distribution	Temperature change	Rainfall change	Impact on fishbreeding
Inner Mongolia-Xinjiang fishery region	Inner Mongolia-Xinjiang; Some parts of Gansu and Ningxia	1.0-1.5°C	>5%	-5%

greatly exceed the slight increase in rainfall. Therefore, water shortages will be more serious and the alkalinity of alkaline-water lakes will be greater (see Table 2.21).

(g) The Qinghai-Tibet plateau region (lakes in an alpine frigid zone)

This region has high elevations (the average elevation is over 4000 meters) and low temperatures. Lakes make up the main water area, and account for 37 percent of the nation's total lake area. These lakes depend on melting snow-water for their water, and low water temperatures constrain fishery production.

Climate changes up to the 2030 should have a positive impact on fishery production. Increasing temperatures are likely to cause lake temperatures to increase and to promote fish growth and development (see Table 2.22).

Table 2.22: IMPACTS OF CLIMATE CHANGE ON FISHERIES IN THE QINGHAI-TIBET REGION IN 2030

Distribution	Temperature change	Rainfall change	Impact on fishbreeding
Qinghai, Tibet, West of Sichuan	1.0°C	5-10%	+5%

Sea Fishery Regions

(a) The Bohai Sea region (the Bohai Sea and the northern Yellow Sea in the southern temperate zone)

The shallow Bohai sea, with its rich nutrition from the Yellow, Haihe, and Liaohe rivers, is an important area for the production of fish, prawn, crabs, and shells. Because of lower temperatures, the major problem for fishery development will be difficulty in surviving the winter. By the year 2030, climate changes in the region, especially the temperature increase, will have an advantageous impact on fishery production in the region (see Table 2.23).

Table 2.23: IMPACTS OF CLIMATE CHANGE ON FISHERIES IN THE BOHAI SEA REGION IN 2030

Distribution	North of the Liaodong Bay, Bohai Bay, the Luanhe River Estuary, the Laizhou Bay and Qingdao; Coastal Area of Yellow Sea in Liaoning and Shandong	
Temperature change	1.5-2.0°C	warmer in the winter
Rainfall change	10%	
Impacts on fishery	+5%	

(b) The Yellow Sea region (the southern Yellow Sea in the southern temperate zone)

This an open sea area, with shoals that run from northwest to southeast. In the winter, the north wind predominates, but generally the waters do not freeze. By the year 2030, there will be a slight impact on fishbreeding production due to climate changes (see Table 2.24).

Table 2.24: IMPACTS OF CLIMATE CHANGE ON FISHERIES IN THE YELLOW SEA REGION IN 2030

Distribution	North of Yangtze River; Coastal estuaries and shallows of South of Yellow Sea (in the south of 37°N) of which the southern boundary is the Yangtze River Estuary to the southern end of Peizhou Island, Korea
Temperature change	>1.0°C
Rainfall change	5-8%
Impacts on fishery	-2%

(c) The East Sea region

This region is an open-inland sea with hills behind it. Beyond the coast are many islands that act as a protective screen. This is the traditional seawater fishing region of China. By the year 2030, climate changes are expected to have a negative impact on fishery production. Although temperatures will increase slightly overall, temperatures in the winter will decrease, which will affect fish survival throughout the winter as well as normal growth and development (see Table 2.25).

Table 2.25: Impacts of Climate Change on Fisheries in the East Sea Region in 2030

Distribution	Shallow areas between the Yangtze River Estuary and Taiwan Bay, of which the southern boundary is Nanao Island to E-Fu-Bi	
Temperature change	< 1.0°C	Lower Temp. in the winter
Rainfall change	10%	
Impacts on fishery	-5%	

(d) The South Sea region

With a large shoal area, water rich in nutrition, and excellent water-temperature, this region is an important natural spawning site and breeding area. By 2030, however, climate changes will have a negative impact on the development of fishery production. Temperature decrease in the winter and rainfall reduction could restrain fish development and breeding. Meanwhile, increases in typhoons and storms will cause large losses of fish (see Table 2.26).

Table 2.26: Impacts of Climate Change on Fisheries in the South Sea Region in 2030

Distribution	Shallows and Shoals of islands around in offshore water areas of the northern part of South sea	
Temperature change	< 1.0°C	Lower Temp. in the winter
Rainfall change	10%	More typhoons and storms
Impacts on fishbreeding	-7.5%	

Impact of Severe Weather

2.83 The frequency of extreme climate is increasing, including typhoons, waterlogging, and sustained drought. Typhoons pose a huge threat to coastal fishing, damaging the installations of fishing areas, flooding fishing ponds, and thereby causing large amounts of fish and prawn to rush into the sea. Waterlogging leaves a vast expanse of water that is a disaster for fishery. It allows grown fish and shrimp to escape and carries away many fish fry and small shrimp. Waterlogging causes huge losses for fishery at present and will continue to be a great threat in the future. Sustained drought is also disastrous for fishbreeding, drying up ponds, reservoirs, and seasonal rivers. Sustained drought can also cut off the flow of lakes and rivers, leading to huge fishery losses.

Integrated Assessment of the Impact of Climate Change on Fishery Production

2.84 The integrated impact of climate change on fishery can be expressed as the following equation: $\Delta y = f(CO_2) + f(R) + f(T) + f(P) + f(D) + f(L) + f(O)$
where:
Δy: change rate of fishery output$
$f(CO_2)$: the impact of CO_2 on fishery
$f(R)$: the impact of precipitation on fishery
$f(T)$: the impact of temperature on fishery
$f(P)$: the impact of typhoons on fishery
$f(D)$: the impact of drought on fishery
$f(L)$: the impact of waterlogging on fishery
$f(O)$: the impact of other factors on fishery

This equation can be simplified as follows: $\Delta y = \Delta y_1 + \Delta y_2 + \Delta y_3$
where:
$\Delta y_1 = f(CO_2)$
$\Delta y_2 = f(R) + f(T)$
$\Delta y_3 = f(P) + f(D) + f(L) + f(O)$
Δy_1 is the impact of CO_2 on fishery. As discussed above, the impact is significant.
$\Delta y_1 = +2.5$ percent.
Δy_2 is the impact of temperature and precipitation on fishbreeding, and it is very complex. The estimation for various regions is listed in Table 2.27, while the assessment data for Δy_3 are given in Table 2.28.

$\Delta y_3 = f(P) + f(D) + f(L) + f(O)$
$\Delta y = \Delta y_1 + \Delta y_2 + \Delta y_3 = 2.5\% - 5.14\% - 2.8\% = -5.44\%$.

In short, overall climate changes will possibly reduce China's fishery production by more than 5 percent.

Table 2.27: INTEGRATED IMPACTS OF TEMPERATURE AND PRECIPITATION ON FISHERIES IN 2030

Fishery region	Distribution	Proportion to national fishery (%)	Change rate (%)	Weighted change (%)
Inland fishery regions	South China region	15	-15	-2.25
	Southwest region the	0.8	+4	+0.032
	middle-lower reaches of the Yangtze River	20	-15	-3.0
	North China region	1.2	-20	-0.24
	Northeast region	5	+12	+0.6
	Inner Mongolia-Xinjiang region	0.5	-5.0	-0.25
	Qinghai-Tibet region	0.5	+5.0	+0.25
Sea regions	Bohai			
	Yellow Sea	20	+5.0	+1.0
	East Sea	8	+5.0	0.4
	South Sea	12	-5.0	-0.6
Total		100.0	5.14	-4.058

Table 2.28: THE ESTIMATION OF FISHERY LOSS DUE TO EXTREME CLIMATE IN 2030

Extreme climate	Present loss (%)	Increased frequency (%)	Future loss (%)
Typhoon	0.5	40	0.7
Waterlogging	0.6	40	0.84
Drought	0.6	40	0.84
Other disaster	0.3	40	0.42
Total	2.0	40	2.80

3. IMPACT OF SEA-LEVEL RISE ON THE COASTAL REGIONS OF CHINA

A. INTRODUCTION

3.1 China's coastal area stretches more than 18,000 km and has more than 6,000 islands. Coastal regions have long been among the country's most well-developed areas. The population of the eleven coastal provinces and municipalities—Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan, Guangxi, Tianjin and Shanghai—accounts for 40 percent of the total Chinese population.

3.2 The cultivated area of coastal regions only accounts for 13 percent of the nation's total. However, the gross value of agricultural and industrial output from the coastal regions constitutes 60 to 70 percent of the gross national product, and 55 percent of national income is produced by eastern and southern coastal areas. Of the 50 most developed cities of China, 36 are in coastal areas, and their population constitutes 72 percent of the total. China's earliest five special economic zones and 14 open cities were located along the coast. The coastal economy has developed rapidly, increasing by an annual average of 13 percent in recent years (Zhang Xingming and Wang Xinian, 1993).

3.3 In eastern coastal areas of China, wide flatlands and lowlands have the following common characteristics: (a) An elevation of less than 5 m, generally in the range of 1-3 m. (b) Gently sloping ground—for example, the slope of the Yellow River delta is 1/7,000 to 1/10,000 and the top of Laizhou Bay has a slope of 1/10,000 to 3/10,000. (c) Loose soil—especially in delta regions, the pressure of deposits slowly makes the ground subside and increases the relative sea-level rise.

3.4 These flatlands and lowlands are easily intruded by seawater. If the slope is 1/10,000, and sea-level rises 10 cm, then seawater will intrude 1 km. According to statistics, all silt coasts and 70 percent of sandy coasts have eroded recently in China, with the most serious erosion in the provinces of Liaoning, Hebei, Shandong, Jiangsu, Fujian, and Hainan. The average erosion rate of silt coasts is about 1 to 2 m/yr, while the rate of some individual coasts may exceed 10 m/yr. For example, in Shandong, there is less than 400 km of fine sandy coast line, of which 260 km is eroding at an average rate of 1.5 to 2.0 m/yr. Since the 1970s, the Shandong coastline has retreated 0.5 to 3 km and 10 km^2 of sandy beaches have been lost.

3.5 The erosion rate of silt coasts differs in various locations. For example, the rate of erosion in the southern Bohai Bay was about 10 m/yr, while the rate of the Diaokou River in northern Shandong was 1,000 m/yr from 1976 to 1981. After the Yellow River moved northward to Shandong and reached the Bohai Sea, the coast line in the abandoned

Yellow River valley of northern Jiangsu has retreated over 20 km since 1855. The erosion area was 1,400 km^2 along 50 km of coastline. In the past 20 years, the erosion rate has remained 20 to 30 m/yr (Ren Meie, 1992). The sludge coast is in an erosion and retreat situation beside the new Yellow River estuary. During the 23 years from 1964 to 1976, the coastlines of Shenxiangou and Tianshuigou have retreated 4 km. According to measurements based on satellite images of the First Marine Institute of the State Oceanic Administration, the total erosion area in the Yellow River delta had reached 173.5 km^2 by 1976 (Xia Dongxing, 1993). Along the 200 km of coastline from Shouguang county to Longkou, the intrusion area is 430 km^2 and the average annual intrusion distance is 150 to 200 m (Yu Zhang and Bai Yusheng, 1991).

3.6 Sea-level rise allows seawater to intrude and osmose into land through channels, rivers, and underground water layers, causing more and more serious soil salinization of coastal flat-lands. During the last 40 years, for example, the rate of sea-level rise in Tianjin was 7.0 to 8.0 mm/yr; the structural sinking of the local earth's crust is 6.0 to 7.5 mm/yr or more. In Tianjin, nonlocal and nonstructural sinking of the earth's crust is also very serious. From 1950 to 1987, the Tianjin ground has subsided 2.27 m, while the largest rate of sinking reached 216 mm/yr and the scope of sinking was about 7,000 km^2. Owing to the lack of rain and overextraction of groundwater, the coastal flatlands from Tianjin to Dezhou have formed a 10,000 km^2 funnel in which the groundwater level has dropped below the mean sea-level. These areas have been confronted with the threat of sea water intrusion (Ren Meie,1992).

3.7 Storm surges are the most severe of all marine disasters in coastal regions. The strength and frequency of storm surges will increase as the sea-level rises. In 1989, Guangdong, Zhejiang, and Hainan all experienced heavy losses due to storm surges. In the Pearl River estuary, tidal levels of eight tide gauges surpassed the highest historical levels by 1 to 63 cm and all exceeded the local warning level by 54 to 111 cm during the No. 8 typhoon. During the No. 8923 typhoon, the highest level of return period of 200 years occurred, exceeding the highest level of historical records by 69 cm and surpassing the local warning level by 140 cm. According to statistics, 121 counties and towns, including 15.907 million people, were affected by storm surges. As a result of the storms, 522 persons were killed or missing and 1103.5 km of dams were destroyed. Direct economic losses reached a value of Y 5.483 billion (State Oceanic Administration, 1990).

3.8 In 1990, Fujian and southern Zhejiang were continuously stricken by several storm surges and experienced even heavier losses. From the last ten days of June through the first ten days of September, Fujian Province was hit successively by four strong storm surges. There was only an 18-day interval between No. 12 and No. 18 typhoons. During this period, more than ten tide gauges in the Fujian and Zhejiang coastal areas outstripped the warning level by 9 to 96 cm. Among them, the Wenzhou tide gauge and the Meihua tide gauge (at the Minjiang Estuary in Fujian) reached their second highest recorded level—to 3.93 m and 4.225 m higher than the mean sea-level of the Yellow Sea, respectively. According to statistics, direct economic losses reached Y 4.11 billion (State Oceanic Administration, 1991).

3.9 The year 1992 witnessed the most serious typhoon storm surges since 1949. The storm surge caused by tropical storm No. 9216 was the most severe disaster since 1949 in the provinces and municipalities of Fujian, Zhejiang, Jiangsu, Shandong, Hebei, Liaoning, Shanghai, and Tianjin. In coastal areas, 14 tide gauges broke historical records for the highest tide level. Ruian and Aojiang of Zhejiang Province, and Tanggu of Tianjin surpassed the warning level by more than 100 cm. During this period, 1,171 km of dams were destroyed; 29.7178 million mu of farm land was inundated; 0.7617 million mu of ponds were washed away; 2.2788 million mu of salt pans were submerged; and 1.5521 million tons of raw salts were lost. The direct economic losses totalled more than Y 9.4 billion. Losses at the Shengli Oil Field in the Yellow River delta and the Dagang Oil Field in the old Yellow River delta were quite heavy. In Shengli Oil Field, seawater broke the dikes and intruded inland up to 25 km. Taking the highest tide level as the datum point, the inundated area reached 960 km^2. Twenty-four villages were besieged with sea water and 2,072 oil wells (a quarter of the total) were submerged. In Dagang Oil Field, 69 oil wells were submerged. Because the Haihe River floodgate in Tianjin was built over 30 years ago and the local sea-level has risen 1.05 m (mainly caused by ground subsidence), the floodgate was not high enough to protect against heavy floods. The floodwaters gushed into 3,400 houses in the coastal region of Tianjin (State Oceanic Administration, 1993). We can anticipate that with future sea-level rise and economic development, losses caused by serious storm surges will increase.

3.10 To sum up, the three main disasters that occur in coastal areas of China—storm surges, sea water intrusion, and coastal erosion—are all closely related to sea-level rise. As sea-level rises, coastal areas (especially areas experiencing the highest rise) will suffer from these disasters more frequently.

B. IMPACT OF SEA-LEVEL RISE ON THE COASTAL REGIONS OF CHINA

Increase in Strength and Frequency of Storm Surge Disaster

3.11 China is among the countries most frequently affected by storm surges. Its coastal areas are hit by storm surges every year. They all rely on shelter dikes to withstand these disasters. The dikes of coastal areas are 12,883 km long, but standard dikes are only 2,966 km, or a quarter of the total. Sea-level rise will reduce the function of dikes and floodgates, thereby aggravating storm surge disasters.

