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Human-environment interactions in agricultural land use in a South China's wetland region: A study on the Zhujiang Delta in the Holocene

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Abstract

The formation and evolution of agricultural land uses in the Zhujiang Delta of South China are examined in the light of the dynamics of people and the environment and their interplay. The origin and propagation of agriculture are found to have a close relationship with the climate and sea level changes in the Holocene era. The development of rice cultivation, horticulture, and dike-pond system exemplifies human-environment interactions in a specified geographical and social context, which are manifested by the impact of environmental changes and population growth on agricultural innovations. The technologies of dike building and land reclamation, which represent local farmers effort to build a new and harmonious relationship with the changed environment, were critical to the agricultural success and sustainability. Imprudent use of a new agricultural technology could damage the environment, as evidenced by a frequent flooding that followed inappropriate dike building and premature reclamation. Diverse agricultural land uses are as a result of the adaptation of agricultural technology innovations to the environmental conditions.

Introduction

China, with 7,000 years of agricultural development, is always a proper country for a research on the subject of agricultural land use. For this study, the Zhujiang (literally 'the Pearl River') Delta of southern China is selected because of its ever-changing wetland environment resulted from frequent flooding and continual seaward extension, and its 4,000 years of extensive agricultural activities.

The delta is located between latitudes 21°40′ N and 23° N, and longitudes 112° E and 113°20′ E (Figure 1). It is the third biggest river delta in the nation (next to the Yangtze and Yellow River Deltas), with an area of 17,200 km^2. Geomorphologically, the delta consists of three sub-deltas formed by sediments, the Xijiang (the West River), Beijiang (the North River), and Dongjiang (the East River) Deltas, originated approximately 40 thousand years age (DGZU, 1988). The process of sedimentation still continues today, extending seaward at a rate of 40 m per year (Gong and Chen, 1964). The delta has a subtropical climate with an average annual temperature between 21 °C and 23 °C, and an average precipitation from 1,600 to 2,600 mm. Because of the impact of the East Asian Moonsoonal circulation, about 80% of the rainfall comes in the period of April to September with a concentration in the months of May to July, when flooding is prone to occur (Ditu Chubanshe, 1977). Another hazard is typhoons, which occur most frequently from June to October. The fertile alluvial deposits, the subtropical climate, and millenniums of exploitation have nurtured the delta into one of the most diversified agricultural areas in China. Its paddy cultivation, sugarcane and fruit horticulture, and dike-pond agriculture-aquaculture have long been known to the nation and to the world.

The objective of this paper is to examine the formation and evolution of agricultural land uses in the delta region in the light of the dynamics of human-environment interactions. An interdisciplinary investigation of the environmental changes and evolution of agricultural technological innovations will be conducted using government gazetteers (*di fang zhi*), archaeological discovery, and findings in agricultural history, geology, and geography. This approach is applied to demonstrate that the development of rice cultivation, horticulture, dike-pond agriculture-aquaculture systems, and dike building and land reclamation technologies in the delta are the results of local farmers' adaptations and/or reactions to the environmental changes in the Holocene era. The Zhujiang Delta is the place where I conducted my first master thesis research. Some materials used in this paper were collected when I worked as a research associate in Guangdong Province. The field survey I (with Dr C. P. Lo) conducted in the summer of 1998, which were sponsored by the National Geographic Society, witnessed a 100-year flood and water logging up to one foot in the city streets of Zhongshan during a storm.

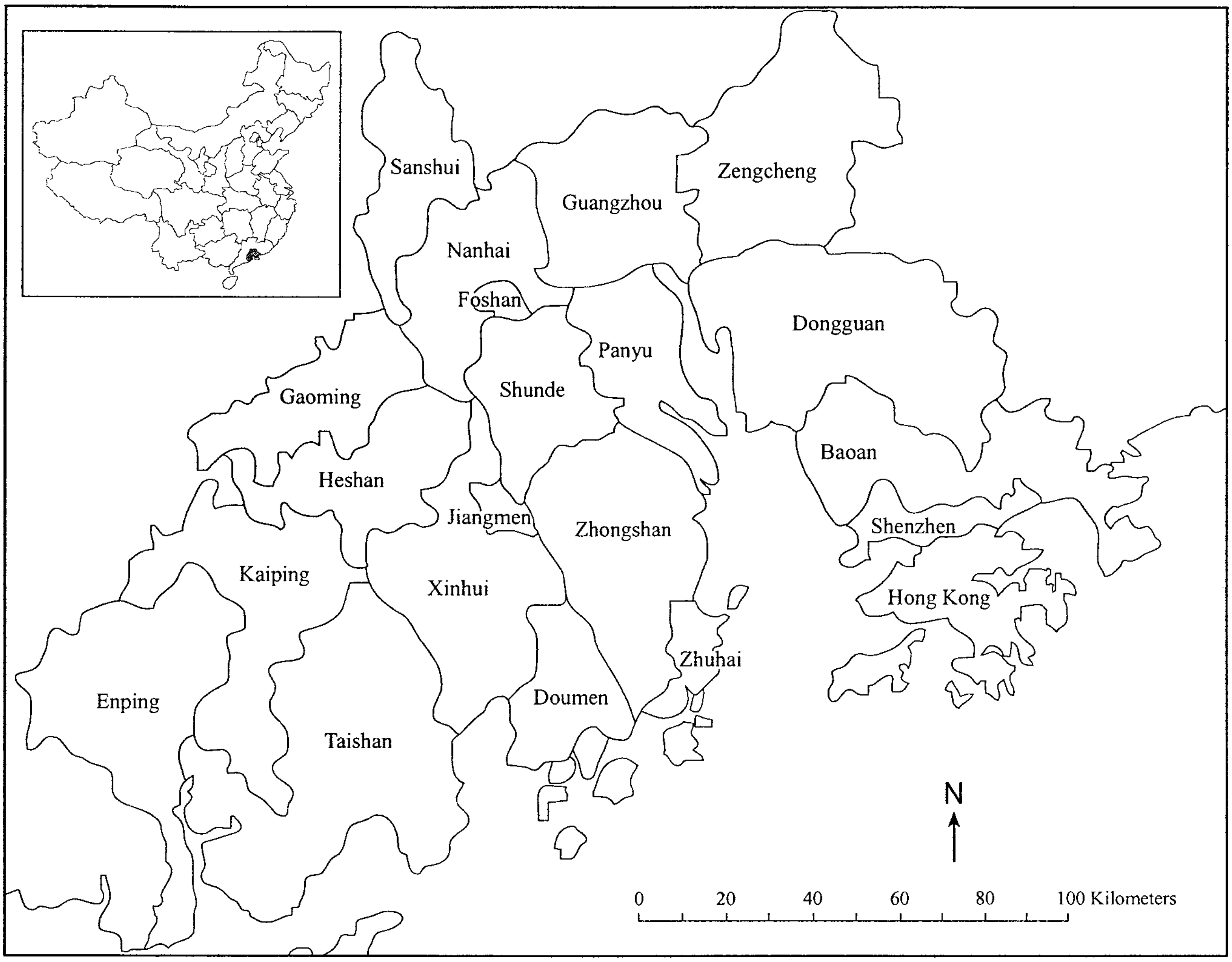

Figure 1. Study area – Zhujiang Delta of southern China.

