ELSEVIER

Agriculture, Ecosystems and Environment 60 (1996) 183–195

Agriculture Ecosystems & Environment

Environmental impact on the development of agricultural technology in China: the case of the dike–pond ('jitang') system of integrated agriculture–aquaculture in the Zhujiang Delta of China

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Accepted 28 May 1996

Abstract

The development of the environmentally conserving dike–pond system of integrated agriculture and aquaculture in the Zhujiang Delta of south China is traced to illustrate the impact of environmental changes on technological innovations. The technologies of dike building, land reclamation, pond fish culture, and crop cultivation on dikes, which were either independently developed or modified from ideas brought in by migrant farmers from northern China, represented farmers' efforts to adapt to the new characteristics of a changed environment as population pressure increased. The new technologies revealed the farmers' awareness of the need for environmental conservation. However, increased population pressure also necessitated more intensive use of the land, both in the highland and lowland regions, giving rise to inappropriate dike building and premature reclamation activities, which in turn brought about more frequent flooding in the delta region. Careless application of a new technology tended to have harmful effects on the environment. Political conditions in different periods of China's economic development have also caused changes in the dike–pond system which has to maintain high productivity and profitability. Recent advances in dike–pond system technology have focused on crop diversification and animal husbandry to match the three-dimensional characteristics of its ecological components. New agricultural technologies can be successful in China only if they can provide a balance between land use and conservation.

Keywords: Zhujiang Delta; Dike–pond system; Environmental impact; Technological innovations

1. Introduction

The objective of this paper is to examine how environmental change has led to the development of agricultural technology as a result of farmers' responses to the change. China, with its long history of agricultural development, is an appropriate subject for this type of research. Many counties in China kept gazetteers ('fangzhi') which documented natural hazards, environmental changes, agricultural technology, commodities, and people in the county as far back as the Tang Dynasty (A.D. 812). The study area selected is the Zhujiang Delta (literally the Pearl River Delta) (Fig. 1), where the highly

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PII S0167-8809(96)01068-7

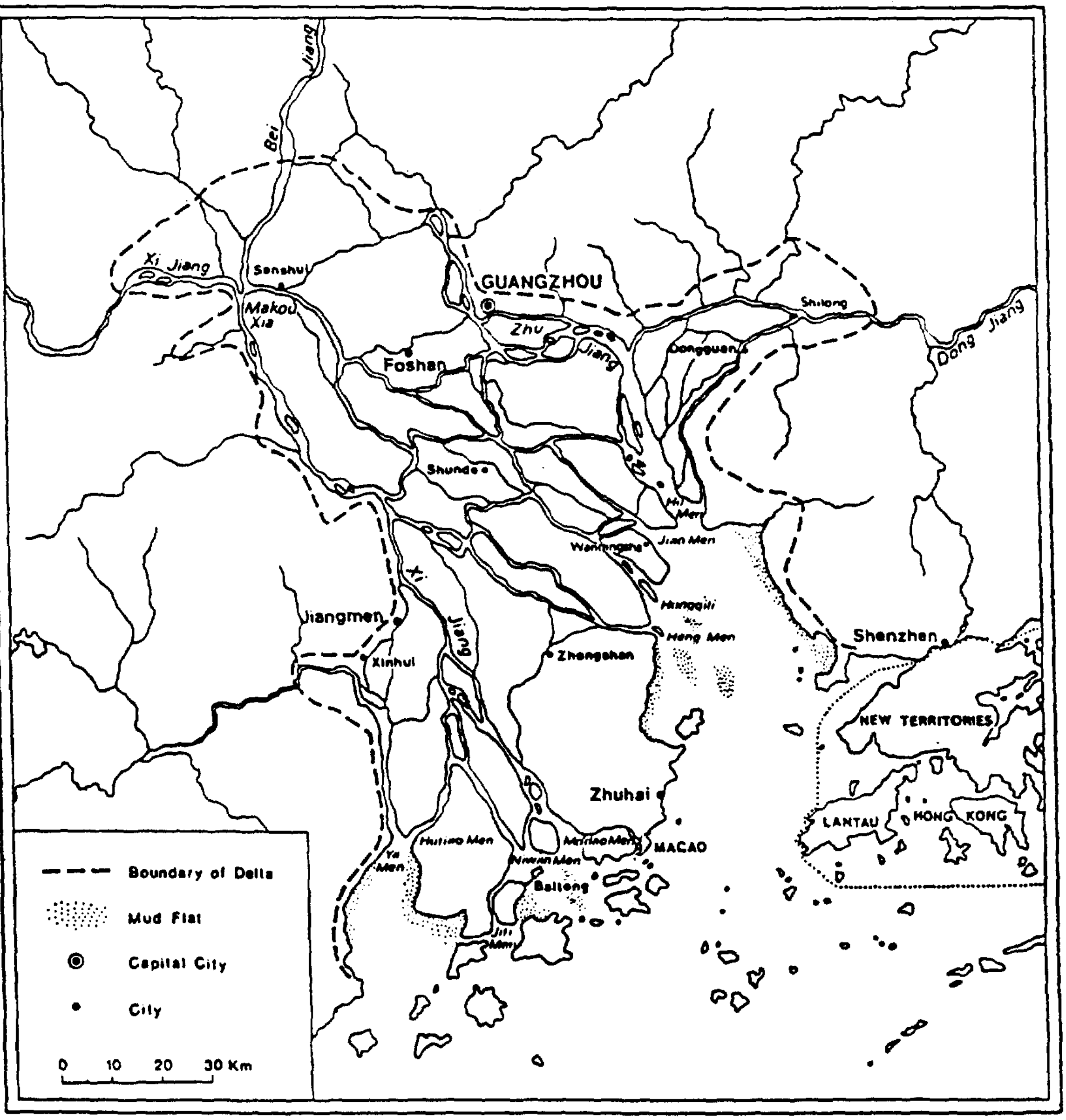

Fig. 1. The boundary of the Zhujiang (Pearl River) Delta.