3.12 At the Tanggu tide gauge of Tianjin over the past 42 years (1951-92) there have been eleven storm surges with tide levels of over 5.0 m and 9 storm surges with tide levels of over 5.1 m. On November 7, 1965, the highest tide level caused by an extra-tropical storm was 5.72 m, while the highest level caused by the No. 8509 typhoon reached 5.4 m and the tide level of No. 9216, a strong tropical storm surge, was 5.93 m. No. 9216 strong tropical storm surge brought Tianjin a direct economic loss of Y 0.4 billion. Tianjin is expected to experience maximum relative sea-level rise. If sea-level goes up 65 cm, the return period of 100 years (the highest level is 5.93 m) will be reduced to 10 years (the highest level is 6.03 m) and storm surge disasters will obviously increase.

3.13 According to historical records, 80 stronger storm surges occurred from 48 A.D. to 1938 in the Yellow River delta and Laizhou Bay. Sometimes seawater intruded into land as far as 40-50 km (Ren Meie, 1992). Since the 1950s, there have been five heavy storm surges: in 1964, 1969, 1980, 1987, and 1992. The most severe storm took place on April 23, 1969, when the northeast wind reached a velocity of 126 km/hr. The level of the Yangjiaogou gauge reached 3.75 m above the Yellow Sea's mean sea-level and sea water invaded 30-40 km inland. Because the sea-level of this area has been rising (2.0-2.6 mm/yr), if sea-level rises 65 cm, then the return period of 100 years (tide level is 3.99 m) will be reduced to 10 years (tide level is 4.02 m). Due to the varying height and lack of connections between dikes (the lowest dike is 4.5-m high) in the Yellow River delta and Laizhou Bay, they cannot resist heavier storm surges at present. It will be impossible for them to resist the heaviest storm surges under higher sea-level conditions in the future.

3.14 The Yangtze River delta is among the more severe storm surge zones. These storm surges cause enormous losses to the large population and developed industry in the Huangpu River area. With sea-level rising, the threat of storm surges is increasing. The tidal barrier on the outer banks of the Huangpu River was built on the basis of a return period of 1,000 years. If relative sea-level rises 65 cm, the tidal barrier just withstands the storm surge with a return period of 100 years, making it susceptible to storm surge disasters.

3.15 Guangdong province accounts for 42 percent of all the land typhoons in China, and the Pearl River delta region suffers from the gravest storm surges. Rising sea-levels in this region will lead to the reduction of sea dike design worthiness. Taking Huangpu harbor as an example, if sea-level rises 65 cm, the return period of 1,000 years will be reduced to 20 years, which will aggravate storm surges in this area, expand the scope of the disaster area, and increase the number of disasters.

3.16 The high tide level of some gauge stations in China in various return periods, calculated by the Gumbel method at different sea-levels, is given in Table 3.1. It can be seen that the frequency of high tide increases as sea-level rises.

3.17 It is worth pointing out that the rate of relative sea-level rise caused by tectonic subsidence, deposition stratigraphic suppression, and runoff flowing to the sea, especially groundwater overpumping, is larger than that due to global climate warming. In the coastal plain of Tianjin, land settlement caused by extensive groundwater extraction is the most severe in China. From the 1950s to the present, land subsidence has reached 2.6 m, forming four subsidence centers in the urban districts of Tianjin, Tanggu, Hangu, and Dadong. The altitude of Tanggu and Hangu has fallen to nearly 0 m, and that of Tianjin port has dropped 0.5 to 0.8 m, putting dams and ports in jeopardy. Because of the control of groundwater extraction and the routing of Luanhe River water into Tianjin, the rate of land settlement in Tianjin is gradually decreasing (Yang Guiye, 1987; Jin Dongxi, 1993).

Table 3.1: HIGH TIDE WITH VARIOUS RETURN PERIODS (m)

Station name	High tide	Return period (year) 10	20	50	100	200	500	1000	Period of date
Yingkou	1	3.02	3.12	3.22	3.30	3.38	3.49	3.58	42 years
40° 38' N	2	3.22	3.32	3.42	3.52	3.58	3.69	3.78	(1951-92)
122° 09' E	3	3.67	3.77	3.87	3.97	4.03	4.14	4.23	
Tanggu	1	2.81	2.98	3.20	3.36	3.53	3.74	3.91	43 years
39° 00' N	2	3.01	3.18	3.40	3.56	3.73	3.94	4.11	(1950-92)
117° 43'	3	3.46	3.63	3.85	4.01	4.18	4.39	4.56	
Yangjiaogo	1	3.10	3.37	3.73	3.99	4.26	4.61	4.87	42 years
37° 16' N	2	3.30	3.57	3.93	4.19	4.46	4.81	5.07	(1951-92)
118° 52' E	3	3.75	4.02	4.33	4.64	4.91	5.36	5.52	
Lianyungan	1	3.42	3.37	3.73	3.99	4.26	4.61	4.87	42 years
34° 16' N	2	3.30	3.57	3.93	4.19	4.46	4.81	5.07	(1951-92)
119° 27' E	3	3.75	4.02	4.33	4.64	4.91	5.36	5.52	
Wusong	1	3.17	3.30	3.51	3.66	3.82	4.03	4.18	47 years
31° 24' N	2	3.37	3.50	3.71	.86	4.02	4.23	4.38	(1944-90)
121° 30' E	3	3.82	3.95	4.16	4.31	4.47	4.67	4.83	
Xiamen	1	4.01	4.14	4.30	4.43	4.55	4.71	4.83	39 years
24° 27' N	2	4.21	4.34	4.50	4.63	4.75	4.91	5.03	(1953-92)
118° 44' E	3	4.66	4.79	4.95	5.08	5.20	5.36	5.48	
Shantou	1	2.65	2.89	3.20	3.43	3.66	3.96	4.19	40 years
23° 20' N	2	2.85	3.09	3.40	3.63	3.86	4.16	4.39	(1953-92)
116° 45' E	3	3.30	3.54	3.85	4.08	4.31	4.61	4.84	
Huangpu	1	2.75	2.86	3.01	3.13	3.24	3.39	3.50	42 years
23 ° 20' N	2	2.95	3.06	3.21	3.33	3.44	3.59	3.50	(1951-92)
113° 28' E	3	3.40	3.51	3.66	3.78	3.85	4.04	4.15	

Note: Table 3.1 was calculated by Wang Xinian et al., National Marine Environment Forecast Center.

1 in the table represents the high tide with different return period over mean sea level (MSL) of the Yellow Sea in 1985.
2 in the table is the same as 1, but consider the MSL to have a rise of 0.2 m by 2030.
3 in the table is the same as 1, but consider the MSL to have a rise of 0.65 m by 2100.

3.18 According to the analysis and observations of geologists and mineral experts, the annual tectonic subsidence in the coastal areas of Tianjin is about 2-3 mm, but due to groundwater pumping, it can be as much as 6-10 mm annually. It can therefore be estimated that sea-level will reach a height of about 70-100 cm (including global sea-level rise of 20-30 cm) by 2050 in Tianjin, while that of Tanggu and Hangu will be higher (Division of Earth Sciences of CAS, 1993).

3.19 According to an academician of the Division of Earth Sciences, Chinese Academy of Sciences, the annual tectonic subsidence in Shanghai is 1-2 mm, and the annual land settlement caused by groundwater extraction is 3-5 mm. Considering global sea-level rise, the relative sea-level in Shanghai will rise 50-70 cm by 2050. Relative sea-level in the Pearl River delta will rise 40-60 cm, including the 1-2 mm of annual tectonic subsidence, 0.5-1.0 cm of annual flood level rise due to the Pearl River runoff, and global sea-level rise (Division of Earth Sciences of CAS, 1993). To summarize, owing to the differing effects of local relative sea-level rise factors along the China sea, the rate and amplitude of sea-level rise will be higher than the IPCC's estimate of global sea-level rise.

More Areas Inundated by Sea Water

3.20 Sea-level rise has a great impact on both the natural environment and on the economy and society in China's coastal regions. As these regions have different geological and landform features—from coastal plains to mountains—the impact on these regions differs too. The impact on coastal plains will be especially serious.

3.21 China's coastal sea-level rise will cause a vast land area to be inundated if not protected. In light of the estimation by drawing, the inundated area would be much larger than normally expected (Han Mukang, 1992).

3.22 Most of China's coastal plains are low-lying deltaic plains (such as the Pearl River delta where Guangzhou city is located and the Hanjiang delta plain where Shantou city is located) or joint delta plains formed by many rivers (such as the coastal plain in North China where Tianjin city is located and the coastal plain in East China from Shanghai to Lianyungang). In China's topographic map, the 0-m contour line coincides with the Yellow Sea datum plane. Therefore, a 2-m astronomical tide plus a 1-m storm surge would cause an actual 3-m rise of sea-level that could inundate the 3-m contour line on the topographic map. The regions within the 2-m contour line would be inundated for a long period of time, while those between the 2-m and 3-m contour lines would be inundated for a short time. Because some areas have had dike embankments to protect them from tides since ancient times, tidal disasters have not occurred in those regions.

3.23 Han Mukang (1991a) pointed out that if the projected 1 m level of sea-level rise is reached and the coastal area is not protected, the regions located lower than the 4 m contour line in China's coastal plains would be entirely drowned by astronomical tides and storm surges (see Figure 3.1) This means that China's four largest low-lying plains would be inundated or flooded—the entire Pearl River delta plain with 14 cities or counties including Guangzhou city, the northeast part of the East China coastal plain with 34 cities or counties including Shanghai, and the southern half of the lower Liaohe River plain with three cities or counties including Yingkou and Panjin. All of Chongming Island, the third largest island in China, would disappear, and Taihu Lake would become connected with the East China Sea. The inundated area amounts to around 92,000 km^2 (see Figure 3.1

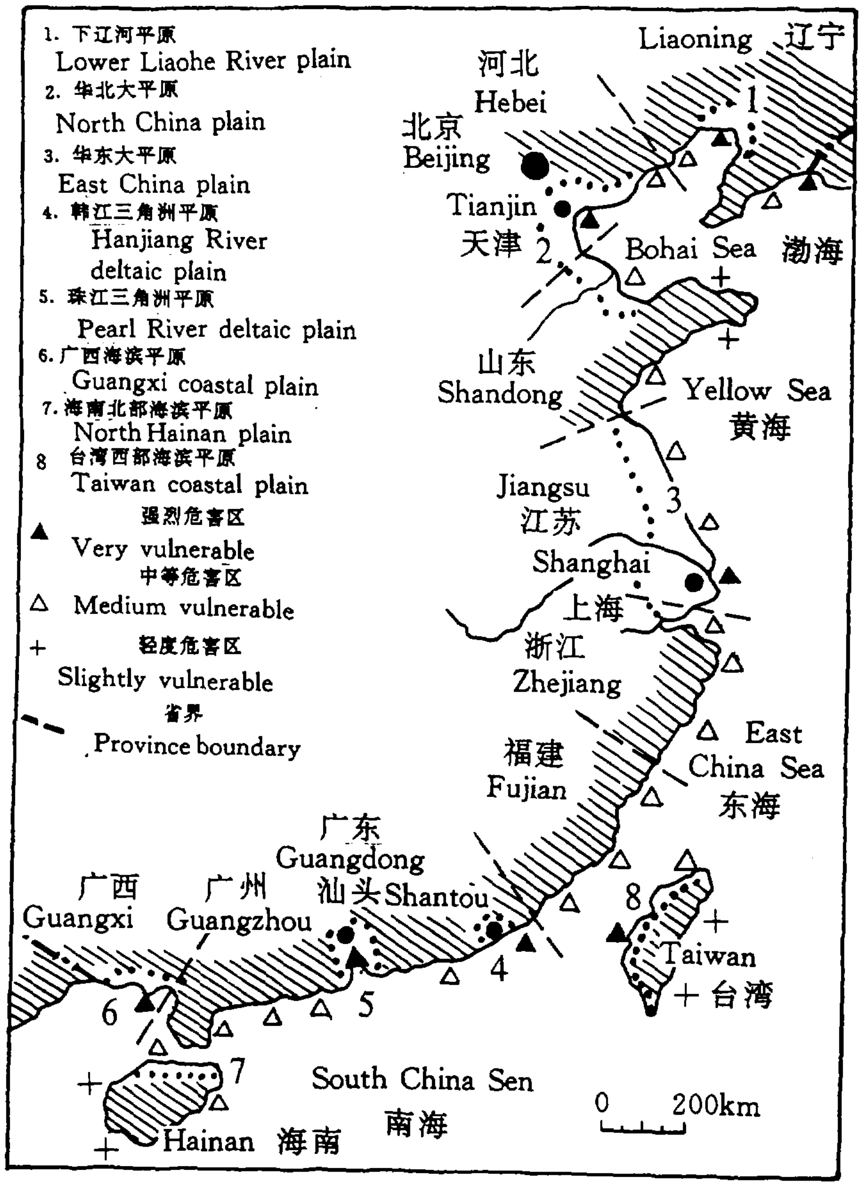

Fig. 3.1 China's vulnerable coastal plains owing to projected one meter sea level rise, defined by dotted line. Shaded area denotes mountainous coast. (From Han Mukang et al., 1991a; 1992).

and Table 3.2), larger than the area of Austria (83,849 km^2) or two of the Netherlands in total (40,884 km^2). If one also takes into account the varying width of the coastal zone and the patches of small delta that will flood in the mountainous regions, the total area vulnerable to inundation would be greater than 125,000 km^2 and the total population affected would be more than 73 million. Some lower islands in the South China Sea would also disappear.

Table 3.2: AREA WITH AN ALTITUDE LOWER THAN 4 M AND AMOUNT OF POPULATION AND CITIES TO BE DIRECTLY AFFECTED BY PROJECTED 1 M OF SEA LEVEL RISE IN COASTAL PLAIN AREAS

Plain name	Area to be inundated (km^2) /a	Population (million)	Population density (/km^2)	No. of cities /b
Lower Liao River plain	4,900	3.27	667	3
North China coastal plain	19,900	10.67	536	14
East China coastal plain	61,000	42.43	695	34
Pearl River Delta plain	6,200	10.69	1,724	14
Total	92,000	67.05	906	65

/a Although the tidal range of Pearl River Delta is small and the high tide is lower, the local MSL is 0.5-m higher than MSL of Yellow Sea, so a 1 m sea level rise will inundate almost the whole delta plain below 4 m.

/b Tianjin and Shanghai govern several districts and counties, but only one city is counted in the table.

3.24 According to the IPCC's forecast, global sea-level will rise 20 cm by 2030, and 65 cm by 2100. If left unprotected, quite large areas of the four coastal plains mentioned above will be threatened. For example, in Tianjin and Shanghai, the regions below 2.2-2.65 m will be inundated, and if a 1-m storm surge were added, the areas below 3.2-3.65 m above sea-level would be inundated (Figures 3.2 and 3.3). Therefore, the entire cities of Tianjin and Shanghai would be inundated and two-thirds of the Pearl River delta area would be inundated (see Figure 3.4).