Environmental changes in the Holocene Period

It has been demonstrated that the rise and propagation of cultures in the Zhujiang Delta had a close relation with its environmental changes in the Holocene period (Weng, 1994). Agricultural land use links agricultural activities with physical environment, and reflects the human-environment relationship in the context of agriculture. To understand how the people in the delta have interacted with the environment to mold agricultural land uses, its environmental changes, especially in the Holocene period, must be first examined.

As early as 100,000 years ago, the earliest human being in southern China ('Maba man') appeared in the mountain areas of northern Guangdong (Xu, 1982). People lived in Karst caves near rivers and wide valleys. A cave could usually support 10 to 100 people. Hunting and gathering were their major economic activities. These observations are supported by archeological findings in the region (Yang, 1986). This way of life discontinued as the Quaternary Ice Age ended, and the global temperature and sea level began to rise. The increased temperature caused forest cover to enlarge, and consequently the density of animals decreased. Hunting became more difficult. As a result, some ancient people started to move to the south. About 6,000 years B.P. in the Middle Neolithic Age (6,500–5,200 years B.P.), these people arrived in the Zhujiang Delta region (Weng, 1992). At that time, the delta region was full of water. The ancient people had to live with aquatic environments such as deltas, riverbanks, and estuaries, and were mainly supported by hunting and gathering. The archaeological discovery of this period, in which a large amount of shellfish and fish remains in combination with fewer amphibians, terrestrial animals, and birds are found in shell mound deposits, proves these judgments.

At an early stage of the Late Neolithic Age (5,200–4,200 years B.P.), there was a substantial decline in the sea level (Li et al., 1991), resulting in more high grounds for human activities. This is the time when some people moved southward to the estuaries and islands near today's Zhongshan, Zhuhai and Shenzhen, continuing on hunting and gathering. Others shifted their attention to the terraces and hills. Hunting, fruit gathering, and planting became their mainstream economic activities. Archaeological discovery of abrupt increase of sandy mounts deposited in this period confirms these observations. The predominant tools were adzes and spears (for digging), while few found for leveling, implying the primeval nature of planting.

At the end of the Late Neolithic Age (4,200–3,500 years B.P.), the climate became warmer and wetter, and the sea level rose slightly (Li et al., 1991). These changes in the environmental conditions pushed people to utilize aquatic ecosystems at a greater scale. It is estimated that this period lasted for 700 years, causing some fundamental alterations in the patterns of economic and cultural activities (Weng, 1994). These observations are verified by the fact that there were few terrace and hill mounts deposited in this period. It is possible that the planting activity was discontinued.

During the Bronze Age (3,500–2,500 years B.P.), climate fluctuated but tended to become warmer and wetter. The sea level first rose by 2.5 m, and then fell by 3.5 m (Li et al., 1991). Economic activities were largely associated with the ecosystems in the terraces and hills. The production tools for leveling greatly increased in this period, implying the outset of rice cultivation. However, since the delta was still such a swampy floodplain, and people had not yet developed the technology for water conservancy, rice cultivation technology must be in a rather primitive stage.

Origins and propagation of horticulture and rice cultivation

Archaeological evidence suggests that horticulture and cereal agriculture did not originate contemporaneously, neither were they a successive process (Weng, 1994). The horticulture appeared in the Late Neolithic Age (4,200–3,500 years B.P.), while cereal agriculture (i.e., rice cultivation) started during the Bronze Age (3,500–2,500 years B.P.). The origins and propagation of either agriculture are strongly associated with climatic and sea level changes in the region.

In the period before the Late Neolithic Age, human activities concentrated in the hills, terraces, and river basins. Horticulture was carried out on high lands, supplemented by hunting, fruit gathering, and fishing. Chinese yams, bananas, cane, taro, and ginger were the main products. At 4,000 years B.P., plant domestication became a major economic activity. Archaeological findings support the above observations, in which few polished stones were identified as production tools while chipped stones predominated, and the pottery, a compelling household item in cereal agriculture, was not fully developed. The spatial pattern of shell mounds deposited in the Middle Neolithic Age shows that if a line is drawn to link the cities of Jiujiang, Foshan, and Guangzhou, then all the shell mounds to the north and to the west of this line are dated before the Spring and Autumn Dynasty, while those to the south and to the east between the Qin (221–207 B.C.) and Tang (A.D. 618–907) Dynasties. This indicates that the propagation direction of horticulture was from northwest to southeast. However, in another half of the Delta (i.e., Dongjiang Delta), earlier shell mounds were largely deposited to the northeast of Shilong, indicating a westward propagation of horticulture. In contrast with these inland deposits, sandy mounts are largely founded in the estuaries of the Zhujiang (the Pearl River), the coast, and the islands, where Zhuhai, Zhongshan, Doumen, Shenzhen, Hong Kong, and Macao are located. The age of these ruins is determined to be the Late Neolithic Age, later than that of shell mound ruins. Clearly, the overall propagation direction of horticulture was from north to south (Figure 2).

Rice cultivation was not carried out in the Zhujiang Delta until the Bronze Age, when neighboring people from North Guangdong introduced the technology. Wild rice (*O. sative L. F. Sponanea*) was widely spread in North Guangdong and its proximity (Weng, 1998). The rice in China today (*O. sativa L. subsp. hsien Ting*) is domesticated from this wild species (Ding, 1961). Archaeological discovery indicates that by the Late Neolithic Age (4,500 years B.P.) *O. sativa L. subsp. hsien Ting* had become an important crop in North Guangdong (Yang, 1986). This finding is in agreement with those by researchers of Chinese agricultural history, who believe rice cultivation originated in the southern China including North Guangdong (Ding, 1957; Tong, 1984; Li, 1985). Through the southward migration of Han Chinese, this new agricultural technology was brought to the Zhujiang Delta 2,000 years later. However, in the period before the Qin Dynasty (221–207 B.C.), rice cultivation was limited to the hill and terrace areas in Guangzhou and nearby areas. The well-known story of the Ram City (Guangzhou's alias) suggests that rice growing technology was brought by 'Nanhai Celestial Being' whose totem was rams. Apparently, these 'Nanhai Celestial Being' were from North Guangdong, not from the South China Sea (Weng, 1992).

During the Qin (221–207 B.C.) and Han (207 B.C.–220 A.D.) Dynasties, there was a substantial fall in sea level (by as much as 4–5 m), and the areal extent of the delta became larger. As southward migrating people increasingly arrived, deforestation in the upper and middle reaches of Xijiang, Beijiang, and Dongjiang occurred. Increased soil erosion accelerated sedimentation in the rivers and the extension of the coastline (Figure 3). The combined effect of sea level change and deforestation contributed to more plain areas suitable for agricultural development. The establishment of Nanyue Kingdom centered in Guangzhou motivated people from central China (*zhong yuan*), the then economic center of the nation, to bring most advanced agricultural technologies into the region. Rice cultivation spread out south and southeast and reached the counties of Nanhai, Shunde, and Jiangmen. The archaeological discovery of iron ploughs in a village called Lanshisheng in Foshan proves the existence of large-scale agricultural activity. From the Sui (581–618 A.D.) to Tang Dynasties (618–907 A.D.), this technology was further propagated to Zhongshan and Xinhui.