productive dike–pond ('jitang') system of integrated agriculture and aquaculture has developed. This system is well known for its ability to maximize energy input and minimize wasted energy output through the recycling of organic wastes among components of the system (Ruddle and Zhong, 1988). The evolution of such a system in the delta is the subject of this research, and in this paper it will be demonstrated that this environment-conserving system is the result of local farmers' reaction to environmental change brought about by population growth and migration in China.

2. Characteristics of the dike–pond ('jitang') system

The dike–pond (or 'jitang' in Chinese) system integrates agriculture and aquaculture into one ecosystem of cultivation highly suited to flood-prone low-lying areas (Fig. 2). In these areas, ponds are excavated, and the dug-out soils or muds used to raise the level of the low-lying ground surrounding the ponds, thus forming the dikes. In this way, the danger of flooding is alleviated, while drought can also be regulated. Inside the pond there are draining ditches which allow pond water to be drained if required. The juxtaposition of ponds (water) and dikes (land) makes it possible for the two separate components to interact and function as one ecosystem (Zhong et al., 1993). Fish are raised in the ponds and crops are grown on the dikes. Feces from the

Fig. 2. An aerial view of the dike–pond ('jitang') landscape of the Zhujiang Delta.

Table 1
Major characteristics of different ecosystem strata in the dike–pond system (source: Zhong et al., 1993, p. 71)

Type	Stratum	Thickness (m)	Major ecological characteristics
Land-based ecosystem	1	0.5–1.0	Good light and temperature conditions; 80% light energy absorbed; suitable for crops to grow for the whole year
	2	1.5–2.0	Weaker light energy, large seasonal variation; mainly diffused light; higher humidity than stratum 1; suitable for wet-tolerant crops and poultry
Amphibious ecosystem	3	0.5–1.0	Excellent soil and water condition; suited to amphibious living things, e.g. ducks
Fresh water ecosystem	4	0.5	Abundant light energy, absorbing over 90% of light energy in the water; strong photosynthesis; abundant soluble oxygen content, producing rich algae
	5	1.5–2.0	Smaller amount of light energy; low soluble oxygen content; low range in temperature variations
	6	0.2	Mud at the bottom of the pond with abundant organic matter; low content of soluble oxygen

fish, which accumulate at the bottom of the pond, are used as organic fertilizer for the crops growing on the dikes, and crop residues, such as stalks, are used to feed the fish. In this way, wastes generated in each system are disposed of efficiently by generating nutrients to sustain production in another component of the system. The ratio of land to water in the system is an important consideration because it affects the energy flows (nutrients) between the two components. To raise more fish, more crops should be grown, and a larger land area is needed for the dike, accompanied by a corresponding increase in the pond area. The typical ratio adopted by the farmers in the Zhujiang Delta is 50% dike to 50% pond, or 40% dike to 60% pond, measured in terms of areas. These ratios have come about through long periods of trial and error by the farmers, a typical approach in the development of agricultural technology in China. The usual size of such an integrated dike–pond system is about 0.41 ha (or about 1 acre).

The dike–pond system is also a three-dimensional ecological system. The distance from the surface of the dike to the bottom of the pond is usually over 5 m. The water level in the pond varies between 1.5 and 2.5 m. The water surface in the pond is about 0.5–1.0 m from the surface of the dike. The height of the crop on the dike is over 2 m from the surface of the dike. Six strata of distinct ecological characteristics are recognized and summarized in Table 1 (Zhong et al., 1993). Different species of carp are raised at different water depths in the pond. Recent research in China has shown that the dike–pond system is a scientific and environmentally conserving method of agricultural production in low-lying, flood-prone areas (Ruddle and Zhong, 1988; Zhong et al., 1993).

The dike–pond system was first found to occur in the Zhejiang and Jiangsu region, at the lower course of the Yangtze River, but the interactive nature of the system was not appreciated at that time. In the Zhujiang Delta region, the dike–pond system came into being some time since the Tang Dynasty (A.D. 618–907). Typical crops grown on the dike include fruit trees such as litchi (*Litchi chinensis*) and longan. The peak development of the dike–pond system in the region occurred in the middle of the Ming Dynasty (A.D. 1368–1644) when the commercial silk industry flourished. Mulberry trees were grown on the dikes. Leaves from the trees were used to feed silkworms, and the wastes from the silkworms were used to feed the fish in the ponds (Fig. 3). This is the so-called 'mulberry-dike fish-pond system', which is believed to have attained the maximum benefit in

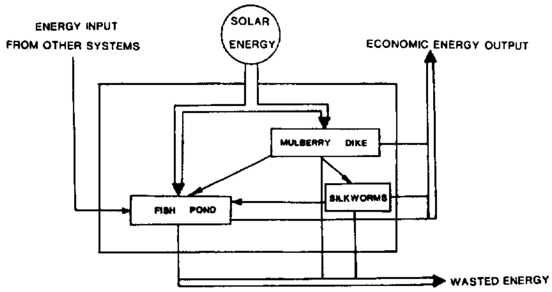

Fig. 3. Energy flow in a mulberry-dike fish-pond system (source: Zhong et al., 1987).

energy flow for environmentally conserving agricultural production (Ruddle and Zhong, 1988). This system flourished in the region until the decline of the silk industry in the early 1900s.