Exacerbation of Saltwater Intrusion and Difficulty Draining Off Sewage

3.25 The saltwater intrusion caused by sea-level rise in the coastal areas takes two forms. First, rising sea-levels penetrate coastal areas, raising the groundwater level. This pollutes the groundwater, makes freshwater salty, and widens the land area affected by salinization and alkalinization. This worsens the ecological environment, causes cultivated land to be lost, and motor-pumped wells to be discarded. Some regions have water-use

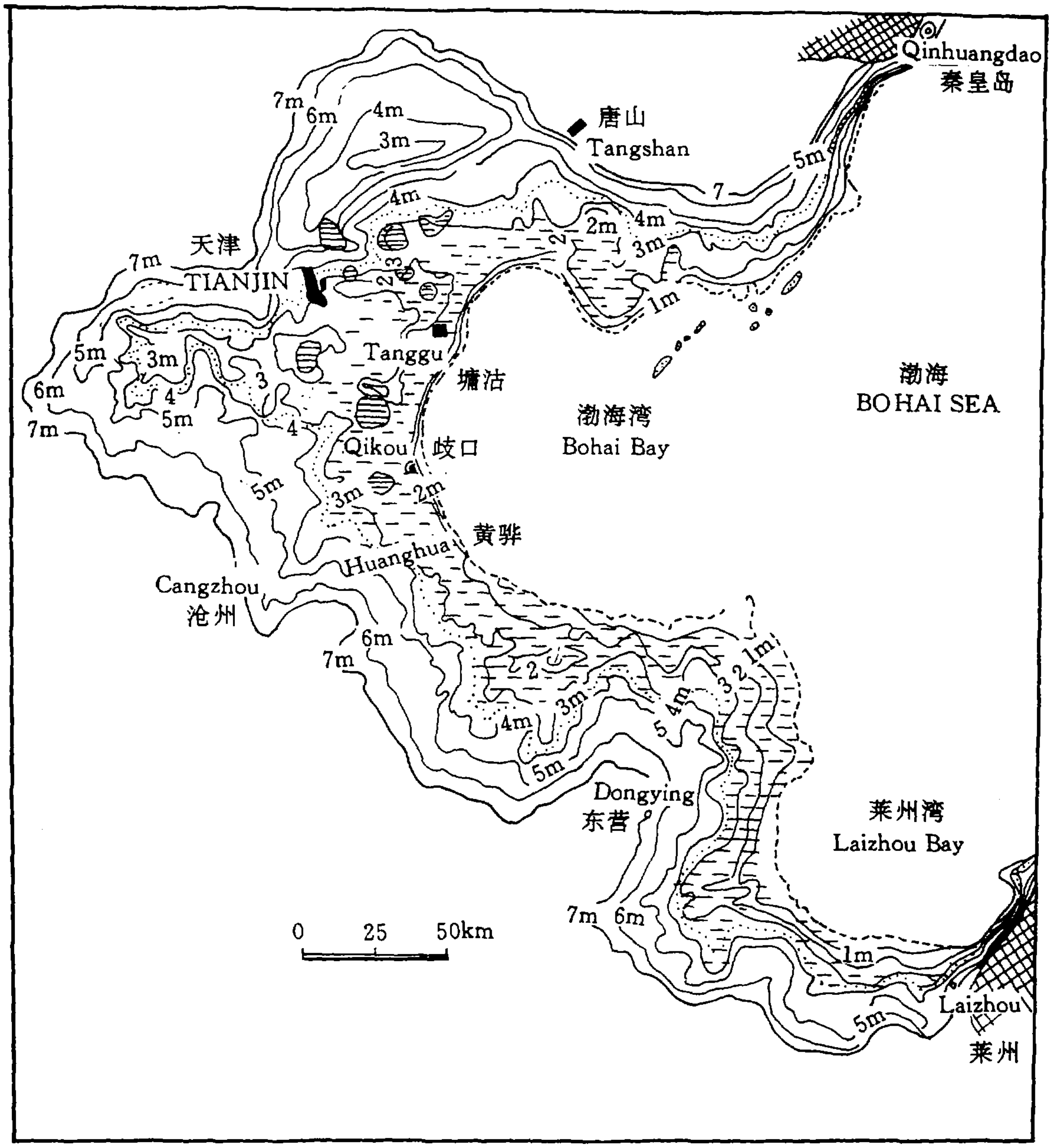

Fig. 3.2 Topography of the coastal plain in North China. The dashed area denotes the flooded area during historic storm surges.

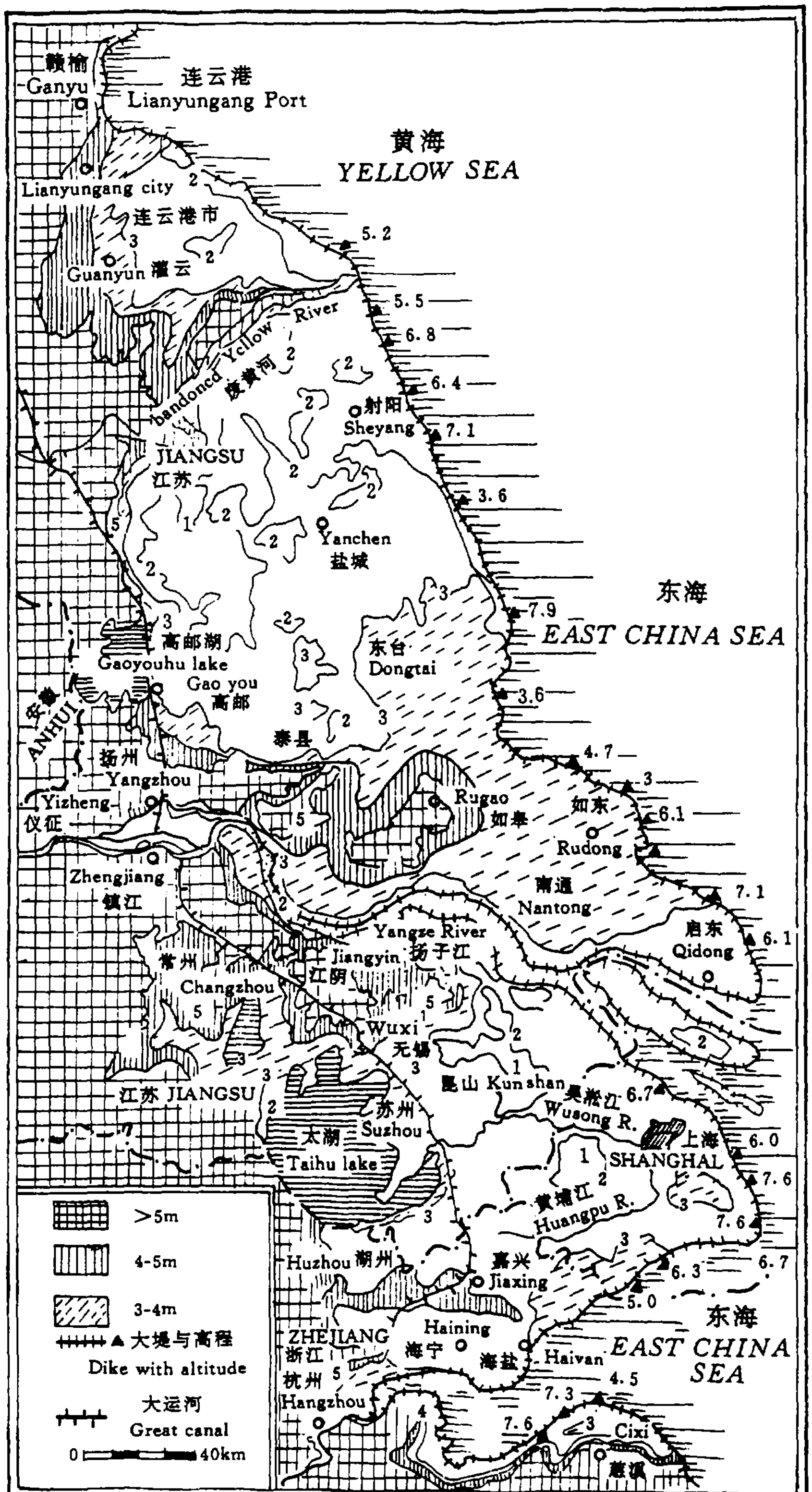

Fig. 3. 3 East China plain. One meter of sea level rise will inundate big area below 4m, including Shanghai sity and Chongming Island, without dike protection.

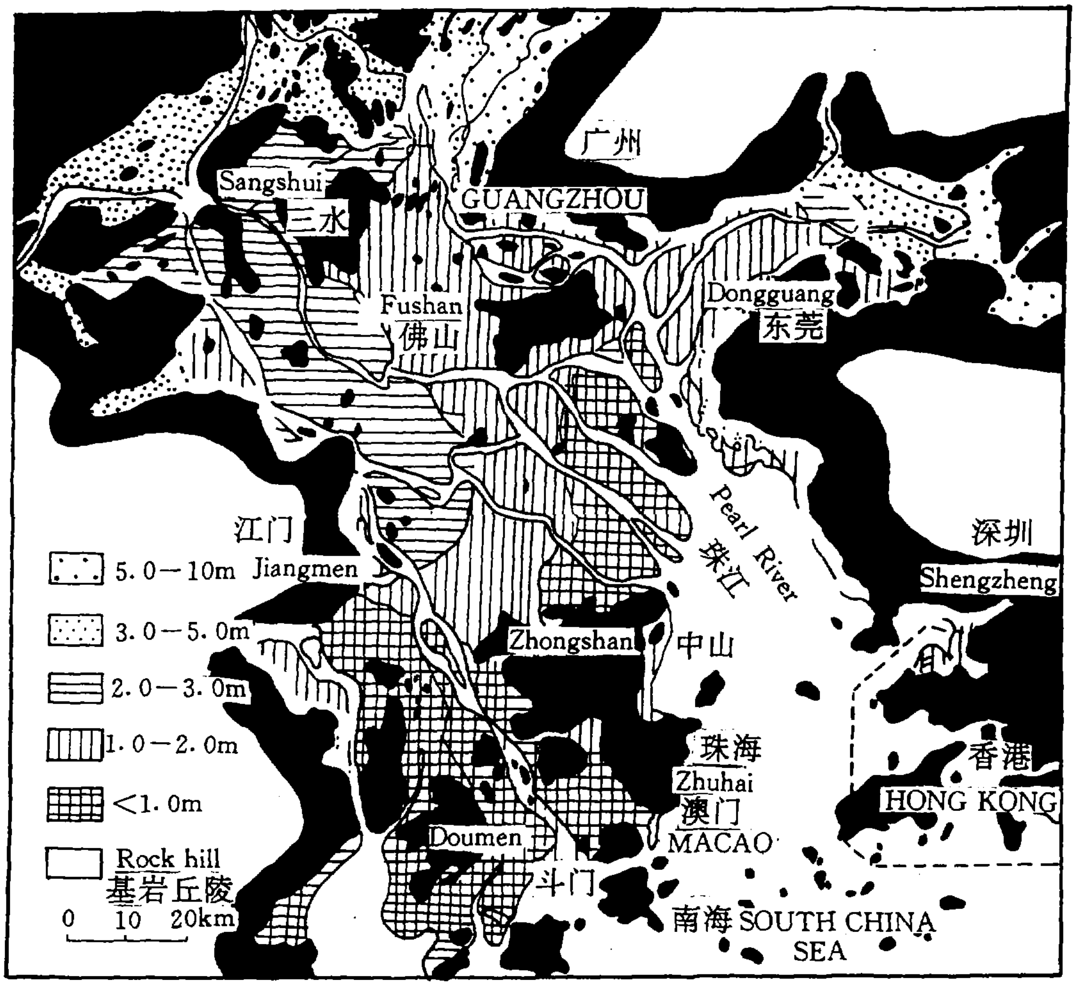

Fig. 3.4 Pearl River Delta plain. A 0.5m of sea level rise wiliinundate 2 / 3 of the delta area (below 3.5m) and a 1m of sea leve rise will inundate almost the whole delta plain below 4m,including city Guangzhou. The 0m contour line in this areais 0.5m lower than the local South China Sea level.(adopted from Li Pingri, modified in detail by Han Mukang)

problems, and hence the incidence of endemic diseases, such as swelling of the thyroid gland and fluorine bone disease, increases. It has a great impact on local industrial and agricultural production as well. Saltwater intrusion into industrial zones and residential areas in cities and towns can soften and destroy the base of industrial facilities.

3.26 In the past 10 years, due to the lack of water and overpumping of groundwater, severe and rapid saltwater intrusion has been artificially caused in some coastal areas of China at the present sea-level, as shown in Table 3.3 (Chen Qi, 1993). Saltwater intrusion in some areas may also be due to sea-level rise and land settlement.

Table 3.3: INTRUSIVE STATUS OF SEAWATER OF COASTAL AREAS IN CHINA
(From Chen Qi, 1993)

District name	Area (km^2)	Rate (m/yr)	Distribution
Liaodong peninsula	230	218.5-550	Southwest part of Dalian
Laizhou Bay	435	404.5 (Max.)	Laizhou, Longkou, Zhaoyuan, Pingdu, Changyi, Shouguang counties, etc.
Shandong peninsula	538.8		Bohai Bay, Laizhou Bay, Yantai, Qingdao, Penglai cities and counties, etc.
Qinhuangdao	18.0	22	
Bohai Bay			East coastal area of Qinhuangdao, Tangshan, Tianjin, Cangzhou, Lijin, Weifang
Northern plain of Jiangsu, Yangtze River Delta			East coastal region of Liangyungang, Huaian, Changzhou, Suzhou, Hangzhou, Ningbo
Pearl River Delta			East coastal region of Guangzhou, Foshan, Jiangmen, Yamen

3.27 The coastal plain of Laizhou Bay on the southern Bohai Sea is a remarkable example of seawater intrusion caused by human economic activities and groundwater overpumping. From 1976 to 1990, the seawater intrusion area had extended to 230 km^2, and the maximum rate was 95.8 km^2/yr and 404.5 m/yr (see Table 3.4) (Shandong, 1991). In addition, according to a report in China Ocean Newspaper on October 28, 1992, the area of sea water intrusion had reached 800 km^2 on the southern coast of Laizhou Bay. If no measures are taken, 2,000 km^2 of rich fields will change into saline-alkaline land by the end of this century.

Table 3.4: INTRUSIVE RATE AND AREA OF SEAWATER IN THE COASTAL PLAIN OF LAIZHOU BAY

(From Laizhou city government of Shandong Province, 1991)

Period	Total area (km^2)	Rate (km^2/yr)	Rate (m/yr)
1976-79	15.8	15.8	46
1980-82	39.2	23.4	92
1983-84	71.1	31.9	177
June 1984-Aug. 1987	169.6	95.8	345
Sept. 1987-Aug. 1988	201.96	32.36	404
Sept. 1988-Aug. 1989	212.44	11.48	-
Sept. 1989-Aug. 1990	230.00	17.56	-

3.28 Seawater intrusion caused by human economic activities happens not only on the low-lying coastal plains, but also in the mountainous coastal areas that are in a state of geological structural rise or stability. This can be seen in the Dalian coastal area of the Liaodong peninsula, the Qinhuangdao to Beidaihe coastal area of the Liaoxi mountain coast, and Longkou, Penglai, and Qingdao on the Shandong peninsula (Hu Jingjiang et al., 1991). The sea-level rise in the future will obviously aggravate seawater intrusion and its harm.

3.29 The second major form of seawater intrusion is saltwater intruding inland due to the propagating tide along the course of a river flowing to the sea. In rivers on low-lying coastal plains, saltwater will intrude farther inland, causing the same environmental deterioration mentioned above on the both sides of rivers and endangering industrial and agricultural production. In the Pearl River delta, for example, saltwater has intruded west of the city of Guangzhou during the dry season. According to Li Pingri's estimate (Li Pingri et al., 1993), if sea-level rises 0.7 m, saltwater will intrude 4 km. In the Yangtze River delta, according to Zou Jiakan's estimate, if sea-level rises 0.5-1 m, the saline contour line of 0.2 percent will move forward as much as 15-30 km (Zou Jiakan, 1993).

3.30 Even more serious, some cities like Shanghai, that rely on river water, will meet with water supply problems. During the dry season (December to March each year) the tap water has been polluted in some cities, endangering residents and industry. From

October of 1978 to May of 1979, during the period of water shortages, the Yangtze River estuary suffered from saltwater intrusion for six months. The longest intrusion distance was 120 km, to the estuary where Changshu is located. The whole of Chongming Island was surrounded by saltwater for 90-100 days, while on the Huangpu River, the Yangtze River tributary in Shanghai, seven out of eight waterworks in Shanghai were polluted by saltwater that exceeded the standard for drinking water. According to Yang Guishan's estimate (see Table 3.5), if sea-level rises 0.5, 0.8, and 1 m, there will be as much as 2021 hours (or about 85 days) when water from the Huangpu River is not usable, in addition to the entire dry season (from December to March).