In the Dongjiang Delta, rice cultivation was not developed well until the end of the Tang Dynasty due to fewer settlements and less amount of available land for agricultural development. However, accelerated sedimentation of the rivers and intensified east-west population movement along the Dongjiang (East River) valley eventually created a belt of rice cultivation along the alluvial plains of the river that spread from Shilong through Zhongtang to Guancheng, the county seat of Dongguan.

By the late Tang Dynasty, the northern China was frequently at war. The southward migrating population dramatically increased, so the demand for land and food got higher.

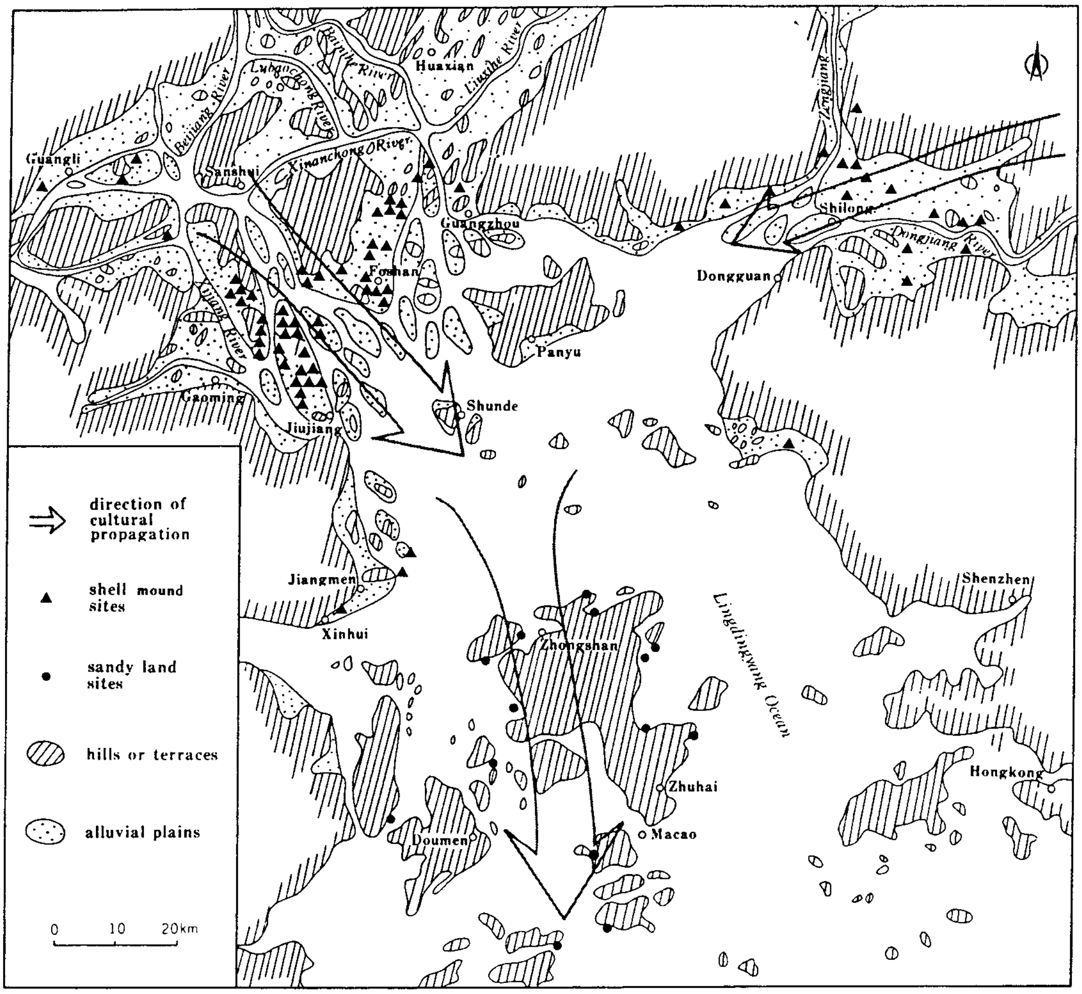

Figure 2. Propagation of horticulture in the Zhujiang Delta.

Wet rice cultivation of double cropping was developed, although in some silly slopes slash-and-burn agriculture was still practiced for the farming of dry fields. From the Song (960–1279 A.D.) to Yuan (1279–1368 A.D.) Dynasties and floods became more frequent. A large number of swamps were filled by sand and loam. The rate of sedimentation at the estuaries of some rivers and their tributaries reached 12.7 meter per year. Consequently, many islands, including Sanjing, Muzhou, Wuguishan, Dahuanpu, Tanzhou, and Huangge Islands, were joined with the mainland, conducive to an accelerated extension of the delta. The coastline extended to the line that links Miaotou, Tanzhou, Xiaolan, and Lile in the Xijiang and Beijiang Deltas, and to Daojiao and Houjie in the Dongjiang Delta (Figure 3). To a certain degree, this extension of coastline reflects the intensity of rice cultivation. Because of at the Song government's interest, quick-ripening rice varieties from Champa, the ancient Indochinese Kingdom (2nd to 17th century) that occupies today's Central and South Vietnam, were introduced, making possible double or even triple cropping in the delta (Bray, 1984). New farming techniques, including better cropping practices, new tools, machines, fertilizers, and irrigation methods, were advocated and spread out by a number of 'master farmers' (Lo 1996), as evidenced by the existence of a large number of specialized agricultural books (*nong shu*). It is suggested that there was a 'Green Revolution' in southern China during the period (Bray, 1984).

During the Ming Dynasty (1368–1644 A.D.), the delta region experienced a greater population increase as a consequence of the southward shift of national economic center. The environmental changes mainly involve that most of the tributaries of the Xijiang (West River) and the Beijiang (North River) became silted, and a large amount of sand was accumulated in the southern Panyu, northern Zhongshan, and eastern Xinhui, extending the coastline to near today's Modao Gate (Figure 3). The Dongjiang Delta had basically formed. During the Qing Dynasty (1644–1911 A.D.), the speed of sand accumulation was even faster, so the tributaries were completely silted up and the Shiziyang Ocean became narrower. By the end of the Qing Dynasty, the eight gates of the Zhujiang formed.