The development of the dike–pond system depended on three technological innovations: (a) diking and reclamation; (b) pond fish culture; (c) crop cultivation on the dike. Tracing the development of these technologies will shed light on how the dike–pond system has evolved in the Zhujiang Delta, a region of continual environmental changes.

3. Environmental changes in the Zhujiang Delta

The Zhujiang Delta is a composite delta formed by the deposition of sediments at the mouth of the Zhujiang River by three major rivers: Xijiang (West River), Beijiang (North River), and Dongjiang (East River) (Fig. 1). Today, the total area of the Zhujiang Delta, as delimited in Fig. 1, is 8601.1 km^2, mostly formed by sediments from two rivers: Xijiang and Beijiang (8033 km^2 or 93.4%). Dongjiang forms a very small part of the delta (568 km^2 or 6.6%). The areal extent of the Zhujiang Delta has varied over time, being greatest in extent at the present time. In the past 100 years, the Zhujiang Delta has extended southeastward, as human impacts on the environment intensified.

The extension of the Zhujiang Delta is also strongly associated with climate and sea level changes in the area. In the Holocene period, the climate in the Zhujiang Delta region became warmer and wetter, similar to a subtropical monsoon climate (Fig. 4). The rise in temperature brought about a rise in sea level (Fig. 4). By the end of this period, the sea level had risen to about 0.5–1.0 m higher than the present level.

The combined temperature and sea level changes resulted in an increase in the forest cover and a decrease in the density of animals per unit forest area. Hunting became more difficult, and the people living in the area began to shift their attention to the low-lying plains bordering the sea for new sources of food (Li et al., 1991). These observations are supported by the fact that the shell mounds deposited in the Middle Neolithic Age (6500–5200 years B.P.) contained mostly shellfish and fish of all types. Fishing and fruit gathering became a mainstay of life for people living near the sea while others still carried out hunting and fruit gathering in the terraces and hills. However, during the Bronze Age (3500–2500 years B.P.), when there was a substantial rise in sea level, people living in the area were forced to move to higher ground, where hills and terraces were utilized to grow crops. Thus, agriculture began to develop. It should be noted that during this period, people living in this area had not yet developed the technology to utilize the flood-prone delta and indeed, there was no incentive to develop the delta.

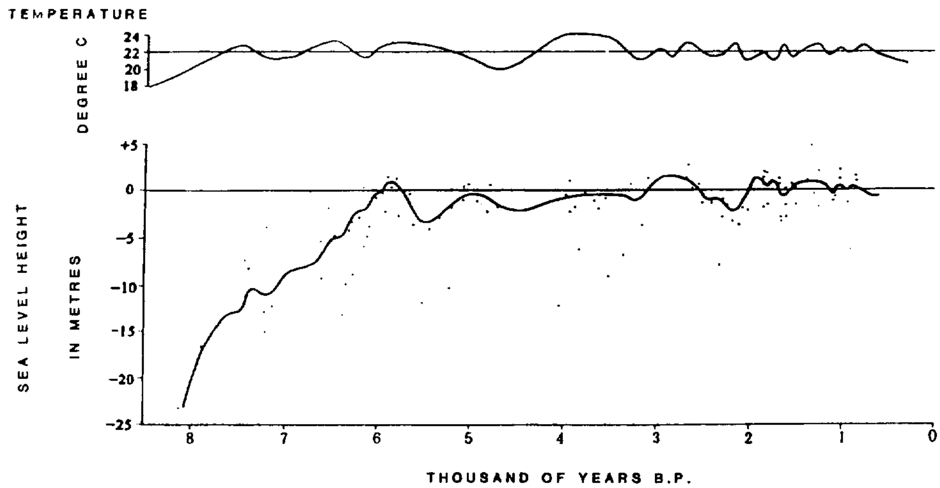

Fig. 4. The relationship between sea level and temperature changes in the Zhujiang Delta since 8000 years B.P.