Table 3.5: Impact of Sea Level Rise on the Time of Chlorinity over 250 ppm at Wusong Station during the Dry Season
(From Yang Guishan,1993)

Item	Present status			MSL rise of 50cm			MSL rise of 80 cm			MSL rise of 1 m		
Flow (10,000 m^3/s)	1.1	1.3	1.5	1.1	1.3	1.5	1.1	1.3	1.5	1.1	1.3	1.5
Time (hours) stopped taking water (TSTW)	923	550	97	2,021	1,105	146	full season	1,679	186	full season	2,219	219
P% (TSTW/full season)	32	19	3	70	38	5	100	58	6	100	76	8

3.31 The two kinds of coastal area impacts described above are not easy to avoid, even if dikes are built to prevent sea-level rise along rivers and coasts. Moreover, after lifting dikes, a vast low-lying area behind the dikes will be easily flooded, causing increased salinization, and deteriorating the environment.

3.32 Sea-level rise will reduce the function of drainage systems that rely on gravity to drain off wastewater. Especially when rainstorms, astronomical tides, and storm surges happen simultaneously, seawater may flow backwards, causing sewage overflow in the city. At the present sea-level, Shanghai city has suffered most from this disaster, and the situation can be expected to become more serious as sea-levels continue to rise in the future.

Increases in Flooded Areas and Abating Port Functions

3.33 The Pearl River delta and Yangtze River delta are crisscrossed by rivers and low-lying plains, and are thus subject to severe floods. Sea-level rise will lower the flood prevention standard of dikes and increase the flood threat. The Taihu Lake river basin of Jiangsu province and the Lixiahe low-lying area are even lower than coastal regions. According to the experts, if the sea-level rises 0.4 m, the Taihu lake's function of draining flood waters into the river will decrease more than 20 percent. If heavy floods like those in 1954 and 1991 occur again, the disaster will be even more serious. The Haihe River basin has the same problem. The altitude of Tianjin is between 2.5 m and 4.5 m, and the altitude of old Tanggu and new Hangu district are lower than the local mean sea-level. If the sea-level rises in the future, the rate of flow and time during which floods drain into sea will decrease, and hence the hidden danger of floods will be aggravated (Division of Earth Sciences of CAS, 1993).

3.34 In the Pearl River delta, the area below the Pearl River datum plane of 0.4 m is 1,469.53 km^2, which makes up 23.76 percent of the area. Meanwhile, the area below 0.9 m is 2,994.76 km^2, making up 48.42 percent of the total. These areas are mainly protected by dikes. Sea-level rise will lower the standard of dikes and thus increase the threat of floods (Tang Yongluan et al., 1993).

3.35 Sea-level rise decreases the elevation of ports and storehouses, which makes inundation by storm surge more likely and reduces port functions. For example, in Tianjin's Xingang Port, the elevation of old quays and storehouses is 0.5-0.8 m lower than the recommended standard. The lowest area of the port has dropped more than 1.0 m under the highest tidal level in history. Therefore, the storm surge on September 1, 1992, brought heavy economic losses for the aging port. The old port in Shanghai faces a similar problem. In addition, sea-level rise will cause the Yangtze riverbed to evolve and will make it more difficult to safeguard deepwater courses. Sea-level rise will also reduce the draining time of floodgates and the functioning of the Suzhou River as an important goods distribution center.

Increasingly Severe Losses from Coastal Erosion and Marsh Inundation

3.36 As seawater deepens, the action of waves and tides increases. Coasts, especially sandy beaches, will suffer from serious erosion and scouring as a result, while the coast line will retreat quickly.

3.37 When sea-level rises 0.5-1 m, most of the present beaches will be inundated, and the old beaches will be eroded. Farmland, towns, and tourism facilities will be threatened, and the situation will be especially serious in areas on the coast with the fewest sand resources.

3.38 Some scholars have tried to calculate the level of seawater erosion at different heights of sea-level rise, based on P. Bruun's formula (1988), in light of local geologic-landform conditions. Ji Zixiu (1993) did research on the north coast of Jiangsu, while Wang Ying (1993) calculated the total area which could be inundated due to sea-level rise on China's main tourism beaches. Their estimates are not completely accurate, however, because they did not take into account changing sedimentary sources on the coast. In fact, owing to some changing natural factors and the interference of human economic activities, severe coastal erosion in China, like saltwater intrusion, is occurring in many coastal areas.

3.39 The coast of the old Yellow River delta in northern Jiangsu Province is the most serious example of coastal erosion caused by natural factors. Since the Yellow River changed its course in Shandong Province in 1855, due to the break of sedimentary source, the coast has retreated 22.3 km during the 131 years from 1855 to 1986, eroding at a rate of 170 m/yr on average. The land area submerged by seawater reached 14,000 km^2 (Li Chengzi, 1981). Every year, Jiangsu Province spends at least several hundred thousand yuan, and as much as several million yuan on protection.

3.40 Another example is the new Yellow River delta in the Bohai Sea. Since the Yellow River began flowing into the Bohai Sea in 1855, its main course moved progressively northeastward until 1986, when it started moving to the southeast of the delta, which was later settled for oilfield development. But the northwest edge of the delta was eroded, and retreated for lack of silt and sand. During the 10 years from 1976 to 1986, the average annual rate of retreat reached 100-300 m or more (Wang Wenjie, 1987).

3.41 There are two main reasons for coastal erosion caused by human economic activities. First, when reservoirs were built in the North China plain on the west coast of the Bohai Sea, and when floodgates or dams were constructed in river estuaries that were not open for a long time, they blocked the source of sedimentation. Therefore, no sand and silt flowed into the sea in the past ten years. In the Luanhe River delta, on the one hand, the main course entrance moved from the southwest of the delta to the east since 1321, until reaching its present location in 1915. On the other hand, three huge reservoirs were built on the upper and middle reaches of the river's present main course, and the water of the Luanhe River was channeled to Tianjin, Tangshan, and Qinhuangdao for use. This led to reduction or even breaks in the sedimentary source on the west and southern edges of the delta, especially the two rows of sandbars beyond the coast. So the coast edge and sandbars eroded and retreated. According to Liu Yixu's investigation (1992), during the 11 years from 1976 to 1987, the maximum retreat rate was 17-60 m/yr. On the coastal plain of Tianjin, located on the middle-west coast of the Bohai Sea, a few sandy stacked and extended coasts have changed into erosion and retreat coasts, scouring the base of dams (see Figure 3.5), because the sedimentary source from rivers flowing into the sea was broken. As a result, sediments from the Luanhe River on the north and the Yellow River on the southwest decreased rapidly.

3.42 The other reason for the interference of human economic activities is that local inhabitants quarry sand and gravel in unreasonable amounts for sale as building materials. For example, in the bay near Lushun on the Liaodong peninsula (where annual coastal retreat is 1-1.5 m), near Yingkou city on the top of Liaodong Bay (where the coast has retreated 4 m since 1969), and on the beaches near Penglai and Longkou on the Shandong peninsula, thousands of tons of sand and gravel are extracted every year for building requirements, and some is even transported for use in Tianjin, Shanghai, and Jiangsu Province.

3.43 In some coastal areas of south China, such as Fujian and Guangdong, local residents cut down mangroves as fuel, which diminishes protection of the coast and increases erosion. The exploitation of coral reef to make lime or cement, and the cutting

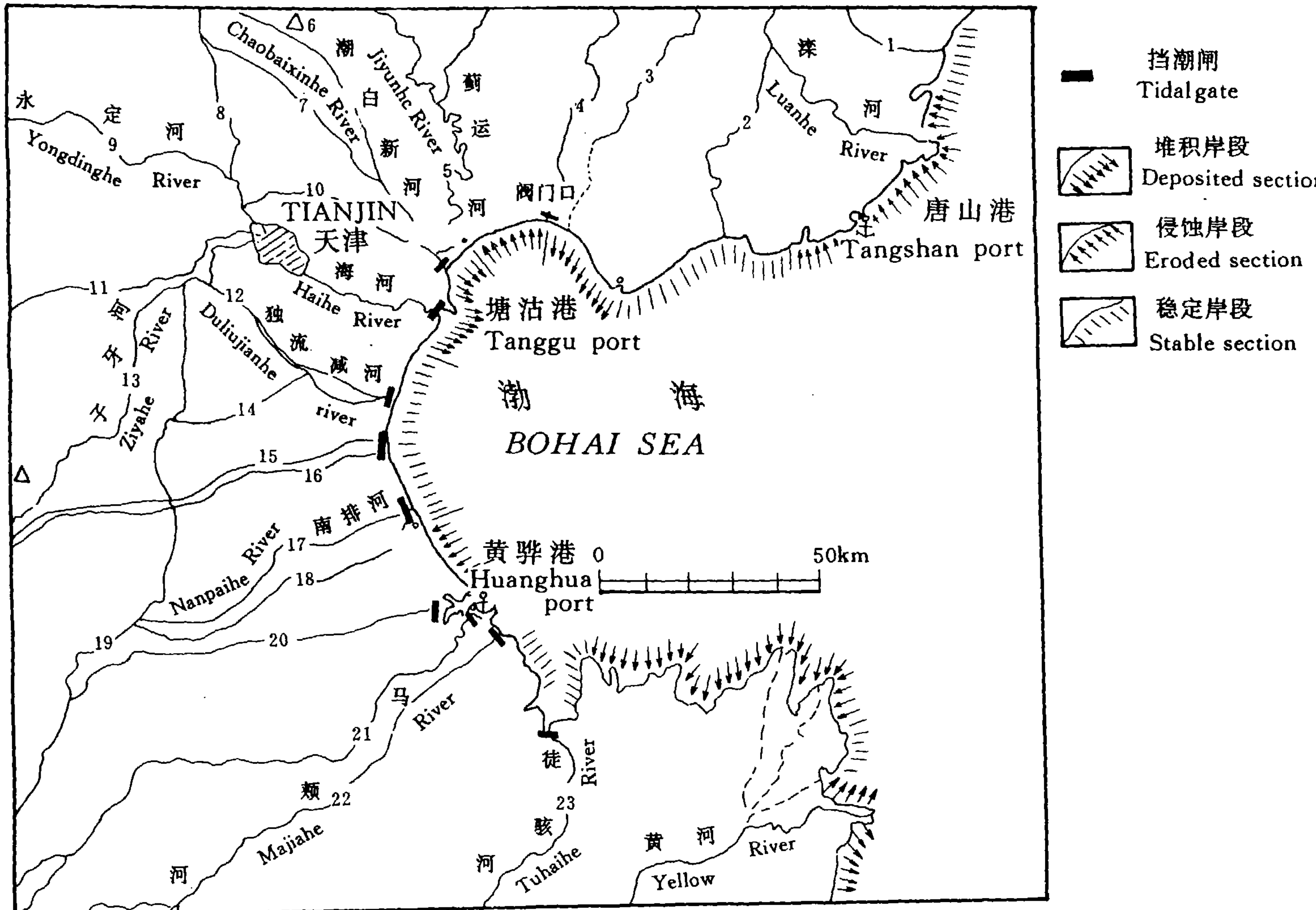

Fig. 3.5 River system on the North China plain. They are damed by construction of reservoirs and tidal gates, resulting in deficiency of sediments and consequently coast erosion.

of mangroves as fuel for making lime, led to serious erosion during the 17 years from 1963 to 1980 along the eastern coast of Hainan. Here, the coast has retreated 600 m, at an average retreat rate of 35 m per year, and coastal villages have been forced to migrate inward (Han Mukang, 1988).

3.44 In some cases, coastal erosion and retreat are jointly caused by two factors at once. The famous sandy beach at Beidaihe, for example, retreated 150 m (at the average rate of 3 m/yr) from 1950 to 1984 (Han Mukang, 1991b). Some plains near the bays of Shandong peninsula retreated 1-3 m a year in the 1980s and the retreat rate of the plains in Fujian was 1-4 m/yr (Zhuang Zhenya et al., 1989; Wang Shaohong et al., 1993).

3.45 As sea-level rises, these types of coastal erosion would be much more severe if reasonable measures were not taken. At the present erosion rate, some sandy beaches such as Beidaihe beach would be lost in 20 or 30 years.

3.46 Sea-level rise diminishes coastal marshes, which will lead to serious erosion and coastal retreat. The regions near the Yangtze River delta are on the verge of the southern Yellow Sea and the northern East China Sea. The area of marshy beach in this region is 54,000 km^2, equivalent to 27 percent of the total marsh beach areas in China. They are distributed throughout the Sheyang River estuary to the Dongzao port, the radial sand bar in northern Jiangsu province, and the Yangtze River estuary. The total marsh area is about 1,000 km^2. On the basis of general tidal flat configuration and altitude, sea-level rise severely threatens the marshes of the eroded coastal area. If the sea-level rises 0.5 m, the tidal flat will be 24-34 percent lost, and if it rises 1 m, the loss would be 44-56 percent. In contrast, the impact of sea-level rise on deposition beaches is much less—if sea-level rises 0.5 m, the beach will be lost 4-6 percent; if it rises 1 m, then losses would reach 9-15 percent. The impact of sea-level rise on the relatively stable coast is in the middle range (Ji Zixiu et al., 1992). As marsh land has better productive capacity and rich biological resources, the impact on the marsh land or the destruction of it due to sea- level rise will bring enormous losses to the national economy and harm environmental protection.

C. Measures to Minimize Impact of Sea-Level Rise and Estimate Investment Expenses

3.47 If sea-level rises 1 m and coastal areas are not protected, as shown in paras. 3.23-3.24, the populous and rich delta plains will be almost inundated, affecting more than 73 million people. The impact on China's economy and society will be inestimable and cannot be permitted to happen. Therefore, various protective measures must be taken. The most important is to raise and consolidate the existing dikes along China's coast, especially in the delta plains. But what will be the impact on China of taking these various protective measures? Examples of disaster prevention practices in some areas are given below.

3.48 **Example 1**. In the Shengli Oil Field of the Yellow River delta, a huge dike was built at the mouth of Yellow River in 1990 to guarantee the safety of the Gudong Oil

Field. This dike, designed to protect against a 100-year storm surge, is built of rubble-concrete. Built on a muddy flat at 1-m altitude, it is 108-km long, 5-m high, with a bottom width of 38 m, and a top width of 10 m. It cost a total of Y 400 million (about Y 4 million/km), equivalent to just four-fifths of the annual output value produced by one oil refinery in this oil field (*People's Daily*, Overseas Edition, December 1, 1990, p. 1). As a result, when a 100-year strong storm surge attacked the coastal areas of North China on September 1, 1992, this huge dike successfully protected the oil field, and only a few parts of it were destroyed.

3.49 **Example 2**. The Shandong provincial government planned to spend Y 100 million (Y 1.11 million/km) in building a long, continuous dike along the Laizhou Bay coast. It will be 90-km long in total and 6-m high (of unclear width), and it is designed to protect against a 100-year storm surge. Its cost is equivalent to one-sixth of the annual output value produced by a large state-run alkaline factory in the province.

3.50 **Example 3**. There are over 150 km of dikes along the coast of Tianjin. On September 1, 1990, more than 120 km of dikes (85 percent) were destroyed or burst, allowing seawater to invade the downtown areas, industrial and mining regions, salt fields, and shrimp farms, causing a direct economic loss of Y 400 million. Tianjin's Flood Control Headquarters plans to rebuild the dike according to standards that would protect against a similar storm surge in the future, which will cost Y 90 million. Suppose that the final cost is Y 100 million (Y 0.84 million/km). This would be equivalent to one-quarter of the direct loss, 1/300 of the gross national product (Y 30.031 billion) of Tianjin in 1990, and 1/33 of gross national product produced by Tanggu and Dagu (2.56 billion plus 0.7398 billion equals Y 3.3 billion).

3.51 It is worth pointing out that, after the No. 8509 typhoon storm surge disaster in Aug. 1985, the Tanggu Government built the dike and dam in the coastal areas near the fishery harbor. The dike was built 6-m high over Dagu datum plane in rubble-concrete, based on the standard prescribed by the Tianjin Flood Control Headquarters of protecting against a storm surge like that of 1985. As a result, it successfully protected against the strong storm surge of September 1992, and helped downtown areas avoid disaster. The tide level of the harbor reached 5.98 m, only 20 cm from the top of the dike. In the coastal areas of Tianjin, the tide level of September 1992 was 0.5m higher than that of August 1985, and was called a 100-year storm surge. But in the new Tianjin harbor, because no measures were taken after the 1985 disaster, such as building dikes, the strong storm surge of 1992 inundated the harbor 1 m, and allowed seawater to enter storehouses, causing heavy losses.