Rice cultivation spread all over the north and central parts of the delta during the Qing Dynasty. Cultivated land accounted for 40% of the delta area, and 77% for Shunde County alone (Situ, 1986). Diking and reclamation proceeded at a much faster rate (Lo, 1996), and waterwheels were widely utilized in irrigation. Because of these developments in water conservancy, tools, and farming methods,

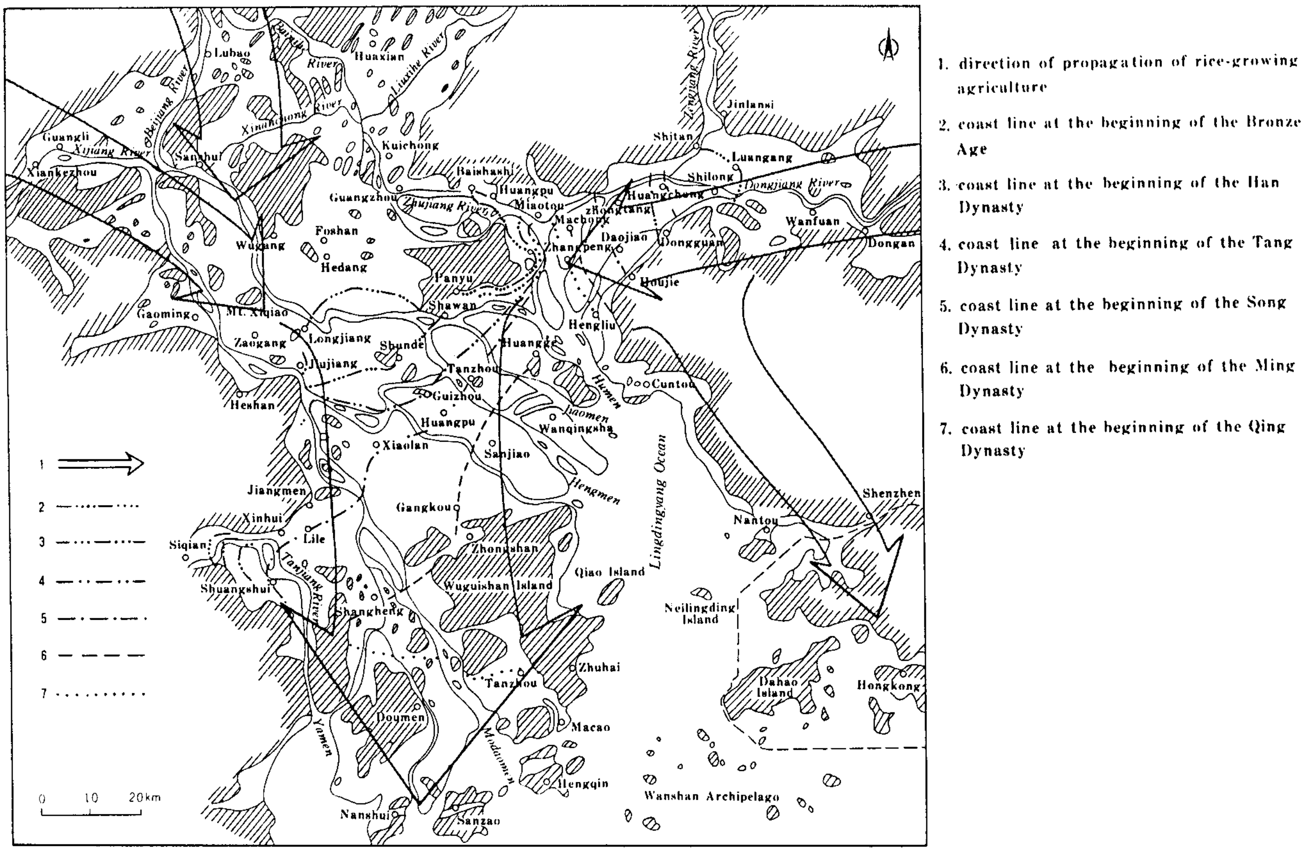

Figure 3. Propagation of rice cultivation in the Zhujiang Delta.

per unit area grain yield significantly increased. The average output reached 280 kg per mu (0.0667 ha), and in some areas 400 kg (Weng, 1993). In fact, the whole of Guangdong Province, of which the delta is a part, became a major rice market in the nation. Guangdong rice (*Guang mi*) was once at high demand. Double cropping of rice was now a common practice. After the middle Ming Dynasty, a dry food crop in winter (e.g., winter wheat, sweet potato, vegetables, fruits, and cash crops) was added, leading to triple cropping a predominant pattern. Moreover, the improvement in grain productivity allowed diverting more lands to high-profit commercial crops. The diversification and commercialization of agriculture started, which contributed to an eventual specialization and regional division of labor (Weng, 1993).

Dike building, land reclamation, and agricultural development

Agricultural development in the Zhujiang Delta was strongly associated with dike building technology. The dikes were initially built to prevent low-lying lands from being flooded. Excess water could also be drained from the enclosed fields by using waterwheels or other methods, thus improving water conservancy and agricultural productivity. The first dike appeared during the Tang Dynasty (Zeng and Huang, 1987), responding to a sharp increase of flood frequency. A statistics of floods in different dynasties is shown in Table 1.

In the period before the Tang Dynasty, the population was spare in the delta, so people were able to select higher ground for agricultural development. However, the population density increased rapidly by the end of the Tang Dynasty resulted from intensified southward population migration. Rapid population expansion made it impossible for higher grounds alone to produce enough food. Low-lying delta had to be brought under cultivation. Dike building thus became necessary. As more dikes were built, enclosed fields grew. River channels became longer and shallower. With the reduction in channel gradients, the rivers became easily silted up. Draining off floodwater needed a longer time. The human activities have apparently altered its relationship with the environment.

The Song and the Yuan Dynasties marks an era when the people in the delta launched large-scale dike building projects. A total of 28 dikes were built in the Song Dynasty, with a total length of 220 km, safeguarding fields of 162,145 ha (ZAHC, 1976). During the Yuan Dynasty, 34 dikes were built, which extended 168 km in length and safeguarded a total area of 15,547 ha (ZAHC, 1976). These dikes were distributed along the banks of the lower Xijiang, Beijiang, and Dongjiang and their branches (Figures 4 and 5). Because the river channels were relatively wide and the flood levels not so high, the dikes built during this period were low (usually 1–1.7 m) and made of dirt rather than stones. Few of them had been linked together.

From the Ming to the mid-Qing Dynasty, the activities of dike building and land reclamation intensified as the popu-

Table 1. A statistics of floods in the Zhujiang Delta.