The extension of the delta toward the sea occurred at varying rates throughout history and reflects the degree of human impact on the environment. At the end of the Neolithic Age (4200–3500 years B.P.), there was a rise in sea level, and the areal extent of the delta was small. The coastline extended all the way to the present-day city of Guangzhou (Fig. 5). As increasing numbers of people moved into the region, deforestation in the upper courses of Beijiang, Xijiang and Dongjiang occurred, increasing the rate of sedimentation in the rivers and hence the formation of the delta. This was particularly so during the Qin (221–207 B.C.) and Han (207 B.C.–A.D. 220) Dynasties, when southward migration of the population occurred and the sea level also fell (by as much as 4–5 m). More plain areas became available for agricultural development. The southward migrating population brought with it new agricultural technologies (He, 1987). The advancement of the coastline in the Zhujiang Delta reflects the intensity of settlement in the region (Fig. 6). In the Tang Dynasty (A.D. 618–907), a long period of

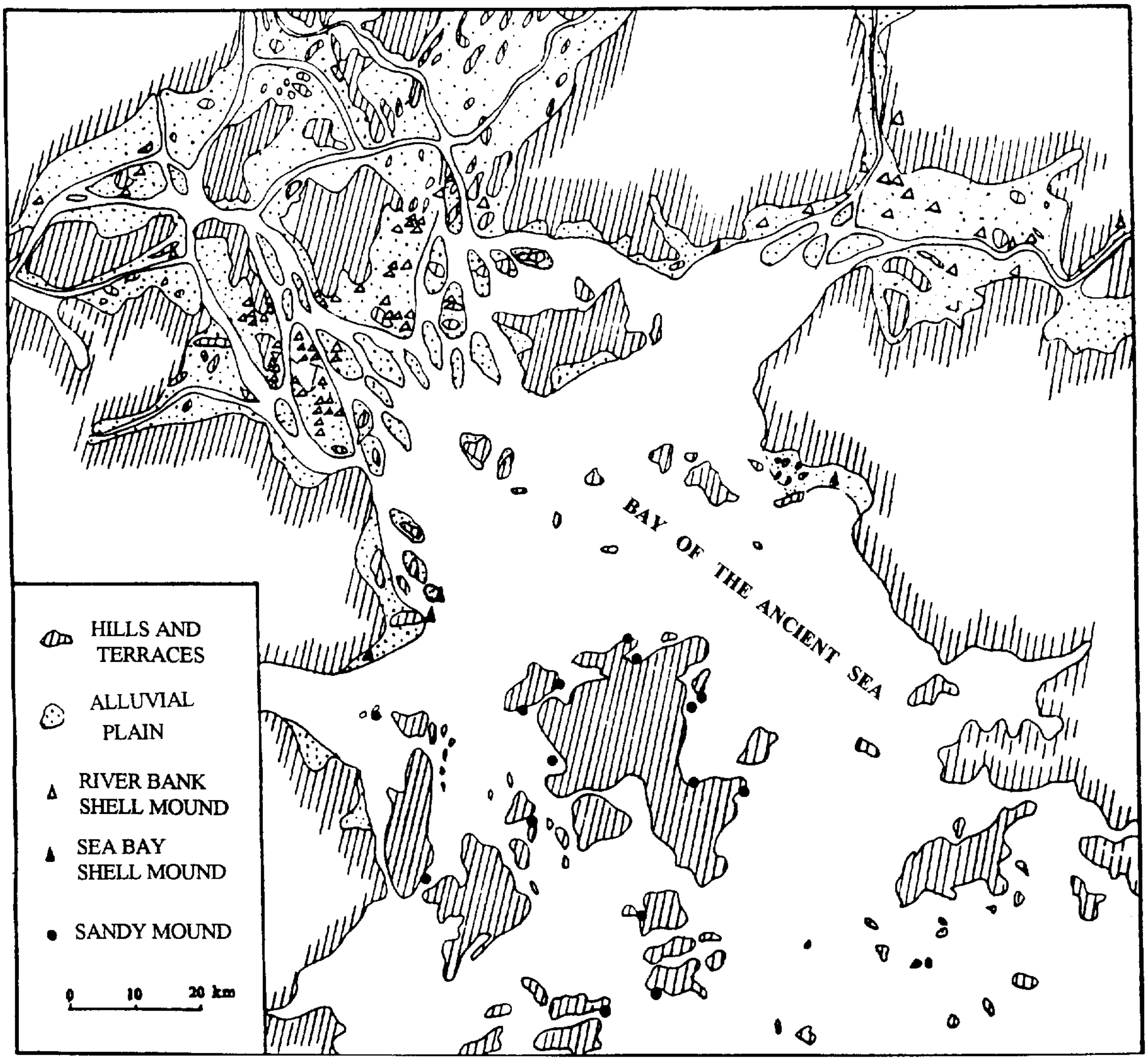

Fig. 5. The coastline of Zhujiang Delta at the end of the Neolithic age.