3.52 In the Yangtze River delta, to prevent against a 1000-year storm surge, the Shanghai government completed two standard projects in 1992. At the Suzhou River mouth, a huge floodgate was built to prevent backflow from the Huangpu to Suzhou Rivers. On the outside beach along the west coast of the Huangpu River, hollow sea walls with reinforced cement (the hollows are used as shops and parks) was rebuilt to prevent downtown areas from seawater inundation. It cost Y 0.35 billion in total, equivalent to 1/212 of the gross national product value (Y 74.667 billion) of Shanghai in 1990. It can guarantee safety under predicted conditions of sea-level rise and storm surge threats through the year 2030.

3.53 This is an example of a large city located at a river mouth. However, in the past, storm surges often overflowed or burst the dike, inundated the city, and hence caused direct losses of millions of yuan. It can be clearly seen from the stated examples above that the local government can afford the cost of rebuilding and raising the dikes and floodgates, and the benefits are remarkable, despite large expenses.

3.54 In order to protect low-lying coastal plains in the deltas of China, and to resist seawater intrusion when sea-level rises 0.5 m and 1 m, huge dikes must be continuously built on a large scale. It is realistic to calculate the expenses of raising the existing dikes 1 or 2 m. The sea-level rise may vary greatly among the plains because of the relative rate of sea-level rise and the differing effect of artificial control measures. For example, in Tanggu on the North China Plain, the sea-level may rise 0.5 m by 2110, and 1 m by 2030, but in the Yellow River delta, especially in Luanhe River delta, the sea-level rise will be much lower. In the Pearl River estuary, the sea-level will rise 0.5 m by 2030, and 1 m by 2060, but in the other areas, the rise will be relatively slow. In the Yangtze River delta, the sea-level of Shanghai may rise 0.5 m by 2040, and 1 m by 2070, but in Chongming Island and northern Jiangsu Province, the rate of increase will be much slower.

(a) **North China Plain**

The mountainous coast from Qinhuangdao to Laizhou Bay, by way of Tanggu, is nearly 500-km long. If raising 1 km of dikes cost Y 1 million as mentioned above, raising the existing dikes 1-2 m will cost Y 500 million and Y 1 billion, respectively. Because the expenses will be shared by Hebei, Tianjin, and Shandong, and the dikes will be built in two stages, the burden will not be too heavy. Even if the expenses were borne totally by Tianjin city, the stages would be equivalent to just 1/60 and 1/30 of the city's gross national product in 1990 (Y 30.031 billion).

(b) **The Yangtze River Delta Plain**

In Shanghai, according to Zou Jiakan's calculation (1993), if the sea-level rises 0.5 m while the land subsides 0.3 m, and thus the actual relative sea-level rises 0.8 m, it will cost Y 1-1.5 billion to raise and consolidate the dikes and floodgates and to strengthen defensive beach works (i.e. not only building dikes). The expense would be equivalent to 1/50 of the gross national product (Y 74.667 billion) of Shanghai in 1990.

3.55 In the Pearl River delta and Lower Liaohe River delta as well as other delta plains, the length and expense of dikes and local financial capacity can also be calculated by the same method as mentioned above.

3.56 The total expenses of raising existing dikes in China can be calculated as follows: If raising 1 km of dike costs Y 1 million, then the expense of raising by 2 m the existing 12,883 km of dikes (not including Taiwan) will be Y 12.9 billion, equivalent to 1.5 percent of the gross national product produced by the nine coastal provinces and two coastal municipalities in China in 1990 (Y 873.867 billion).

3.57 Here we have analyzed only the cost of building dikes and dams. The cost of other protective measures such as preventing seawater intrusion and environmental deterioration in the agricultural zones of low-lying plains, rebuilding drainage systems in urban districts, and building pumping stations in the easily flooded areas, are not estimated due to the complexity of these situations.

3.58 Finally, because land subsidence in coastal areas caused by overpumping of groundwater is quite severe, one of the most important countermeasures is to strictly control the withdrawal and use of groundwater to mitigate the impact of sea-level rise on coastal areas. Shanghai and Tianjin have taken some of these measures and achieved a marked effect.

4. IMPACT OF GLOBAL CLIMATE CHANGE ON CHINA'S TERRESTRIAL ECOLOGICAL ENVIRONMENT

A. IMPACT OF CLIMATE CHANGE ON THE WETLANDS OF CHINA

Area and Distribution of Existing Wetlands in China

4.1 Wetlands are a special kind of ecosystem that fall between terrestrial and aquatic environments. Different people have different definitions of wetlands. Wetlands in China mainly include marshes, shallows of sea and lakes, and a portion of lakes.

Area and Distribution of Lakes, Lake Shallows, and Marshes

4.2 Figure 4.1 shows the distribution of Chinese lakes and marshes. China is a nation with many lakes. There are approximately 2,600 natural lakes larger than 1 km^2. The total area of lakes is about 74,277 km^2, accounting for 0.8 percent of total national area. The eastern plain and Qinghai-Tibet plateau are two regions of densely distributed lakes, consisting of 50.5 percent and 29.4 percent of the nation's total lake area, respectively. These two regions as well as Mongolia-Xinjiang, Yunnan-Guizhou, and northeastern China are the country's five biggest lake regions. The average depth of lakes in the eastern plain is less than 4 m, belonging to the shallow lakes category; the lakes created by wind in desert in the Mongolia-Xinjiang plateau and those created by rivers in the marshes of the northeast plains region are also generally low in depth (see Table 4.1).

4.3 According to an investigation of China's 25 main lakes, there are 1,978 km^2 of lake shallows, making up 43.3 percent of statistical lake area (see Table 4.2). This indicates that the lake shallows of China are mainly distributed in the lower reaches of the Yangtze River and Huaihe River. There are about 7,562 km^2 of shallow area, accounting for 94.8 percent of the nation's main shallow areas.

4.4 Marshes are broadly distributed throughout China, from coastal to inland areas, from plains to mountain plateaus, and from frigid-temperate zones to the tropics. They are most numerous in the Sanjiang plain, Daxinganling, and Xiaoxinanling in the Northeast and in the Qinghai-Tibet plateau. According to preliminary statistics, the total marsh area is about 100 to 110 million hectares (Institute of Changchun Geography, 1989; Integrated Nature Survey Committee of Chinese Academy of Sciences, 1990; Editing Committee of Chinese Vegetation, 1983). Detailed information about these marshes is shown in Table 4.3.

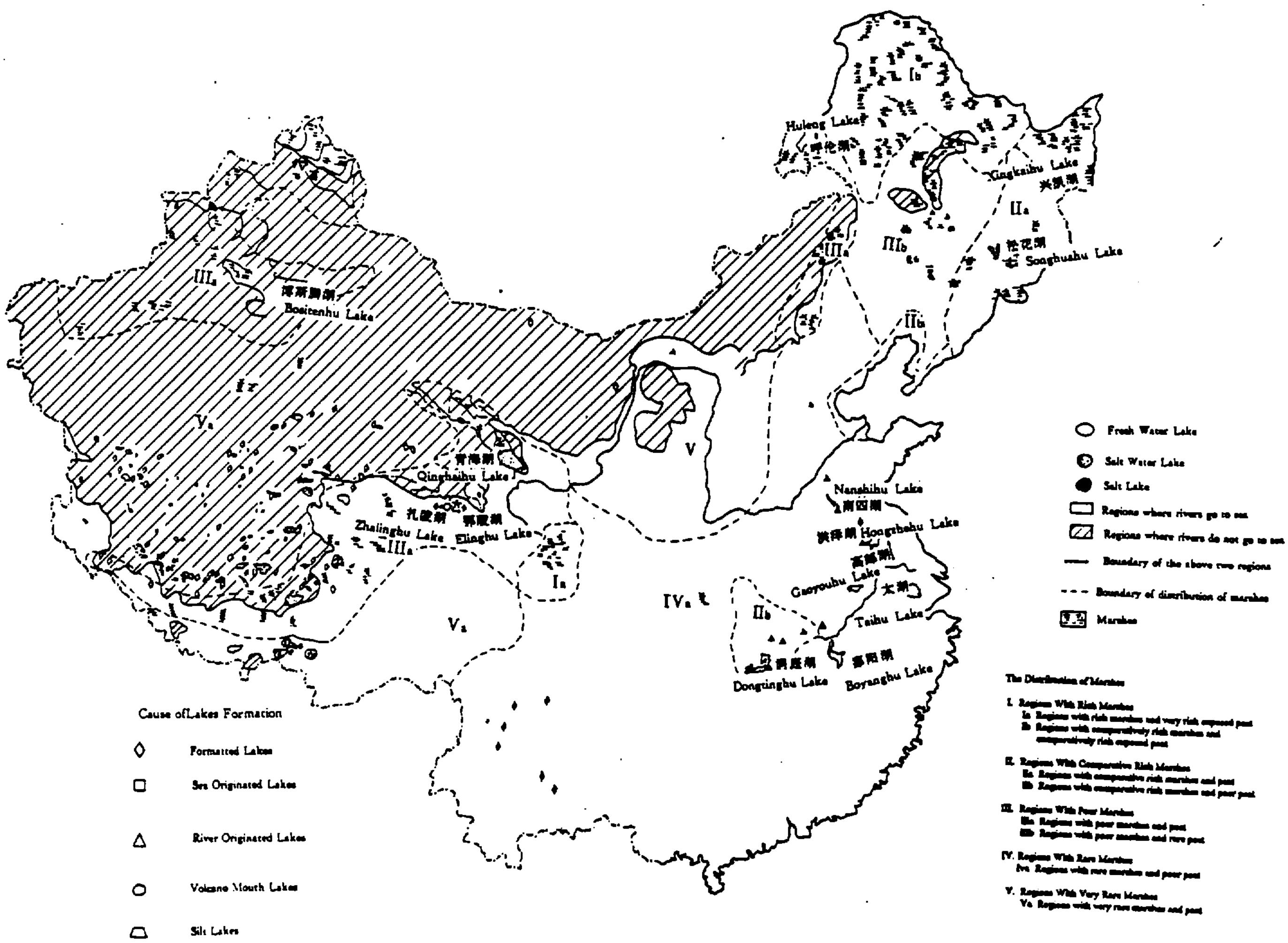

Fig. 4.1 The distribution of main lakes and marshes in China. (From Changchueng Institute of Geography. Chines Academy of Sciences, 1989).

Table 4.1: THE MAIN SHALLOW LAKES OF CHINA
(From Wang Hongdao et al., 1984)

Lake	Province	Geographical North Latitude	Position East Longitude	Area (km^2)	Average depth (m)
Taihu Lake	Jiangsu	31°20'	120°16'	2,425	2.1
Hongzhe Lake	Jiangsu	33°20'	118°40'	1,960	1.4
Fulenghu Lake	Inner-Mongolia	48°57'	117°23'	2,315	5.7
Lansihu Lake	Shandong	34°59'	116°57'	1,266	4.2
Chaohu Lake	Anhui	31°35'	117°35'	820	4.4
Gaoyouhu Lake	Jiangsu	32°50'	119°15'	663	1.3
Honghu Lake	Hubei	29°52'	113°14'	402	1.9
Liangzihu Lake	Hubei	30°19'	114°13'	334	1.7
Dianchi	Yunnan	24°51'	102°04'	297	5.1
Lianhuanhu Lake	Heilongjiang	46°35'	124°08'	276	2.2
Moon Lake	Jilin	45°42'	123°55'	206	2.3
Xingkaihu Lake	Heilongjiang	45°14'	132°26'	4,380	0.6

Table 4.2: THE AREA OF THE MAIN LAKE SHALLOWS
(From Wang Hongdao et al., 1984)

Lake	Shallow area (km^2)	Lake	Shallow area (km^2)
Dongtinghu Lake	1,688.0	Boyanghu Lake	2,536.0
Taihu Lake	254.0	Hongzehu	1,021.0
Nansihu Lake	410.3	Gaoyouhu Lake	220.0
Longganhu Lake	187.0	Chaohu Lake	171.7
Honghu Lake	110.0	Luomahu Lake	90.0
Bohu Lake	85.0	Shijiuhu Lake	96.4
Huangdahu Lake	77.2	Nushanhu Lake	53.9
Baoyinghu Lake	35.3	Shaobohu Lake	35.3
Wuchanghu Lake	31.7	Taohu Lake	12.1
Dianchi Lake	8.3	Gehu Lake	8.1
Erhai Lake	7.2	Liangzihu Lake	176.7
Yangchenhu Lake	2.3	Fuxianhu Lake	0.5

Table 4.3: THE AREA AND DISTRIBUTION OF MARSHES
(From Integrated Nature Survey Committee of Chinese Academy of Sciences, 1990)

Region	Area (10^4 ha)	Area (%)	Main distribution region
I. Eastern Region	750	75.0	
1. Northeast Region	500	50.0	Daxinanling, Xiaoxinanling, Changbaishan Mountain
Sanjiang Plain	110	11.0	Sanjiang Plain, Songnen Plain
East Part of Xiaoxinanling	56	5.6	West Liaohe River Region
2. Other Region	250	25.0	Sand marshes in eastern Inner Mongolia, Bashang Region, Upper reaches of Luanhe River, Baiyangdian, Wenanwa, Reed marshes in the middle to lower reaches of Yangtze River Caohai in Guizhou, Jianhu Lake, Yuhu Lake and Diannanhe shallow in Yunnan, etc.
II. Western Region	250	25.0	
1. Qinghai-Tibet Plateau	200	20.0	Nuoergai Region in Northwest of Sichuan, Hongyuan Region, the Origin of Yangtze and Yellow River, Chaidamu Basin, Naqu Region in North Tibet, Hengduanshan Region, etc.
2. Mountain Region in North Tibet	50	5.0	Tianshan Mountain, Aerdaishan Mountain, Beshihu Region, etc.
Total	1,000	100	

Area and Distribution of Sea Shallows

4.5 The coastline of China is about 18,000 km long, stretching from the mouth of the Yalu River in Liaoning province in the north to the mouth of the Beinanhu River of Guangxi in the south. There is an estimated 20 million hectares of intertidal sea shallow area in China. The coastal area north of Hangzhou Bay is mainly a flat, sandy, and broadly intertidal region that accounts for 76 percent of the total national sea shallows area. The coastal region to the south of Hangzhou Bay is mainly rocky. It is estimated from the speed of sand accumulation in major river mouths and coastal plains that the created area of sea shallows is about 26,000 to 33,000 hectares annually (Editing Committee of Natural Protection in China, 1987).

4.6 Table 4.4 provides more detail on the distribution of sea shallows. The total area of shallow lakes, lake beaches, marshes, and sea shallows is about 26 x 10^4 km^2 (Lu Jianjian et al., 1988).

Table 4.4: THE DISTRIBUTION AND AREA OF SEA SHALLOWS
(From Integrated Nature Survey Committee of Chinese Academy of Sciences, 1990)

Region	Shallow area (10^3 ha)	Region	Shallow area (10^3 ha)
Liaoning	266.7	Shanghai	58.0
Hebei	276.0	Zhejiang	266.7
Tianjin	4.0	Fujian	246.7
Shandong	333.3	Guangdong	182.0
Jiangsu	420.0	Guangxi	75.3
Total			2,132.0

Impact of Climate Change on the Wetlands Ecological Environment of China

4.7 China's wetlands are under increasing pressure due to natural silt accumulation, fishery purposes, drainage for disease control, pollution, and other human activities. The Asian Wetlands Bureau and World Nature Foundation estimate that about 40 percent of Chinese wetlands with international importance are under medium to serious threat, and future climate change will further affect the wetland ecosystems.

Impact on Marshes

4.8 Future climate changes will probably reduce the area of the Sanjiang plain marshes, one of the world's biggest wetlands, and decrease the productivity of another, the Nuoergai marsh.

4.9 The Sanjiang plain is in the humid climate zone, where rainfall is greater than the sum of water evaporation and stream outflow. Marshes are distributed widely and air temperature is high. This is beneficial to plant growth. The freezing time, about 200 days, restricts microbiological activities, so organic matter decomposes slowly. The thick peatbed is normally 1-2 cm, but can be as deep as 9 cm.