County	Song Dynasty (960–1279)	Yuan Dynasty (1279–1368)	Ming Dynasty (1368–1644)	Qing Dynasty (1644–1911)	Republic of China (1911–1949)	P.R. China (1949-)	Data Period
Baoan				2	1	4	1660–1981
Dongguan	1	3	18	20	16	12	812–1987
Guangzhou			5	9	3	7	975–1983
Heshan			11	31	5	5	1422–1983
Nanhai			26	56	16	12	810–1985
Panyu			3	12	5	6	996–1985
Sanshui			12	18	2		1535–1915
Shunde			16	11	36	11	1448–1983
Xinhui			2	7	9	8	1516–1985
Zhongshan		1	9	5	8	6	1199–1987

Source: Yuan, 1992

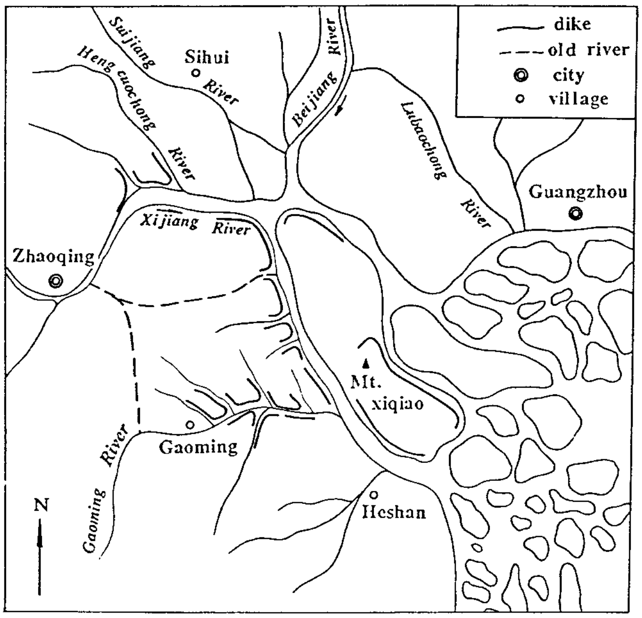

Figure 4. The distribution of dikes built in the Song and Yuan Dynasties in the Xijiang and Beijiang Deltas.

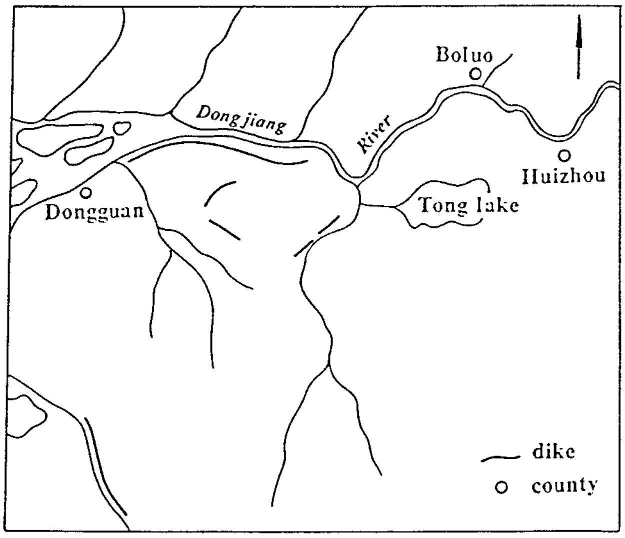

Figure 5. The distribution of dikes built in the Song and Yuan Dynasties in the Dongjiang Delta.

lation grew. Increased use of marshes along riverbanks and islets in the estuaries caused the river channels to prolong and narrow. River channels were silted easily, so that the size of floods became larger and the duration longer. Consequently, there was a notable increase in flooding frequency in the Ming Dynasty. Gaoyao County in the lower reaches of the Xijiang was an extreme case. There were 41 floods during 276 years of the Ming Dynasty, averaging 1 flood per 6.73 year (Weng, 1994). For the whole delta, 44 floods were recorded to have inundated at least 3 counties, averaging 1 flood every 6.27 year (ZWCC, 1990). During the Qing Dynasty, flooding was even more frequent. From 1736 to 1839 A.D., there were 30 floods in 103 years in the delta region, averaging 1 flood per 3.43 year (ZWCC, 1990). The impacts of these floods were not constrained to the main streams in central delta but also reached the tributaries in the estuaries. To protect the land from flooding and to ensure high agricultural productivity, 181 dikes were built during the Ming Dynasty with a total length of 735 km, twice as long as the length of dikes built in both the Song and Yuan Dynasties. In the Qing Dynasty, 190 dikes were built with a total length of 774 km. The Ming's dikes were found mainly in the following three locations (Figure 6): (1) along the main stream of the Xijiang below Sanrong and its tributaries including Xinxing, Hungdongsui, and Gaoming Rivers; (2) along the main stream of Beijiang below the Feilai Gorge and its tributaries including Suijiang, Lubaochong and Xinanchong Rivers; and (3) in the intersectional area of Xisui and Beisui Rivers and in the central and western parts of the delta below Sixianjiao. There were few dikes built in the Dongjiang Delta in the Ming Dynasty.

During the Qing Dynasty, diking activities continued to spread southward in the Xijiang and Beijiang Deltas, approaching the estuaries area. A few dikes appeared in the lower reaches of the Dongjiang above Shilong.

The period from the late Qing Dynasty to 1948 witnessed the most frequent and the most serious flooding in the history. Not only population explosion and economic growth demanded more farmlands, but also the landlords' greed for more profit had contributed to premature land reclamation and diking. Because of the lack of governmental rules,