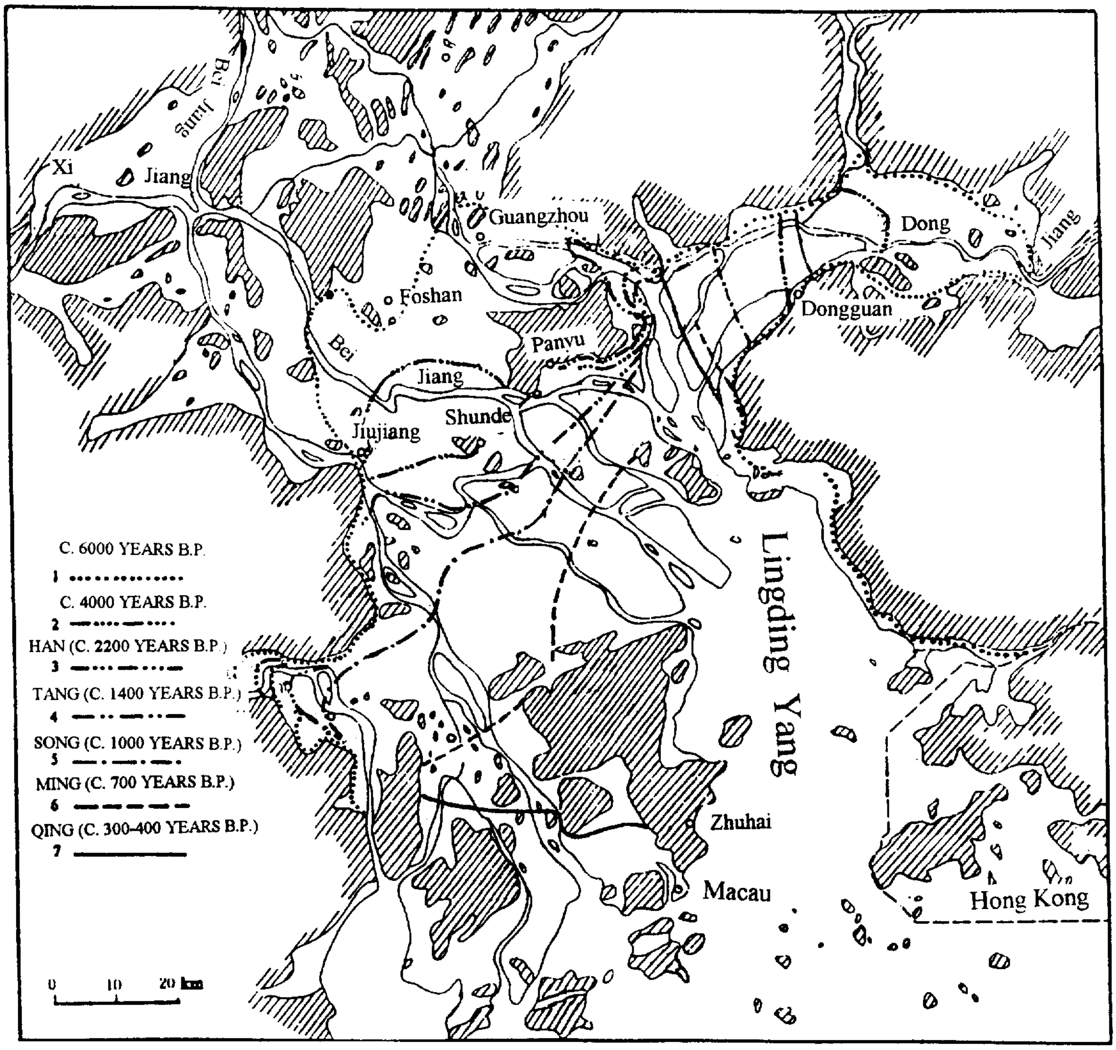

Fig. 6. Shoreline changes in the Zhujiang Delta since 6000 years B.P.

prosperity brought about great population increases in northern China, where the political center of China was located. Southward migration of the population intensified. In the Song Dynasty (A.D. 960–1279), owing to political instability and invasion by the Mongol nomads, more people migrated southward to settle permanently in the delta region surrounding the city of Guangzhou. The environmental impact was an increase in the rate of sedimentation at the estuaries of the rivers and their tributaries, caused by further depletion of the forest areas, resulting in an accelerated extension of the delta (Fig. 6). Subsequent population expansion due to natural increase necessitated the use of the delta for agriculture to produce more food. The technology of dike building and reclamation was introduced to the delta during this period. Dike building and land reclamation activities intensified further in the Ming (A.D. 1368–1644) and Qing (A.D. 1644–1796) Dynasties. Human greed for agricultural land resulted in premature land reclamation and diking. As more dikes were built, more land was reclaimed. These human activities caused the river channels to extend, thus reducing the cross-sectional areas of the rivers. The

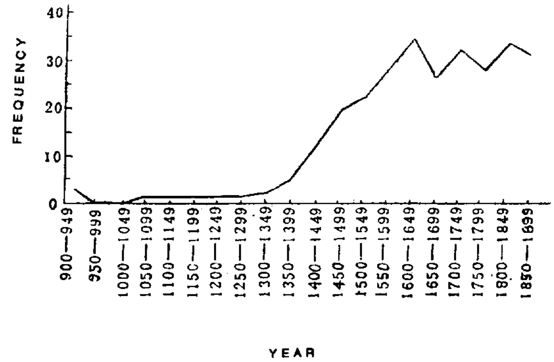

Fig. 7. Frequency of flooding in the Guangzhou district, A.D. 900–1899.

rivers became shallower and easily silted up. As a result, the frequency of flooding in the delta region increased from the time of the Song Dynasty, when there were only nine floods (one flood every 35 years), to the 90-year reign of the Yuan (Mongols) Dynasty (A.D. 1279–1368), when floods occurred 14 times (one flood every 6 years). From the Ming Dynasty (A.D. 1368–1644) to the Qianlong reign of the Qing Dynasty (A.D. 1644–1796), there were 216 floods in 428 years, or an average of one flood every 2 years in the region (Fig. 7). Clearly, intensified human activities in the delta area have damaged the ecological balance of the natural environment.