4.10 According to various statistics and predictions (Gao Suhua et al., 1991; Jin Zhiqin et al., 1991; Ren Zhenhai et al., 1992) the northeastern Sanjiang plain has been becoming warmer during the last 40 years, especially during the winter. According to estimates based on the GISS, GFDL, and UKMO models, under conditions of $2xCO_2$, the accumulated temperature would be close to that in which rice can be cultivated for two seasons (Jin Zhiqin et al., 1991). Rising temperature will increase water evaporation and may change this from a permanent water zone to a temporary one, but the days of existing temporary water zone have been reduced. The rise of temperature, especially during the winter, will also activate microbiological activities and change the decomposition speed of organic matter as well as soil ventilation. This will further cause marshes to become pasture. Presently, most of the Sanjiang plain has been drained and become arable land. Climate warming will strengthen this trend and reduce the wetlands area.

4.11 Another broad marsh is found in the Nuoergai plateau of Sichuan, which is 3,400 m above sea-level. This region belongs to the frigid zone. The average temperature during the growing season is low, about 9.1 to 11.4°C in July. However, the high altitude, high radiation and transparency, and large daily temperature fluctuations, are good for product accumulation. Plant productivity is thus about 7,075 kg/ha annually (Editing Committee of Chinese Vegetation, 1983). Climate statistics for the last 40 years show that it has been becoming colder and rainfall has been decreasing in the southwest region. If this trend continues, low temperatures will reduce plant growth as well as the primary productivity of ecosystems, though it is difficult to predict the impact on the area and distribution of marshes.

Impact on Low-Depth Lakes and Lake Beaches

4.12 Climate changes will increase the lake beach area in the middle to lower reaches of Yangtze River and plain area. As mentioned above, the eastern plains have many low-depth lakes and lake beaches, and this region will also be relatively strongly affected by future climate changes.

4.13 Most of the lakes in this region receive water from rivers. The relationship between lakes and rivers is close and there are great annual changes in the water quality of lakes. The lower the reaches of rivers, the smaller the variations in the water level of lakes. The lake basins are low and flat. During flood season, lakes are broad; during the arid season, islands and beaches can be seen. "They are lakes when the water is high and rivers when the water is low" is one lively description of this situation (Wang Hongdao et al., 1989).

4.14 It is estimated that summer rainfall will higher than that of winter; there will be higher temperature increases in the winter than in the summer, and the rainfall variation will be larger in the summer, registering approximately a 1.50 mm daily increase, leading to a 12.9 percent increase by the year 2050. According to other estimates based on rainfall analysis and rainfall standard error, the possibility of heavy rains in June and July will increase through 2050, especially along the Yangtze River basin (Wang et al., 1993).

4.15 Because of the increase in rainfall, the water input of lakes during the rainy season will increase greatly, while the rising water level of rivers and sea will reduce the ability of rivers to flow to the sea. This, in turn, will decrease the flow of lake water to rivers, which will affect the ability to reduce flooding of lakes. The flat landscape in this region will allow the area of lakes to increase, sometimes even spreading to what is now arable land. In addition, increasing rainfall will probably reduce the height of present lake beaches and increase water level variations.

Impact on Sea Shallows

4.16 This will flood most of the present sea shallows and reduce their area, change the ecological environment, and affect the species distribution.

4.17 First, the warming trend will lead to rising sea-levels and flood the majority of present sea shallows, mainly the sand-clay plain sea shallows spread over the coastal regions to the south of Hangzhou bay. Because the landscape is flat and the inter-tidal region is broad, the sea shallows here account for about 76 percent of the nation's total. If the sea-level rises 50 cm, about 4,000 km^2 of the area would be flooded. But since this region has a high population density of 800 persons/km^2 and is a developed economic zone, it is unlikely that the sea will be allowed to flood the region. Sea shallows will therefore be greatly reduced.

4.18 An increase in storm surge frequency is another feature of climate changes. The erosion effect of storm surges on the beaches will change the ecological environment of sea shallows, e.g., the shape of dunes, shift of sands, plant organization, and seasonal features (Zhen Yuanqiu, 1991).

4.19 The warming trend will also move the distribution of mangrove forests northwards, and increase their area. Mangrove forests are found on clay-sand coasts, and create a special biological and coastal topography. The distribution of mangrove forests is limited by low temperatures in the north. Mangrove forests thrive in regions where the lowest daily temperature should be higher than 20°C. Their low temperature limit is about 10°C (Zhong Congpei, 1984). They are distributed mainly in Guangdong, Fujian, and Taiwan. They can also be found in Pingyang of Zhejiang Province, 28°N, but because of low temperatures, they cannot renew themselves. Climate warming will drive mangrove forests north and some temperature-sensitive species will also move north. This will help distribute the present mangrove forests more widely and enrich the species (Lu Changyi, 1991).

4.20 Although climate warming will bring beneficial effects as mentioned above, it will also threaten the existing mangrove forest distribution area because of sea-level rise. The sea-level has increased by about 0.115 cm annually for the past 100 years. Statistics from stratigraphy show that the distribution of mangrove forests is closely related to the speed of sea-level rise. The record indicates that mangrove forests on islands with low sea-level can only keep up with a sea-level rise of 8 cm per 100 year and will disappear when the speed exceeds 12 cm per 100 years. But they can withstand a higher speed of sea-level rise (up to 25 cm per 100 years) on islands with higher elevation, since these have thicker deposits (Wang Xiaobo, 1990).

Impact on Biodiversity of Wetlands

4.21 The possible impact on wetlands includes threats to wildlife and reduced biodiversity. Wetlands contain more than 500 species of freshwater fish and more than 300 species of birds, which make up about one-third of all national species. Moreover, about half the birds ranked as top priority species for protection live in wetlands. Statistics shows that 54 percent of endangered Asian birds (i.e. 31 out of 57 species) live in Chinese wetlands. In addition, 46 out of 166 world species of Grus apcneemis, Nipponia nippon, Anas angustirostris, and 9 out of 15 world cranes live in Chinese wetlands. The rich biodiversity of Chinese wetlands thus holds an important position in the world.

4.22 The future climate changes will have an adverse impact on China's wetlands in several areas. First, the great change in habitats will have serious adverse effects, mainly in terms of flooding the majority of sea shallows. This will take away the homes of many rare aquatic birds, such as the Grus Japonica inside 400 km^2 of the coastal shallows of Yancheng. Second, many natural and human barriers will make it difficult for them to migrate to other areas by themselves. Third, future climate changes will transform the majority of existing natural wetland areas into man-made ecosystems, making them uninhabitable for wildlife as well as simplifying the ecosystem structure and reducing biodiversity. The transformation of the Sanjiang plain wetlands into arable land is an example of this. Fourth, climate and especially temperature changes will directly threaten the existence of some species, such as Lcuciscus brandti Dyvonski, a fish found only in the Suifanghe River and Dumenjiang River. Its spawning time is regulated by water temperature—a drop in temperature followed by increasing temperature with a variation over 9°C is critical for spawning. The optimal temperature for embryo development is 10-18°C. Temperature overs 19°C will cause death among those in the stage of differentiation of organs, hatching, and larvae phases (Yin Jiashen et al., 1991). Thus, climate warming will adversely affect the spawning and hatching of these fish.

Strategy for Mitigating the Adverse Impact of Climate Change on Wetland Ecosystems of China

Reinforcing Construction of River Mouth and Shallows Ecosystems

4.23 As mentioned above, the function of wetlands as water pools and flood protection areas will be more and more important with the increase and concentration of precipitation in the future. Unfortunately, the wetlands of river mouths and shallows have been seriously damaged. For example, wetlands in the Liaohe River region of northeast China have been changed into arable land and their ability as water pools and for flood prevention has disappeared. The biggest river mouth wetlands along the coast in the northern Liaodong Bay have also been seriously impaired and their flood prevention capability had decreased at the rate of 50 percent every ten 10 years from the 1960s to the mid-1980s (Dong Houde et al., 1991). This situation must change. The changeover of wetlands to arable lands should be stopped and the natural function of river mouths and shallow ecosystems should be restored. Ecological engineering should be considered in those areas already seriously damaged or expected to become so.

Reinforcing the Ecological Construction of Sea and Lake Shallows

4.24 The shallows and coast should be protected by planting natural salt marsh plants, man-made mangrove forests, and Spartine anglica. This will increase both primary productivity and economic income.

4.25 Spartine anglica is a plant resistant to both salt and water, developed in China in 1963. By 1981, it had reached 0.36 million hectares, from a start of just 21 trees (Zhong Congpei, 1984). It has the ability to resist wave and water erosion, protect shallows and dams, increase silt accumulation and land formation, improve saline soil, and increase fertilizer origins. It also has tremendous production ability and broad adaptability as well as developed culture methods, and can be used to control the adverse effects of climate changes on sea shallows in the future (Zhong Congpei, 1984; Editing Committee of Chinese Vegetation, 1983).

Strengthening Research on Models for Resource Exploitation of Wetlands and Establishing Pilot Projects

4.26 Experience has been accumulating on the exploitation of wetland resources over many years of changeover between wetlands and arable land in China, and has been taken into account in the ecological-agricultural practices of recent years. Examples include the ecosystem model for rice-bacteria-fish-marten in the Sanjiang plain marshes (Ni Hongwei et al., 1991), and the ecological-economic model consisting of forest, fishery, and husbandry subsystems in the Dafeng sea shallows (Wu Pinsheng et al., 1991). This should be combined with a model that predicts climate changes, including the parameters of climate warming, to better predict exploitation of the wetlands that will experience climate changes.

Strengthening the Protection of Wetland Biodiversity

4.27 The process of identifying those species that need protection should be speeded up. The construction of natural wetland preserves should be reinforced. On-site protection or protection in other sites should be prepared so that wetland species can be moved to suitable new sites.

B. Impact of Climate Change on Desertification in China

Present Condition and Reason for Desertification in China

4.28 Desert areas, mainly found in dry regions, result from arid climate and rich sands. Desertification, however, is not restricted to arid regions, but can also be found in semi-arid pasture and some semi-humid regions. Chinese experts describe desertification as taking place under the fragile ecological conditions of arid or semi-arid regions and sometimes semi-humid regions, when former non-desert lands take on the features of a wind-blown sandy desert environment caused in part by excessive human activities. They consider sandy desert environments to be characterized by wind-blown sand, not restricted to arid desert regions, with features similar to the desert ecological environment. This definition stresses the importance of an arid or semi-arid climate, with excessive human economic activities only an outside factor. Even without this factor, further drying will also cause desertification.

4.29 Desertified lands are distributed widely, though not continuously, over about 5,500 km in China from Heilongjiang in the east to Xinjiang in the west. They are found in Heilongjiang, Liaoning, Jilin, Hebei, Shanxi, Inner Mongolia, Shaanxi, Ningxia, Gansu, Qinghai, and Xinjiang, in 212 counties, with a total area of 0.334 million km^2. Desertified lands cover about 0.17 million km^2, and potentially desertifying lands about 0.158 million km^2 (Zhu Zhenda et al., 1989).

Table 4.5: THE DISTRIBUTION OF DESERTIFIED LANDS IN CHINA
(From Zhu Zhenda et al., 1989)

Region	Total area (km^2)	Developing desertified lands (km^2)	Strongly developing desertified lands (km^2)	Seriously desertified lands km^2
Hulunbeier	3,799	3,481	275	43
Lower reach of Nenjiang River	3,564	3,286	278	-
West of Jilin Province	3,374	3,225	149	-
East side of Xinanling Mountain	2,335	2,275	60	-
Keerqin pasture	21,576	16,587	3505	1,175
Northwest of Liaoning Province	1,200	1,088	112	-
Upper reach of Xilamulun River	7,475	3,975	1,875	1,625
Weichang and North of Fengning	1,164	782	382	-
Bashang, north of Zhangjiakou	5,965	5,917	48	-
Xilinguole and Cahaer Pasture	16,862	85,871	7,200	1,075
Region of hind mountain (Wumeng)	3,867	3,837	30	-
Region of front mountain (Wumeng)	784	256	320	208
Northwest of Shanxi Province	52	52	-	-
North of Shaanxi Province	21,686	8,912	4,590	8,184
Eerduosi (Wumeng)	22,320	8,088	5,384	8,848
Houtao, Wulanbu and Beibu	2,432	512	912	1,008
North of Langshang Mountain	2,174	414	1,424	336
Center and Southeast of Ningxia Province	7,687	3,262	3,289	1,136
The front plain of west part of Helanshang Mountain	1,888	632	1,256	-
South side of Tenggeli Desert	640	-	640	-

4.30 It can be seen from Figure 4.2, and Tables 4.5 and 4.6, that desertified and potentially desertifying lands are mainly found in regions above 35°N latitude. Due to

Table 4.6: THE DISTRIBUTION OF POTENTIALLY DESERTIFIED LANDS IN CHINA

Region	Area (km^2)
Hulumbeier	4,266
Lower reach of Nenjiang River	1,501
West of Jilin Province	4,512
Keerqin pasture	5,440
Upper reach of Xilamulun River	7,793
Hebei Bashang	5,536
Xilinkele pasture	47,687
Hind mountain of the Wulancabumeng	4,928
North of the Wulancabu pasture and north of the Lannshan mountain	19,200
Northwest of the Shanxi Province and north of the Shaanxi Province	5,840
Central-western parts of Eerduosi	10,720
Southeast of Ninxia Province	2,560
Alashan region	17,856
Hexizoulang region	2,036
Caidamu basin	3,520
Talimu basin	12,690
Zhungeer basin	2,806
Total	15,800

desertification trends, the area of desertified lands increased from 0.137 million km^2 in the 1950s to 0.176 million km^2 in the 1970s, In other words, the desertified area increased by 39,000 km^2 over a period of some 25 years, at an average rate of 1,560 km^2/year. At this speed, the area of desertified lands will reach 0.2513 million km^2 by the year 2000 and 0.5012 million km^2 by the year 2030 (Table 4.7). This is only a conservative estimate because it does not consider the impact of global climate changes. The reasons for land desertification in China are both natural and human, and their combined effects will speed up the process of desertification.

4.31 The natural factors include frequent, above-threshold sand wind speeds (18 km/hr) with the simultaneous appearance of the arid season, and the loose structure of superficial substances, consisting mainly of physical sands.