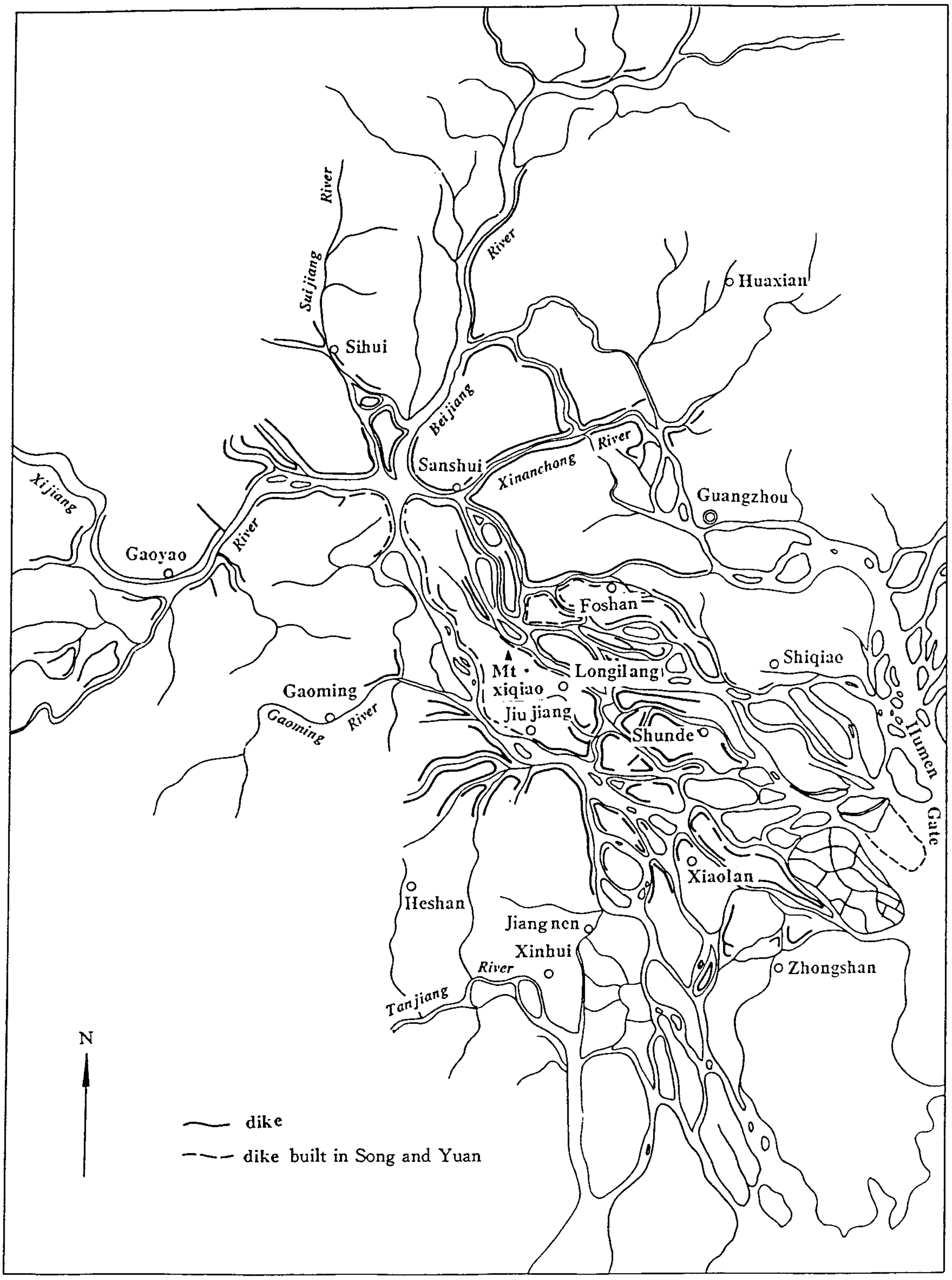

Figure 6. The distribution of dikes built between the Ming and mid-Qing Dynasties in the Xijiang and Beijiang Deltas.

blindness in farmland development and utilization increased, leading to a vicious circle in the relationship between dike building and flooding. As more dikes were built, more floods occurred. Therefore, many old dikes need to be reinforced to become higher and more solid, and need to be linked together. The dikes built during this period were concentrated in the waterway area, including the counties of Shunde, Xinhui, Zhongshan, Dongguan and their coastal areas (Figure 7). Dikes appeared even in the coastal area of Panyu County and near Modaomen and Hengmen Gates. Indeed, by the end of this period, dikes could be found everywhere in the delta except for a few places such as the Tanjiang Delta, southern Panyu, and western Dongjiang Delta, where fields were irrigated with tidewater.

In summary, the agricultural technology, particularly rice cultivation, could not succeed without dike building technol-

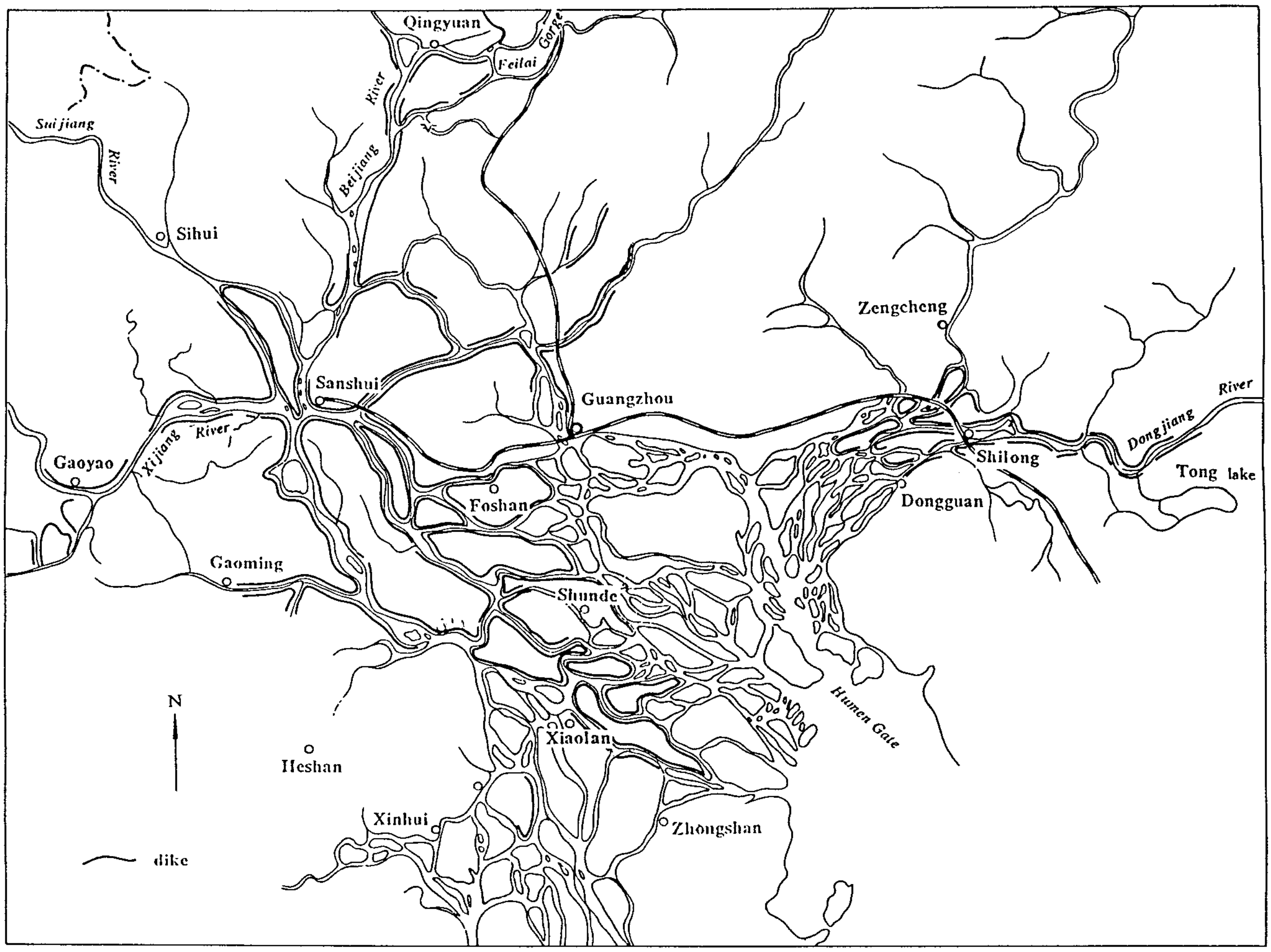

Figure 7. The distribution of dikes in the Zhujiang Delta, 1948.

ogy. Dike building began as local farmers' acceptance of the challenge of a wetland environment full of water disasters. However, this activity facilitates the evolution of an aqueous environment to paddy fields, and thus lays the foundation for propagation of rice cultivation technology. Furthermore, the dike building changes the water, heat, and soil conditions, making it possible to improve gradually farming methods. The cropping pattern was one crop per year before dike building. The method of slash-and-burn was practiced in high grounds while the method of fire and water farming (*huo geng shui ru*) in wetland environments (Yu, 1988). Rice cultivation requires eliminating the grass with fire before sowing seeds, and killing the weeds by flooding the fields. This low productivity but labor saving method was popular in the southern China because it suited to the wetland environments (Peng, 1987). The one-cropping pattern continued in some parts of Guangzhou, Panyu, Shunde, Xinhui, and Zhongshan until the beginning of the Qing Dynasty. This is especially true in the sand fields, where water conservancy facilities were not very well equipped. Only after dikes had been built could a double cropping system be established. Since the twentieth century, a variety of triple cropping pattern has been developed. The predominant pattern is two crops of rice and a dry food crop in the winter such as vegetable, fruit, sugar cane, or other cash crops (Lo and Pannell, 1985). It should be noted that the cropping patterns in the delta have undergone a great change since 1978 when the policy of economic reforms was initiated. The increased commercialization of agriculture results in the production of less grains but more economic and cash crops. All-season, high-profit agricultural products, including vegetables, fruit, flowers, seafood, and poultry, are advocated.