4. Agricultural technology innovations as adaptations to environmental changes

In the period before the Qin Dynasty (221–207 B.C.), archaeological evidence suggests that the population concentrated mainly in the hills and terraces as well as the river basins, while the low-lying delta area was not settled at all. Rice cultivation was carried out on the higher grounds supplemented by fishing and fruit gathering. Wild rice (*O. sativa* L.F. Spontanea) was widespread in this part of China, and the rice cultivated in China today is the domesticated variety of this species (*O. sativa* L. ssp. hsien Ting) (Weng, 1994).

From the Qin Dynasty to the Southern and Northern Dynasties (221–581 B.C.), southern China became more developed as a result of the establishment of counties by Emperor Qin in the Zhujiang Delta area. This encouraged the southward migration of Han Chinese, who brought new agricultural technologies to the region. During this time, the population density and the agricultural productivity in the delta were low. The major economic activities were rice cultivation and fishing. The method of rice farming used is known in Chinese as 'huo geng shui nou' or 'fire and water farming', especially developed for rice cultivation in the sparsely-populated, coastal, riverine, and wetland environments where land is available in abundance. This method of rice cultivation makes use of fire to clear the grass in the field, direct broadcasting of seeds, and flooding the field with water to kill the weeds. By this method, the productivity per unit area is low, but it is labor-saving, so productivity per labor unit is high (Peng, 1987). This cultivation method is unique to this part of China, and represents the development of an agricultural technology adapted to the environment.

During the Han Dynasty (207 B.C.–A.D. 220), mulberry and silkworm rearing were introduced to the Nanhai County of the Zhujiang Delta region. Mulberry and silkworm rearing originated in the Yellow River region of China as long as four to five thousand years ago. The archaeological discovery of a half cocoon cut open by humans, in a village called Yincun near the Yellow River in Shanxi Province, is believed to be 1600–2300 years old (Zhang, 1960). People migrating from northern China brought the technology of raising silkworms and growing mulberry trees to the region. Owing to the more favorable climatic conditions for mulberry trees, and the more stable political situation in southern China following the Song Dynasty, mulberry–silkworm production prospered. The technology, which was highly developed, was improved and modified to suit the physical conditions of the south.

During the Tang Dynasty (A.D. 618–907), north–south population movements intensified. The economic center of China began to shift southward (focusing on Guangzhou), and increased influences from the middle and lower courses of the Yangtze River were felt. Wet rice cultivation (two crops a year) was well developed, but on some hilly slopes, slash-and-burn agriculture was still practiced for the farming of 'dry fields'. Silk and mulberry cultivation was already well developed around the Guangzhou area. In the hilly areas at the lower course of Xijiang

River, a new method which combined pond fish culture with rice cultivation was developed to cultivate the newly formed land on the hillslopes. This involved using the new land for fish culture for 1 or 2 years. The main source of water was rainfall during the rainy season. The field could be subdivided into different compartments to raise different kinds of fish. When the new land became fertilized, the water in the field was drained away and rice was cultivated. This method can be regarded as the forerunner of the dike–pond cultivation system practiced in the delta. During this period, the Zhujiang Delta was not yet fully formed, and the farmers' focus was still the drier, hilly areas.

During the Song Dynasty (A.D. 960–1279), the southward shift of population increased, and the whole of Guangdong Province, of which Zhujiang Delta is a part, became highly developed. There was a rapid population increase, which resulted in an intensified demand for food. The Song government paid special attention to agricultural technological innovations. A 'Green Revolution' took place in southern China, in which new, quick-ripening rice varieties from Champa, the ancient Indochinese kingdom (2nd to 17th century) occupying the coastal region of today's central and South Vietnam, were introduced, which made possible double cropping (or even triple cropping in some areas) of rice (Bray, 1984). The new farming techniques were spread by a number of 'master farmers' (equivalent to the rural extension officers of today). A large number of agricultural books (nong shu) were written on the new methods of farming, which included better cropping practices, new tools, machines, fertilizers, and irrigation methods. The diking method was probably introduced to the farmers in this way, and the migrant farmers from the north brought the technique to the Zhujiang Delta area.

Agricultural development in the low-lying delta area was made possible by the dike building technology, modified to suit the specific environmental conditions in the delta. The dikes prevented the delta from being flooded so that rice crops could be grown. In the Song Dynasty, 28 dikes were built with a total length of 66 024 zhong (about 220 080 m), reclaiming an area of 24 822 qing (about 334 837 ha) as cropland (He, 1987). They were concentrated at the lower courses of Xijiang and Beijiang, as well as the area above Dongguan and Shilong. The height of the dike was about 1–1.7 m, high enough to protect the land from flooding. Excess water could be drained from the diked field through an opening inside the dike. The construction was crude, but dike building initiated a new stage in water conservancy in the Zhujiang Delta, and helped raise the agricultural productivity of the region. The dike building technology is closely associated with the land reclamation technology, which was acquired from the Yangtze River area. Diking and reclamation continued to be the most important activities in the Zhujiang Delta during the Yuan (Mongols) Dynasty (A.D. 1279–1368). As a result, a large amount of new farmland was reclaimed, and agricultural productivity increased sharply in the delta region. The city of Guangzhou became an important rice market. With a surplus in grain, economic crops were developed, the most important of which during this period was sugar cane.