4.32 Excessive human exploitation is also an initiating factor for land desertification. Such exploitation mainly consists of excessive agricultural activity, animal husbandry, and deforestation. Such economic activities are closely related to increasing population density. In regions on the border of agriculture and husbandry practice, where

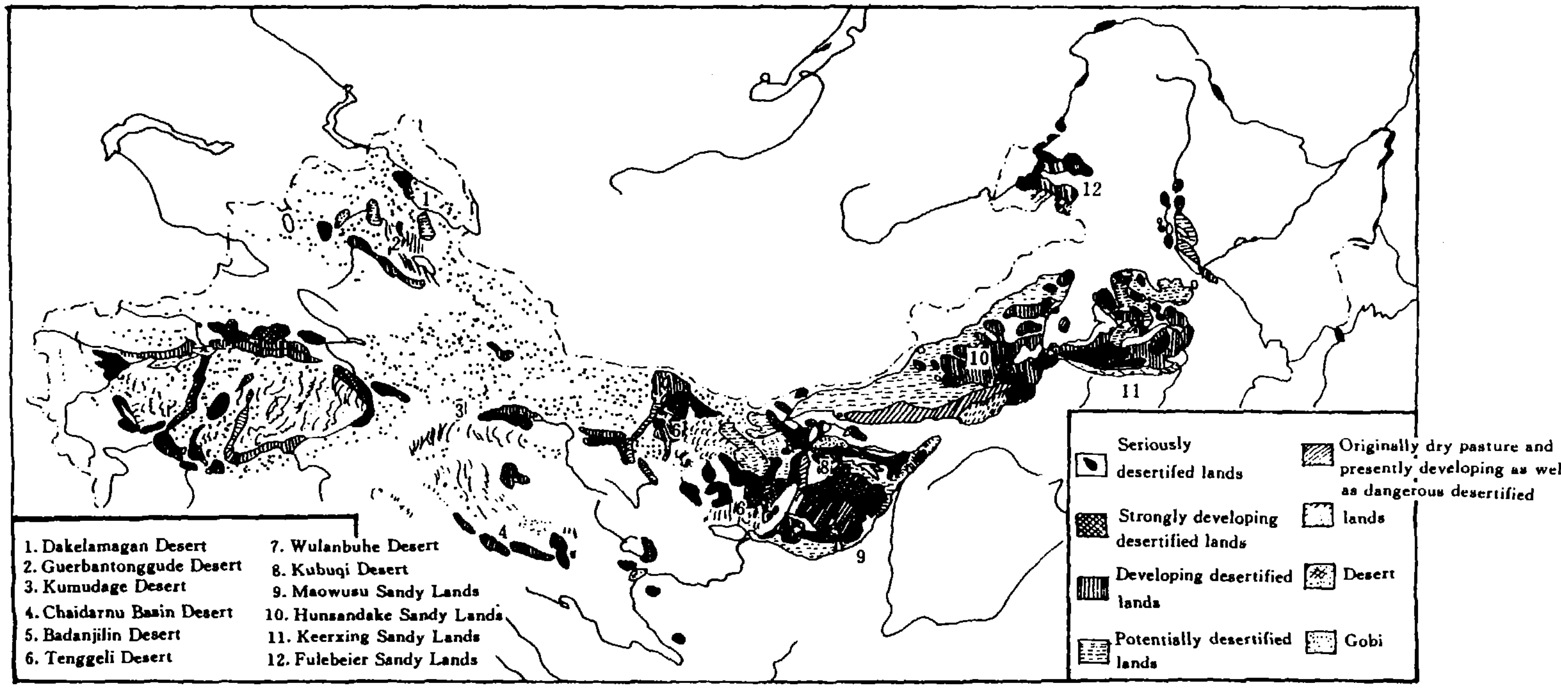

Fig. 4.2 The distribution of desert and desertified lands in Northern parts of China.

Table 4.7: THE PREDICTION FOR THE LAND DESERTIFICATION DEVELOPMENT IN THE NORTHERN REGIONS OF CHINA
(From Zhu Zhengda et al.,1989)

Type of desertified lands	2000		2030	
	Estimate for area (10^4 km^2)	Data higher than 1970s (10^4 km^2)	Estimate for area (10^4 km^2)	Date higher than 1970s (10^4 km^2)
Developing desertified lands	9.75	1.65	13.54	5.44
Desertified lands under development	9.28	3.18	19.46	13.36
Seriously desertified lands	6.10	2.70	17.12	13.72
Total	25.13	7.53	50.12	32.52

Table 4.8: THE SITUATION OF DESERTIFICATION CAUSED BY HUMAN ECONOMIC ACTIVITIES

Type of desertified lands	Area (km^2)	Percentage in total desertified lands
Mainly excessive agricultural practice	4.47	25.4
Mainly excessive husbandry	4.99	28.3
Mainly excessive collecting trunks	5.60	31.8
Mainly excessive mining, construction of roads and city building	0.13	0.7
Mainly excessive exploitation of water resources	1.47	8.3
Mainly dune moving under the impact of wind power	0.49	5.5

population density increased by about 3.08 percent annually, average population density increased from 10-15 persons/km^2 in 1949 to 40-60 persons/km^2 (and in some places as high as 80 persons/km^2) in 1980. As the growing population relied more heavily on the land resources, increased exploitation of pasture lands has taken place. Table 4.8 lists the degree of desertification in the northern regions caused by excessive economic activities. It should be noted that desertification caused by natural wind power moving sand dunes accounts for only 5.5 percent.

Impact of Climate Change on Land Desertification in China

4.33 Proof of global warming caused by the greenhouse effect comes from an increasing body of evidence. According to meteorological data, the average temperature increase of 0.5°C since the middle of last century, the recession of glaciers, and the rise of sea-level (10 to 20 cm since the nineteenth century) are due to global warming. The arguments over global warming are no longer about whether it is occurring, but about its degree and speed. Future research will attempt to determine the exact impact and best strategy for dealing with this climate change, relying on both experience and models.

4.34 Dry climate is another main factor in land desertification, as well as special geological and geographical conditions. It should be noted that global warming will cause the northern parts of China, located at the eastern end of the Euro-Asian continent, to experience less rainfall and more drying. Therefore, climate change will have a major impact on the desertification process in northern China.

4.35 All the models for the next 50 years predict that the average temperature in China will increase by about 3.9 to 4.8°C (Wang et al.,1992), the rainfall in the southern and southwestern parts will increase by 9.3 to 12.7 percent, and rainfall in the north will decrease. Even more serious, the water evaporation increase caused by this warming will reduce soil moisture by 2.4 to 2.9 percent, especially in arid and semi-arid regions of northern China. The rainfall decrease, temperature increase, and soil moisture decrease, will further worsen the ecosystem in arid and semi-arid regions and speed up the process of land desertification.

4.36 Although the CO_2 concentration will strengthen the productivity of plants, the main constraint on plant growth in the northern parts of China is water content, not air temperature and CO_2 concentration. Some materials indicate that deserts move faster in arid years, and are restricted by plant growth in rich rainfall years.

4.37 According to predictions based on soil temperature variations, desertification in the northern parts of China will speed up. Among the three main northern regions, desertification in north China will be fastest, followed by the northeast region and then the southwest. But because of the great potential desert area in northwest China, the annual increase in desert size will be greatest in this region.

4.38 Due to a lack of first-hand materials, only qualitative estimates can be made as to the desertification of arid and semi-arid lands in China caused by climate warming. The quantitative data will depend on detailed studies, especially those related to the impact of climate changes on the global ecosystem.

Impact of Climate Change on the Prevention and Control of Sands

4.39 Drying and human economic activities are two main causes of land desertification. Climate warming will cause the pace of desertification to increase in northern China. The present methods of control are mainly biological, i.e., plants are used as a barrier to desert movement. This has been demonstrated to be an effective method of preventing desertification for the past 80 years, and will probably be mankind's main choice in the future. But climate warming not only affects land desertification, but also makes it more difficult to prevent and control sands due to further drying. The existence and growth of plants in arid and semi-arid regions of northern China is influenced mainly by available water, with temperature of only secondary importance. So climate warming will probably have adverse effects on the conservation and development of forests in arid and semi-arid regions of the north and make it more difficult to develop man-made forests there.

Strategy for Mitigating Land Desertification

4.40 Prevention of desertification must take into account both ecological benefits and economic output, appropriate methods of exploitation, and so on, in order to combine exploitation and conservation goals.

4.41 Control of land desertification should be treated as complex system engineering, with the goal of improving the overall ecosystems of arid and semi-arid regions. Various methods of economic exploitation should be developed, with husbandry dominant. Population should be controlled and its impact on desertifying lands should be reduced. The energy structure of rural regions should also be changed to reduce plant destruction.

4.42 On semi-arid lands with a mixture of agriculture and husbandry, natural enclosures should be adopted to change the dominance of agricultural and augment pasture areas. Man-made pasture and grass bases should be carefully established to ensure proper output of grass and proper plantation in pasture regions. In arid regions, overall planning and proper water distribution should take place making use of inland rivers. Preventive forests should be established at the center and margins to control sands, as well as in the periphery to isolate oases of sands and establish integrated systems.

C. Integrated Analysis of the Impact of Climate Change on the Terrestrial Ecosystems of China

4.43 China is located in the eastern portion of the Euro-Asian continent, opening on to the Pacific Ocean in the southeast. Northwestern China is in the heart of Asia, and the southwest connects with the peninsula of the southern Asian continent. Special climate and topographical conditions determine the plant latitudinal distribution from north to south (Wu Zhengyi et al., 1983). Presently, temperature and moisture limitations determine plant distribution (see Table 4.9), i.e., climate conditions determine plant distribution in China.

4.44 Planting systems are a dominant factor in terrestrial ecosystems. The distribution of planting systems is determined by climate conditions. Rapid climate change will certainly affect the distribution and development of planting system and have a great impact on other biological factors in natural ecosystems. It is clear that emphasis should

Table 4.9: THE DISTRIBUTION OF PLANTATION WITH CLIMATE CHANGES IN CHINA

Type of plantation	Annually average temperature (°C)	Active accumulated temperature higher than 10 °C	Annual rainfall (mm)
Coniferous tree forests in cold-temperate zone	-8-2	750-2,500	250-750
Coniferous-broad leaf tree forests in temperate zone	2-9	1,500-3,500	>490
Broadleaf tree forests in warm-temperate zone	9-14	2,500-5,500	>500
Evergreen broadleaf tree forests in subtropic region	14-22	4,000-8,000	>750
Rain forests, monsoon rain forests in tropic region	22-26	>7,500	>1,200
Pasture in temperate zone	-3-8	1,500-3,500	150-500
Desert in temperate zone	2-12	2,000-4,500	>200
Tundra Tibet plateau	<8	<2,500	no limit

be given to the effects of planting systems in studying the impact of climate change on terrestrial ecosystems.

Impact of Climate Change on Exploitation and Conservation of Natural Resources of China

Impact of Climate Change on the Distribution and Productivity of Planting in China

4.45 The distribution of planting systems closely correlates with climate. This indicates that future climate change will greatly affect the distribution and productivity of characteristic types of plants.

4.46 The horizontal distribution of natural plant cover has been determined since the fourth glacier epoch. Forests, pasture, and desert regions from the southeast to the northwest can be classified into five forest zones, from cold to tropic regions. The tundra, bushes, and deserts of the Qinghai-Tibet plateau are also stable. Because there have been no violent climatic and geological changes since then, the plantation patterns have not changed much. However, popular concern centers on what kind of effect future rapid climate changes will have on the distribution of plantation types.

4.47 According to estimates of GCM of NCAR, the temperature, rainfall and soil moisture of China will change between 1990 and 2050. The trends for such changes will move from south to north over a theoretical distance of about 500 km, from low to high latitude. It can therefore be predicted that the area of rain forests and monsoon rain forests will increase greatly while the highland plantation system in the southwest will decrease greatly, i.e., the vegetation in its lower regions will be replaced by other types of vegetation. Cold-temperate coniferous tree forests and temperate coniferous tree forests as well as mixed coniferous-broadleaf tree forests will decrease significantly. The distribution area of those two types of vegetation will move to the Siberian region from the north, and cold-temperate coniferous tree forests will almost disappear in China. Because there is no simultaneous increase in rainfall predicted to accompany the temperature increase in northwestern Xinjiang, soil will become more arid and climate will be hotter and dryer. The corresponding plant characteristics will also change from temperate-desert into temperate-pasture or subtropic-desert. Table 4.10 shows changes in the distribution of plant types in China.

Table 4.10: THE IMPACT OF CLIMATE CHANGE ON THE DISTRIBUTION AREA OF PLANT TYPES IN CHINA

Type of plantation	Percent area (%) /a	Optimal estimate for 2050	Minimum estimate for 2050	Maximum estimate for 2050
Coniferous tree forests in cold-temperate zone	2	0	0	2
Coniferous-broadleaf tree forests in temperate zone	7	6	3	9
Broadleaf tree forests in warm-temperate zone	11	-	9	15
Evergreen broadleaf tree forests in subtropic region	21	-	21	24
Rain forests, monsoon rain forests in tropic region	1	7	3	10
Pasture in temperate zone	16	11	7	15
Desert in temperate zone	14	10	-	14
Tundra in Tibet plateau	28	20	8	26
Nondetermined /b	-	-15	4	13

/a Present (1950-80)
/b Nondetermined-maybe warm temperate zone or tropic desert.

4.48 Generally speaking, due to increasing temperatures and CO_2 concentration, the productivity of plants in China will increase. Most important is the impact of CO_2

increases, with climate warming and prolonging of the plant growing season of secondary importance. It is estimated (Gao Suhua et al., 1991) that a 1°C average annual temperature increase will prolong plant growth by 15 days (10°C continuous days). If there is a 3°C average annual temperature increase, the growing season for plants will increase 30 days, except in the southwest region (see Table 4.11). It is generally agreed that under climate warming conditions, the productivity of high latitudinal regions will be much lower than that of low latitudinal regions. Regions rich in water resources will also have higher productivity (see Table 4.12). Productivity of plants in the northern hemisphere, including China, will increase by about 28 percent.

Table 4.11: THE CHANGES OF GROWING PERIOD IN THE CASE OF AVERAGE ANNUAL TEMPERATURE INCREASE IN PARTS OF CHINA
(From Gao Suhua et al., 1991)

	Datong 40°06'N	Lingyi 35'04'N	Hangzhou 30°14'N	Kunming 25°01'N
Annual growing period	153	210	233	258
1°C increase in T year (d)	10	11	10	28
2°C increase in T year (d)	20	22	20	56
3°C increase in T year (d)	30	33	30	84

Table 4.12: THE CHANGES OF PLANT PRODUCTIVITY (%) IN THE CASE OF AVERAGE ANNUAL TEMPERATURE INCREASE
(From Gao Suhua et al., 1991)

Temp. increase	Datong	Lingyi	Hangzhou	Kunming	Lianxian
1°C	7	5	4	5	3
2°C	15	11	9	10	7
3°C	21	16	13	14	10

Impact of Climate Change on the Exploitation, Development, and Conservation of Biological Resources in China

4.49 China has a vast territory and complex natural conditions. It is also rich in species-resources. According to statistics, China has 470 families, 3,700 genus and 30,000 species of moss, fern, and plants. These include many ancient or single genus and species, as well as 200 local-characteristic genus and 10,000 local-characteristic species. Many plant species constitute different types of vegetation and provide suitable habitats for terrestrial animals. In the 1970s there were 156 families, 714 genera, and 2,100 species of terrestrial vertebrates, including 430 species of beasts, 1,170 species of birds, 315 species of peptides, and 196 species of amphibian. These rich biological resources play an important role in China's economic development, as well as in the global biological resource bank (Jin Jianming et al., 1991).

4.50 Like vegetation distribution, the distribution of biological species correlates with climate zones. Therefore, global climatic changes will also have a great impact on the distribution, exploitation, and conservation of biological resources in China.

4.51 The moving of vegetation caused by climate change will also affect the habitats of other animals and biological resources. If such change is slow and not strong, many animal and plant species can move as vegetation moves. Some strongly-adaptive species can even change their distribution area, i.e., choose other habitats. But fast changes, especially combined with human activity, will probably exceed the ability of many animals and plants to migrate. Because those species will be in an increasingly endangered position, the Chinese government enacted the "Protection List of Rare and Endangered Plants (I)" and "National Prior Protection List of Wildlife " in 1984 (amended in 1987) and published in 1988. These laws are designed to protect a total of 389 species of plants and 257 species of animals. More than 500 nature preserves have been established, which provide protection for the majority of rare animals and plants. But rapid climate and vegetation changes will probably decrease the ability of many nature preserves to provide needed environmental conditions and to protect biodiversity.

4.52 Because of climate warming, cold-temperate coniferous forests are expected to almost totally disappear from China. These are the most abundant forests in China, widely distributed from north to south and east to west. Their attitudinal distribution increases from north to south, and they can be found as high as 4,300-4,500 m above sea-level.

4.53 Cold temperate coniferous forests are major wood resources. The wood production in northeast China constitutes about half of national output. The forests here decrease greatly in the case of climate warming for the limit of height of mountains. Many rare forests species like Larix dahurica, Picea asperata, Abies fabri, Pinus koraiensis, other animal species like northeast tiger, and other plant species like Panax ginseng will also decrease significantly. In the northwest and southwest regions, those forests will move upwards with climate warming. But as these are slowly growing species, their migration speed and adaptability can not match the speed of climate change, so they will also decrease greatly, creating serious ecological problems. First, wood resources will be destroyed and will increasingly have to be drawn from tropical and subtropical forests. Those woods, however, are not rich enough and their quality not good to meet society's demands, which may lead to further cutting of forests and even fewer wood resources. Second, the cold temperate coniferous forests are located near the origins of several main rivers. Their function in protecting water and soils is of critical importance. If those forests are destroyed, the entire ecosystem in those regions would be further weakened.