Distinctive agricultural land uses

Agricultural land uses in the Zhujiang Delta reflect clearly the dynamics of human and environmental factors and their interplay. As has been discussed above, agricultural development was closely related to dike building and land reclamation. Based on the development of these agricultural technologies and their relations with environmental evolution, five types of agricultural land uses can be identified: (1) saline fields; (2) sandy fields; (3) enclosed fields; (4) dike-pond land; and (5) hilly fields. Figure 8 shows the distribution of these five fields in the delta.

Saline fields are found near the coast, and most susceptible to flooding by seawater. They are often water logged, and have an elevation between −0.5 and 0.8 m. Since newly reclaimed, these lands are still in the process of desalin-

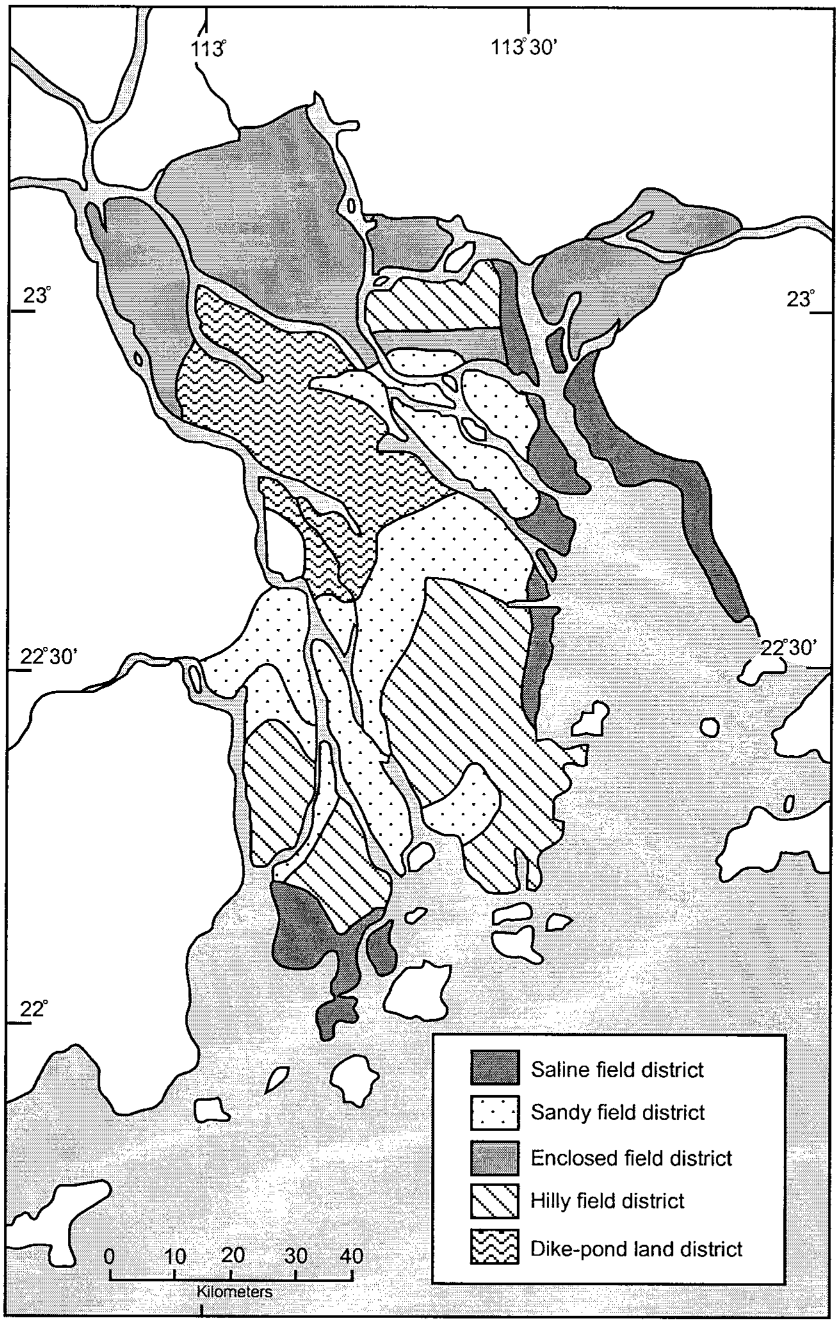

Figure 8. Agricultural land use types in the Zhujiang Delta (After Lo and Pannell, 1985).

ization. The salt content of soil may reach 0.3–1% (Miu et al., 1988), so saline fields are not suitable for rice cultivation at the beginning. However, experienced local farmers have developed the environmentally safe methods to utilize these premature lands. Soon after reclaimed, these lands are partitioned into rectangular or square fields with dikes, with drainage ditches and holes built. They are first used for horticulture and sugarcane cultivation. After several years irrigated with river water, the salt in the fields will be gradually washed away. Saline fields are then expected to evolve into muddy soil (*ni tian*) fields, and be suitable for various agricultural purposes.

Enclosed fields are those that have been long reclaimed, and normally seen at inland or interior locations. In the Xijiang and Beijiang Deltas, enclosed fields are concentrated in the region north to the line that links Huangpu, Shiqiao, Longjiang, and Jiangmen, 40–60 km away from the coastline. These fields are enclosed with dikes, with an elevation of 0.7–1.7 m. Soils have been intensively modified by agricultural activities, and are thus fertile and high yielding. The best quality soil is known as muddy flesh soil (*ni rou tian*), which has an organic horizon of 15–20 cm. With this soil, annual rice production can yield 750–1,000 kg per mu (Miu et al., 1988). However, there is only a limited distribution of this soil in the entire enclosed fields, approximately 20% in the Xijiang and Beijiang Deltas and 10% in the Dongjiang Delta. The size of each field is small and the pattern regular. A great variety of crops are grown in the enclosed fields, including rice, vegetables, fruit, peanut, sugarcane, and many other cash crops.