During the Ming and Qing Dynasties (A.D. 1368–1840 A.D.), China experienced even greater population increases. The economic center was now located in southern China. Agricultural technology advanced, and diking and reclamation proceeded at a much faster rate (Lu, 1988). A total of 1493.2 km of dikes was built during this period, an increase of about seven times the length of dikes built in the Song Dynasty. Water conservancy was very well developed in China during this period, which ensured high grain productivity (Jiang, 1986). More land was used to grow economic crops for greater profits, and the commercialization of agriculture in the delta area began.

The increased commercialization of agriculture stimulated local farmers' interest in pond fish culture in the diked areas of the delta. Another commodity of interest was fruit, which grows well in the hilly areas of southern China. The production of fruit on the dikes surrounding the ponds and fish was very profitable. This form of agriculture developed in the area around Jiujiang (Fig. 6) in the middle of the Ming Dynasty (about A.D. 1500). As silk production became important in the 16th century, mulberry trees replaced fruit trees on the dike, thus giving rise to the mulberry-dike fish-pond system. Such a system was found to be capable of maximizing silk and fish production in the low-lying, flood-prone delta area without causing environmental problems, by fully utilizing the wastes generated by the two components in a mutually supportive system (Fig. 3). This system is highly labor intensive, and requires cheap water transport to market its products (fish and silk). Also, fish fry for the pond fish culture should be abundant. The Zhujiang Delta area provided just such conditions for this form of dike–pond system to thrive. In addition, the climate in the area allows mulberry bushes to grow throughout the year. As the mulberry leaves can be harvested seven to eight times a year, this allows the same number of generations of silkworms, which feed on the mulberry leaves, to be raised. This ensures high productivity in silk, and hence a large profit, which cannot be matched by rice cultivation alone. In 1581, the counties of Nanhai and Shunde, which have the largest uninterrupted alluvial plain, developed the first mulberry-dike and fish pond landscape with 20000 mou (1345.7 ha) of dike–ponds. Since then, the area has been further extended. By 1926, the total area of mulberry dikes and fish ponds in the two counties had reached 720000 mou (48445.7 ha) (Zhong, 1958). For the Zhujiang Delta as a whole, the total area of mulberry dikes and fish ponds increased from 964000 mou (64863.4 ha) in 1921 to 1397000 mou (93998.1 ha) in 1925 (Situ, 1994).

The high degree of commercialization of agriculture in the Zhujiang Delta implies that profit is the motivating force for agricultural innovations. The importance of the mulberry dikes and fish ponds system lies in the high price of silk in the world market. When the price dropped in 1929, mulberry was replaced by sugar cane on the dike. The constant factor was the fish in the pond. Mulberry dikes have continued to decline in recent years, following the economic reforms of 1978, and a greater variety of crops has been grown on the dikes, and new species of fish introduced to the ponds (Lo, 1990). Four basic types of dike–pond systems have emerged:

1. mulberry and sugar cane dikes with fish ponds;
2. mulberry and sugar cane dikes with fish ponds in combination with horticulture and paddy rice cultivation;
3. mulberry and sugar cane dikes with fish ponds in combination with elephant grass, vegetables, and paddy rice cultivation;
4. predominantly paddy rice and sugar cane cultivation, horticulture, and fish ponds, with dikes not being used at all.

These variations in crop combinations reflect differences in the physical environment of the delta and the accessibility of the sites from the market(s).

In recent years, the dike–pond system has undergone further changes to maximize the nutrient energy flow (Fig. 3) and take advantage of the three-dimensional characteristics of the three ecosystems (Table 1). Instead of monoculture, over three types of crops, usually fruit, flowers, and vegetables, are grown on the dike, in addition to raising poultry (ducks and chicken), while in the fish ponds, three vertical layers of fish are raised. Feces from the poultry help raise the organic content of the soil in the dike and increase the source of food for the fish. Such a combination maximizes productivity because it makes the best use of the interaction of sunlight, temperature, water, and soil by fitting into the niches of the three-dimensional ecosystems (Table 1). This raises the technology and management of the dike–pond system to a much higher level, enabling it to compete in a market-oriented agricultural environment. Clearly, the dike–pond system is quite capable of change in the face of environmental changes (notably, pollution) generated by an increasingly industrializing economy.

5. Technological implications of the integrated dike–pond system

The success of the integrated dike–pond system in the delta relies on the proper use of the following agricultural technologies: (1) dike building, (2) land reclamation, (3) pond fish culture, and (4) crop cultivation on dikes.

By interviewing local farmers, a detailed description of the land reclamation technology as practiced in the delta was obtained (Agricultural Records of Zhujiang Delta Writing Group, 1976). The results suggested that local farmers developed the technology through experimentation. They emphasized the importance of identifying the five proper stages of sedimentation, which are described as follows:

1. fish swimming stage when the water is 2–3 m deep at low tide;
2. the scull touching the sea bottom stage when the water is 1–1.5 m deep;

3. the cranes standing stage when the water further decreases to about 0.2 and 0.3 m;
4. grass spreading stage when most the beach area is exposed at low tide;
5. the diking stage when land becomes more frequently exposed above the water after a period of 2–3 years.

These observations indicate the local farmers' awareness of the importance of environmental protection. They realized that diking and reclaiming prematurely would increase the liklihood of flooding in the area, yet in practice some farmers did breach these rules.