4.54 China's southern forests are located in tropical and subtropical regions. They include rainforests, monsoon forests, and evergreen broad-leaf forests. The composition of these forests is complex, with many rare and endangered species. Climate warming will drive these forests to higher latitudes and increase their distribution area. However, pressure from rising demand for wood and the relatively slow migration speed of forest species compared with the speed of climate change will become the main barriers to forest development in the south.

Relationship of Terrestrial Ecosystems affected by Climate Change to the Development of China's Society and Economy

4.55 There is no substitute for the many resources provided by terrestrial ecosystems. Presently, global ecosystems are threatened by shortages of food and fresh water, decreasing forests, desertification of arable lands, erosion of water and soils, the disappearance of biological species, and serious environmental pollution, in addition to the potential impact of climate warming. The appearance and development of these problems are more or less related to and/or regulated by climate change. Therefore the effect of climate change on terrestrial ecosystems will certainly have an impact on the development of China's society and economy.

4.56 First, the decrease in forest vegetation will cause problems for forest production. The number of forests that produce high quality wood will decrease. With the great decline in cold-temperate coniferous forests, for example, the China fir tree, which constitutes one-fifth of the nation's commercial wood production, will be affected by high temperature and die. The mason pine, which makes up 50 percent of southern forests and 30 percent of national forests, will move south due to arid conditions, and its production will decline. The habitat of the Yunnan pine, the main forest tree in southern China, will change to tropical or temperate pasture. On the other hand, arid conditions in the north will increase the frequency and area of fire. The decrease in wood production area will have a direct impact on the construction and paper-making industry.

4.57 The increasingly arid conditions of soils in the north caused by climate change will speed up the desertification of lands and the recession of pasture. This will reduce the area of grazing pasture and the pasture's carrying capacity for animals. The imbalance between demand and supply of animal protein will be more serious. The recession of pasture will also affect the local people, driving some of them out of their homes.

4.58 Fast-changing forest vegetation will affect the habitats of rare animal and plant species. Natural conservation policies and measures will have to change dramatically. Animals and plants will have to be moved to other places for protection and man-made ecosystems will be established for this need. However, these needs may be costly and of low efficacy.

4.59 Precipitation will increase due to climate changes. Imbalances between distribution of precipitation and evaporation of water will increase flooding in the south due to greater rainfall and greater frequency and intensity of heavy showers. The disappearance of forests due to climate warming will make soil erosion more serious and make it more difficult to prevent and control floods. Even more important is the effect this will have on agricultural practices and irrigation works.

4.60 Biological resources and gene pools will also be affected by rapid changes in climate, as many rare species disappear. China is a major site of medicine production and consumption, and most Chinese medicines come from wild plants and animals. Medical research and agricultural demands for better plants are dependent on these animal and plant resources.

4.61 Generally speaking, rapid climate change will greatly affect China's society and economic development, and analysts agree that the impact will be negative. Therefore, mitigating or removing the impact of climate changes should be the goal of our long term efforts.

Regulations for Mitigating the Impact of Climate Changes

4.62 Society needs to take measures to reduce the emissions of greenhouse gases, especially CO_2, which it is commonly agreed will be the critical factor in the control of climate warming. But to reduce greenhouse gas emissions will require a long-term global effort, and the effects of climate warming have already appeared in some degree. Some regulations are therefore needed to mitigate the impact of climate change. However, the natural regulation of ecosystems will also be important.

4.63 Measures are needed to mitigate the direct and indirect effects of climate change by the ability of plants to absorb CO_2 and by protecting existing forest ecosystems. The focus of current efforts in China is to reinforce the establishment of protective forest belts in the north and along the Yangtze River (Wang Xianbo, 1992) and to protect mangrove forests in the coastal regions. Research is urgently needed on the migration and restoration of plant species, communities, and ecosystems to provide theoretical and technical support for the protection of biodiversity and natural ecosystems. It is necessary to continue nationwide forestation activities, especially the forestation and conservation of natural forests in arid and semi-arid regions, as well as reinforcing the construction of nature preserves and increasing the area of forests and nature preserves. Meanwhile, the "Forest Protection Law" and "Environmental Protection Law" should be further implemented to help the natural ecosystems of China adapt to global climate change.

5. CONCLUSIONS

A. The Uncertainties of Climate Change Impact

5.1 There are many uncertainties not only in predicting climate change, but also regarding the impact of those climate changes, both in scientific and socioeconomic terms. These kinds of uncertainty reduce levels of confidence in predicting climate change and its impact.

5.2 Scientific uncertainties are a result of incomplete knowledge of the climate system, including emissions and distribution of greenhouse gases, as well as predictions for global and regional climate change. Socioeconomic uncertainties are due to the fact that it is difficult to accurately project trends such as population growth, energy production and demand, gross national product (GNP), innovations in scientific technologies, and so on. Socioeconomic factors depend not only on social scientists, but also on the politicians' consciousness of global climate change and their resultant policies. Obviously these policies are closely related to economic development and political stability, both nationally and internationally. It is therefore clear that studies of global climate change and its future impact require not only close cooperation between natural and social scientists, but also the support and joint efforts of politicians in order to obtain satisfying results. Solutions to the problems of global warming will require the combined efforts of all the countries in the world.

5.3 Although there are uncertainties regarding future climate change and its impact, this report discusses this topic on the basis of current research findings and experiences. Despite the shortcomings of existing data, we still hope to indicate general climate change trends and their impact on various sectors under given conditions, so that the whole society, especially politicians who make policy, will take them seriously.

5.4 This report considers conditions of global temperature increase as well as changes in precipitation and soil moisture. However, the impact of increased solar ultraviolet radiation induced by stratospheric ozone depletion and subsequent increased concentrations of tropospheric ozone have not been included.

B. Response Strategies in China to the Impact of Climate Change on Agriculture, Animal Husbandry, and Fishery

5.5 Great changes will occur in agricultural production due to modern scientific and technological developments. Even in the distant future, however, the agricultural harvest in China will still rely basically on weather and climate, and future climate warming will have a major impact on China's agriculture.

5.6 By the middle of the 21st century, temperature zones in China are expected to move 2-4 degrees of latitude to the north. If this happens, it will be favorable to agriculture: first because of an increase in the multi-planting index, which is equivalent to an increase in planting area; and second, because there will be less cold damage to crops in the spring in the southeast and in the early summer in the northeast. Under a given temperature, an increase in CO_2 concentration can strengthen photosynthesis, and yields will increase. However, the actual process is not so simple. Although precipitation will increase in some areas while the climate is warming, greater evaporation will decrease soil moisture by about 11.5 percent, which will aggravate drought conditions and increase the threat to crops. Desertification will consequently be more serious in the northwest, and develop further in north, central, and northeast China. The northward shift of temperature zones will lead to a readjustment of the whole ecosystem, threatening the agro-ecological system and agricultural production stability, affecting crop adaptability, and reducing output. When factors such as increased flooding and more damage from diseases and insect pests are included, agricultural production in China is expected to drop over time given a warmer climate in the future. It has been estimated that the drop in production will be in the range of 5 percent or more under doubled CO_2 concentrations.

5.7 The major impact of climate change on animal husbandry will be on the output of grasses, the most important component of feedstuff. The husbandry business on vast grasslands and portions of farmland relies primarily on grass output, so it is of utmost importance to animal husbandry whether grass output increases or declines under the scenario of global warming. Because most grasses in China are C3 plants, when the direct and indirect positive effects of CO_2 concentration on grass output and soil fertility are taken into account, grass production is expected to increase by 8-20 percent under conditions equivalent to a doubling of CO_2. The productivity of grass, however, is closely dependent on temperature. In the northern regions, where China's major areas of pasture are found, drought is the main problem and will become more severe with climate warming. The combined effect of temperature and precipitation will lead to a decrease of grass output by about 10 percent. When pests, diseases, and natural disasters, are taken into account, China's grass output may fall by 10 percent or more under global warming scenarios in the future.

5.8 Fisheries in China, which includes both inland and sea fisheries, is affected by the production of feeding-organisms, which in turn is affected by CO_2 concentration, river temperature, and precipitation. Considering the effect of temperature, precipitation and severe weather, overall fishery production is expected to decrease 5 percent or more by the year 2030 under conditions of climate warming. This estimate includes fish production in the inland fishery districts of south China, southwest China, the middle-lower reaches of the Yangtze River, northeast China, north China, Inner Mongolia-Xinjiang, Qinghai-Tibet, and the sea fishery districts of the Bohai Sea, Yellow Sea, East Sea, and South Sea.

5.9 In order to control and mitigate the potential impact of climate change on agriculture, animal husbandry, and fisheries in China, adaptive strategies and measures should be taken. These include eco-environmental construction, adaptive planning, conservation of species, selection and cultivation of adaptive species, and scientific and technical research. According to rough estimates, the cost of implementing such measures will be Y 2.3 billion per year, or a total of some Y 16.0 billion just in the seven years from 1994 to 2000. Here we do not consider economic capabilities or the uncertainties of estimating investment expenses. However, China must put great investment into reducing the negative effects of global warming to the lowest possible level, or risk even greater losses in the future. This is something that both the Chinese government and people should take seriously.

C. Impact of Sea-level Rise and Mitigation Strategies

5.10 In the coastal areas of China, because of the effects of local relative sea-level rise, the rate and range of sea-level rise is expected to be greater than the IPCC's estimate of global sea-level rise. In addition to the subsidence of both geological structures and groundwater pumping, it is estimated that by the year 2050, the relative sea-level will rise 70-100 cm, 50-70 cm and 40-60 cm in the coastal areas of Tianjin, Shanghai, and the Pearl River delta, respectively.

5.11 China's coastal areas have many wide, flat, and low-lying lands with elevation below 5 m, gently sloping ground, and loose substance. Rising sea-levels will cause this vast plains region to be inundated. When sea-level rises by 1 m, if the coastal area is not protected, it is estimated that regions below the 4 m contour line on China's coastal plains would be entirely inundated by the astronomical tide and storm surges. The inundated area will amount to around 92,000 km^2.

5.12 The intensity and frequency of storm surges will increase as sea-level rises, causing heavy losses to life, property, and economic development in the coastal areas. Typical losses caused by storm surges in the coastal areas in recent years are presented in Table 5.1.

5.13 Due to sea-level rise, saltwater will intrude further inland. On the Yangtze River delta, if sea-level rises 0.5-1 m, the saline contour line of 0.2 percent will move forward as much as 15-30 km. This will create water supply difficulties in cities like Shanghai that rely on river water for use. Already, during the dry season (December to March each year), urban tap water has been polluted, endangering residents as well as industrial production. Rising sea-levels will also increase flooding, decrease port functioning, and cause severe erosion and inundation of wetlands along the coasts.

5.14 One of the most important strategies for adapting to the sea-level rise induced by global warming is to build more dikes and dams. Many successful examples prove that building dikes and dams is a powerful counter to storm surges, and is feasible in economic terms. China has some 12,883 km of dikes at present. If it costs Y 1 million to raise one kilometer of a dike 2 m, the building expenses will be Y 12.9 billion. This is equivalent to 1.5 percent of the 1990 gross national product created by the nine provinces and two municipalities that make up coastal China. This project could be implemented in stages over several years to make it more economically feasible. Local

Table 5.1: TYPICAL EXAMPLE OF LOSSES FROM STORM SURGE

Year	Number of storm usage	Disaster situation	Damage area	Economic losses (Y billion)
1989	8,923	1,103.5 km of dams destroyed; 15.91 million people hit	121 counties and towns in Guangdong, Zhejiang and Hainan	5.48
1990	9,012 9,018		Fujian and the southern part of Zhejiang	4.11
1992	9,216	1,170.7 km of dams destroyed; 29.7178 million mu of farm lands inundated; 0.7617 million mu of ponds washed away	Fujian, Zhejiang, Jiangsu, Shandong, Hebei, Liaoning, Shanghai, Tianjin	9.4

governments should also be able to afford preventive measures to protect them from coastal erosion, sea water intrusion, and environmental deterioration, improve urban water drainage and supply systems, and other protective measures that yield excellent benefits. Strictly controlling the withdrawal and use of groundwater is one of the most important methods of mitigating the impact of sea-level rise on coastal areas of China. In a word, sea-level rise is one of the most important problems facing policy-makers, and protective measures need to be taken as early as possible.

D. IMPACT ON THE TERRESTRIAL ECOLOGICAL ENVIRONMENT AND MITIGATING MEASURES

5.15 The impact of climate change on the terrestrial ecological environment includes the direct and indirect impact on wetlands, vegetation, desertification, biodiversity, society, and the economy.

5.16 As China's northeast region becomes warmer, and the southwest region becomes colder, the Sanjiang plain marshes will decrease in area and the productivity of the Nuoergai marshes will decline. These are two of the world's largest wetland areas. Due to climate change, the lake beach area in the middle-lower reaches of the Yangtze River and plain areas will increase. Warming will lead to rising sea-level and increasing storm surge frequency, which will flood most of the existing sea shallows, reduce their area, change their ecological environment, threaten their wildlife, and reduce their biodiversity.

5.17 The impact of global warming will cause precipitation to decrease in the northern arid parts of China. This will cause more dryness and speed up desertification, which will make it more difficult to control sands and establish protective forest belts. The desertification of lands and recession of pasture will reduce the grazing lands and the ability of pasture to hold herds. Imbalances between the demand and supply of animal protein will be more serious. Receding pastures will also affect the livelihoods of local people, and even drive some of them from their homes.

5.18 As temperature increases, vegetation will shift from south to north by about 500 km by the year 2050. One can therefore predict that the area of rainforests and monsoon rainforests will increase, and the highland plantation area in the southwest will decrease. Plant characteristics will change from temperate desert into temperate pasture or subtropic desert in Xinjiang, China's northwest.

5.19 Changes in forest vegetation will create difficulties for forest production. On the one hand, high quality wood production will decrease. On the other hand, arid conditions in the north will increase the frequency and area of forest fires. The lack of wood resources may lead to a vicious cycle with further cutting of forests. The rapid changes in forests will affect the habitats of rare animal and plant species, and many rare species may be lost. Fast climate change and the unacceptability of vegetation will probably make it difficult for many nature preserves to provide needed environmental conditions and protect biodiversity. As a result, policies and measures for natural conservation will need to be modified greatly in China. Animals and plants will have to be moved to other places for protection, and man-made ecosystems will need to be established.

5.20 Floods in southern China will also increase, due to greater rainfall as well as the increasing frequency and intensity of heavy showers. If the speed of forest migration can not match that of the disappearance of forests due to climate warming, soil erosion will be more serious and it will become more difficult to prevent and control floods. There will also be important effects on agricultural practices and irrigation works.

5.21 Generally speaking, the impact of future climate changes on the terrestrial ecosystem will largely be negative. Therefore, mitigating or removing these negative impacts should be the focus of our long-term efforts. Unchecked reclamation and cultivation should be stopped. In those regions that are being seriously damaged, or where serious damage is predicted, ecological engineering and reasonable planning should be considered. The shallows and coasts should be protected and the best way to protect wetlands should be studied. Population growth should be controlled in China's arid and semi-arid regions. The energy structure of rural regions should also be changed to reduce plant destruction. On semi-arid lands with a mixture of agricultural and husbandry, natural enclosures should be adopted to change the dominance of agriculture, augment the pasture area, and plant forest belts.

5.22 Prevention of land desertification must combine exploitation and conservation by taking into account both the ecological effects and economic benefits. The ability of green plants to absorb CO_2 should be used to protect the comprehensive functioning of terrestrial ecosystems. Greater efforts are necessary to reinforce the establishment of protective forest belts in the north and Yangtze River regions and to protect mangrove forests in the coastal areas. China must continue nationwide afforestation activities, especially in arid and semi-arid regions. It is also necessary to reinforce the construction of nature preserves, increase the area of forests and nature preserves, and protect biodiversity, to mitigate the direct and indirect impacts of climate change.

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