In between saline and enclosed fields are sandy fields, which have a fairly long time of reclamation, and are located between the coast and the inland. In the Xijiang and Beijiang Deltas, sandy fields are distributed south to the Huangpu, Shiqiao, Longjiang, and Jiangmen line. The formation of sandy fields is closely related to two factors: the extension of the delta by the deposition of sediments, and the land reclamation technology. During the Ming and Qing Dynasties, a large amount of new farmland was reclaimed from marshes and sea beaches. Two methods were used in reclamation: One was cultivation before building dikes, and the other was building dikes before cultivation. The first approach reclaimed just emerged sand bars or river islands, and irrigated fields with tidewater after eliminating salt. This approach has a disadvantage of inability to protect crops from the damage of flooding. The second approach was more popular and environmentally conservative. The whole reclamation process takes approximately 4 to 10 years, which can be subdivided into three stages (ZAHC, 1976; ZWCC, 1990): (1) the rocks deposit stage, when the water is about 0.2 to 0.3 m deep; (2) the grass growing stage, 1 to 5 years after stage one, to plant reeds to speed up trapping sediments when the beaches are exposed at low tide; and (3) the dike building (with solid dirt) stage, 3 to 5 years after stage two, when the land becomes more frequently exposed. This approach of reclamation reflects local farmer's awareness for environmental conservation in agricultural land uses.

Sandy fields are normally flat and weaved in by a dense network of waterways. The drainage density in the Xijiang and Beijiang Deltas is 0.81 km/km^2, and 0.88 km/km^2 in the Dongjiang Delta (Huang et al., 1982). Most sandy fields may be irrigated with tidewater. Local farmers customarily classify the sandy fields into three types according to height and irrigation conditions. The high sandy field is irrigated by tidewater less than 12 days per month with an elevation of 0.7 m above mean sea level. The median sandy field has 12 to 20 irrigation days per month, with an elevation between -0.2 and 0.7 m. The low sandy field, with an elevation between -0.8 and 0.2 m, has more than 20 days irrigated by tidewater. The soils in low sandy fields tend to have a high level of ground water table, and are much less suitable for agricultural purposes than high and median sandy fields.

Dike-pond lands are composed of dikes on which fruits are planted and ponds in which a variety of fish is raised. Dike-pond lands are geographically distributed in the central Delta's low-lying, flood-prone area, and concentrated in counties of Shunde, Nanhai, and Zhongshan. The development of this peculiar agricultural land use can be traced back to the early Ming Dynasty. Followed from dike building in the Tang and Song Dynasties, floods became more frequent. River sediments may only be deposited outside the dikes, causing the water level outgrew the elevation of the fields inside the dikes. Therefore, water became frequently logged, causing a disaster after a period of heavy rain. Most water logging problems occurred during June and September, threatening both early and late crops. Local farmers solved this problem by excavating ponds in low lands and placing dugout soils or mud surrounding the ponds to form the dikes. In this way, the level of ground water is lowered, and the ability to combat flooding improved. Apparently, the dike-pond land use is a good example of human agricultural activity adapting itself to the environmental changes.

Because dikes and ponds are ecologically well integrated, the dike-pond land is also known as dike-pond agriculture-aquaculture system. The fish feces that accumulate at the bottom of the pond are used as organic fertilizer for the crops growing on the dikes, while crop residues such as stalks are used to feed the fish (Lo, 1996). Through this recycling of organic wastes between the pond and dike components, the dike-pond system has maximized energy input and minimized wasted energy (Ruddle and Zhong, 1988). The ratio of dike to pond (in terms of area) is thus an important consideration because it affects the material and energy flows between the two components (Lo, 1996). The predominantly used ratio is 40% dike to 60% pond, although there are other ratios such as 30% dike to 70% pond, 70% dike to 30% pond, and 50% dike to 50% pond (Miu et al., 1988). The typical size of a dike-pond system is about 1 acre. The dike-pond systems are named differently according to the type of crop growing on the dike. The most popular systems include 'mulberry-dike fish-pond', 'sugarcane-dike fish-pond', and 'flower-dike fish-pond' (Zhong et al., 1993).

Hilly fields are found in the terraces, hills, debris slopes, and diluvial and alluvial fans all over the delta. The Zhujiang Delta is surround by hills to the east, west, and north that have an average of 500 m above mean sea level. Inside the delta itself, there are over 160 hills and terraces located at heights between 100 and 300 m (Huang et al., 1982). They occupy one fifth of the total area, and are remnants of former islands. The hills are concentrated in the south (including Zhongshan, Doumen, and Xinhui), and were formed by the intrusion of granitic rock during the Yenshanian Orogeny. The terraces are located in the north, extending from Panyu to Guangzhou. They are the results of river dissection, averaging 20 to 40 m in height. The red earth is the typical soil for hilly fields. A well-developed organic horizon, a clay accumulation horizon, and a Plinthite in the base characterize this type of soil. One disadvantage of the soil is its high acidity (pH value: 5.0–6.0). A variety of crops, especially fruits (e.g., sugarcane and banana) and dry crops (e.g., yam, corn, peanut, beans, and cassava) are grown in the hilly fields. Irrigation and soil and water conservancy are fundamental for good harvests and agricultural sustainability.

Conclusions

In this study, human-environment interactions have been examined in the agricultural land uses in the Zhujiang Delta, China. Three agricultural systems (i.e., rice cultivation, horticulture, and dike-pond agriculture-aquaculture), and two technologies (i.e., dike building and land reclamation) are found to best reflect the complexity of the relationship between people and the physical environment. Five distinctive agricultural land use types (i.e., saline fields, enclosed fields, sandy fields, dike-pond land, and hilly fields) have been formed in response to the environmental constraints, and have all showed a harmonious human-environment relationship.

The combined effect of climate and sea level changes provides a general environmental context for the origins and propagation of horticulture and rice cultivation. Independently developed in Guangdong, horticulture represents the development of an agricultural technology adapted to the environment of terraces or river valleys typical in South China using the method of slash-and-burn. The technology of rice cultivation was brought to the delta by the immigrants from northern China, and was modified to suit to a wetland environment as the population pressure increased. In the course of agricultural history, environmental changes create feedback effects on land uses and human driving forces by disturbing the established human-environment relationship. The rapid seaward extension of the delta unregulated reclamation of land for agriculture, and the prospect of reclaiming land from the sea attracted even more settlers (Lo, 1990).

Agricultural land uses brought about both positive and negative impacts on the environment. The dike building technology was developed to protect the enclosed fields from flooding. The integrated dike-pond agriculture-aquaculture system was well designed to solve flooding and waterlogging problems in a low-lying wetland environment, and to optimize agricultural outputs by recycling wastes and efficiently transmitting energy among the components. The land reclamation technology was called for when more agricultural land were needed. The significance of the three-stage implementation of reclamation is to conserve the ecosystem through the combined uses of biological and engineering measures. However, the failure to keep balance between agricultural land use and conservation could bring about severe environmental deterioration, such as deforestation, soil erosion, silting up of river channels, flooding, and water logging.

Agricultural land uses were changed when the existing environmental and socioeconomic settings changed, but socioeconomic factors were the main driving forces. Rice cultivation in the Qin Dynasty was very different from that in the Song Dynasty. Low population density and premature agricultural technology led to the single-cropping pattern of rice cultivation using the fire and water farming method in the Qin Dynasty. This type of rice cultivation was replaced with the double cropping of wet rice based on interplanting by the end of the Tang Dynasty, when population pressure increased and the technology of water conservancy and farming improved. The continued population-induced agricultural intensification made it possible for a triple cropping pattern of two crops of rice and a dry food crop since the dawn of the twentieth century.

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