Full descriptions of the method of reclaiming the land are available (Agricultural Records of Zhujiang Delta Writing Group, 1976). Three stages are identified:

1. throw rocks and boulders into water to dampen the force of water and to help sediments accumulate, which should take place at the 'crane standing' stage mentioned above;
2. grow grass (1–5 years after stage 1) to help trap sediments;
3. establish the dike (3–5 years after stage 2).

Therefore, proper reclamation takes about 4–10 years to complete. Once again, this reflects the environmental awareness of the local farmers in carrying out reclamation.

The method of building dikes is also fully described (Agricultural Records of Zhujiang Delta Writing Group, 1976). Local materials, such as, silt, mud, bamboo sticks, and twigs are utilized. It is explained how the foundation of the dike can be strengthened, how the reclaimed land should be partitioned by dikes, how drainage ditches and drain holes can be established, how the grass can be cleared and the land leveled, and finally what types of crops should be grown first to rid the newly reclaimed soil of the salt. Again, the local farmers seemed to have developed the method based on 'trial and error' with a high degree of environmental awareness.

Pond fish culture, the main component of the dike–pond system, seemed to be independently developed in the Zhujiang Delta, based on the fact that the types of fish raised were different from those raised in other parts of China. The main type of fish raised was, and still is, the grass carp, which is particularly suited to calm water. Pond fish culture in the Zhujiang Delta area was first recorded in a book published in the mid-9th century during the Tang Dynasty (A.D. 860–873). It mentioned the southerner's practice of collecting fish fry from the rivers (particularly the Xijiang). The greatest development in pond fish culture took place during the late 13th century during the Yuan Dynasty. In A.D. 1344, because of water conservancy construction, some of the rivers in the Xijiang region had to be dammed, and pond fish were raised in these dammed rivers by the local people. Up to the early 15th century (early Ming Dynasty), pond fish were mainly raised for the farmers' own consumption. After the mid-Ming Dynasty, however, when southern China was becoming increasingly developed, commercial pond fish culture assumed greater importance. The main center of development of pond fish culture was in the northwest of the Zhujiang Delta, especially in the Jiujiang Village of Nanhai County, where the early form of the integrated dike–pond system emerged. The Chinese books published in the Spring and Autumn Period (770–476 B.C.) had already warned of the danger of over-fishing in the sea, and the need to conserve fish stocks by not catching small fish. Pond fish culture was viewed as a way to conserve fish at the sea. Pond fish culture is also the most suitable form of economic activity in a low-lying deltaic environment. In recent years, pond fish fetch a high price in the market, which explains why fish is the unchanged component of the dike–pond system.

The diversity of crops grown on the dikes reflects the advanced cultivation technology: fruit (citrus, banana, litchi, and longan), mulberry, vegetables, sugar cane, and flowers. The high temperatures and plentiful rainfall of the delta area help their growth. As mentioned before, the fish ponds developed in Jiujiang were associated with fruit trees grown on the dikes surrounding the ponds. The technology benefitted from the 'Green Revolution' of the Song Dynasty, which led to the introduction of new crops.

6. Conclusions

It has been demonstrated from an examination of the evolution of the dike–pond system in an ever-changing Zhujiang Delta environment that environmental change induces technological innovations.

Local farmers developed the new technology by observing and experimenting with a view to adapting it to the new environment. A driving force for innovation is an urgent need to make use of the new environment. In the case of China, population growth provides the driving force.

Many of the technological innovations have shown an awareness of the need to protect the environment. The diking and reclamation methods were developed to ensure that the land was not prematurely reclaimed and that only locally available materials were used to build the dikes. The dike–pond system developed contains sound ideas of waste recycling and optimum energy utilization for the production of crops and fish in a sensitive flood-prone wetland area.

Despite the environmental conservation overtone, human adaptations to environmental changes have brought about new environmental challenges, such as, deforestation, flooding, silting up of river channels, and an accelerated extension of the delta. Human carelessness or greed may be the cause of these environmental disasters. Commercialization of agriculture in recent years has brought about further environmental deterioration because of farmers' obsession with maximizing profits. As every farmer cultivates the same crop, the price of the crop drops, adjustments have to be made, and a new, profitable crop found. The dike–pond system has also undergone changes in terms of the type and diversity of crops grown and a technological innovation to integrate not only farming and fishing, but also animal husbandry for higher productivity and profits. The technological innovation came about as a result of the research effort undertaken by the Chinese to understand the energy flow pattern of the dike–pond culture system in the second and third dimensions (Zhong et al., 1993).

Finally, successful agricultural development in China reflects a delicate balance between land use and conservation owing to the immense size of China's population. Environmental changes disturb the balance. Technological innovations are necessary to help re-establish the balance. Past Chinese agricultural technologies are superior in that they show a deep understanding of the interactions between humans and the environment, and were developed through 'trial-and-error'.

Acknowledgements

This research was supported by the University of Georgia Humanities Center's Eugene P. Odum Grant for Research on the Interface between Humanities and Science. The author is grateful to the encouragement given by Professor Eugene Odum on this research. He is also grateful to Professors Huang Guangyiu and Situ Shangji of the Department of Geography, Zhongshan University, Guangzhou, China, for help in library research, and to Professor Zhong Gongfu of the Guangzhou Institute of Geography for his expert advice on this research. I am also grateful to the comments of two anonymous reviewers of an earlier draft of this paper, which helped improve the paper.

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