Land Transformation in Agriculture
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CHAPTER 5.IV
The Impact of Wetland Reclamation

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5.IV.1 INTRODUCTION

The complex ecosystems that characterize coastal south-east Asia are areas of intimate interaction between aquatic and terrestrial ecosystems, and are zones of high inherent biological productivity and complexity. They are among the most complex, diverse and biologically productive ecosystems in the biosphere, and among the least understood and most fragile. Even more than their temperate zone counterparts, tropical and sub-tropical coastal ecosystems are liable to severe damage from unsuitable development schemes.

Despite the predominance of both freshwater and marine aquatic environments in the tidally influenced wetlands of humid, tropical coastal zones, forest and grassland habitats provide man with a wide range of foodstuffs and economically important raw materials, and levée and beach-ridge soils, for example, provide fertile areas for agriculture. The outstanding natural characteristic of wetland ecological systems is an all-pervasive interaction between terrestrial and aquatic components, a fundamental characteristic clearly reflected in many of the resource systems traditionally employed to exploit wetland renewable natural resources. Such systems have long been used, usually on a relatively small scale, but not inevitably so, to effect agricultural transformations that yield foodstuffs and complementary materials on a sustained basis and with very little environmental repercussion (Ruddle, 1982). Many, but not all, such systems are thoroughly grounded in generations of empirical biological and ecological knowledge, and not uncommonly they employ sophisticated, low-energy technologies of research transformation (Ruddle and Grandstaff, 1978). On the other hand, policy-makers and planners generally foresee more specialized uses for reclaimed wetlands in terms of a combination of large-scale, heavily capitalized agriculture, aquaculture, animal husbandry and forestry; as sources of freshwater for irrigation, industrial and domestic uses; or as sites for ports, industry and human settlements. Some of these destroy the natural ecosystem and others are highly disruptive, although not inherently so if properly conceived and implemented.

Since a worldwide survey of the complex and varied transformations that have been effected in coastal wetlands is beyond the limited scope of one chapter, the coverage here is limited to two contrasting case studies from south-east Asia. The first is from Sumatra, Indonesia, where wetland reclamation for the Transmigration Scheme is being attempted by rapid and large-scale environmental change. Serious problems have arisen with this strategy. It is contrasted, in the same region, with traditional and successful, yet small-scale, wetland agricultural transformations.

The second case exemplifies the quite different results that have been obtained during the two millenia-old and still continuing agricultural transformation of former tidal wetlands of the Zhujiang (Pearl River) Delta of southern China, where for many centuries the resource development policy has been one of gradualism, an adaptation of the natural order to 'turn the worst into the best', to take advantage of changing market demand and ecological opportunity. In this densely populated region no sudden, fundamental method has been applied to radically alter the wetland environment. The result has been the gradual evolution of one of the world's largest and most successful systems of integrated agriculture–aquaculture.

It should be noted that the notion of continental wetlands now includes coral reefs and other nearshore marine ecosystems. Coral reefs are excluded from this treatment, perhaps arbitrarily, as are mangroves. Aquaculture has also been left out, since the widespread brackish water systems based on the reclamation of rapidly accreting shorelines are not essentially agricultural transformations; small-scale integrated farming systems are still not an important feature of the tropical agricultural landscape; and in the case of ricefield fisheries, wetlands were reclaimed for ricefields and fish derived from them has always been a secondary consideration (Ruddle, 1980, 1982).

5.IV.2 AGRICULTURAL TRANSFORMATION OF INDONESIAN COASTAL WETLANDS

Indonesia accounts for 14% of the world's coastline. Some Indonesian coasts, like the north coast of Java, have population densities in excess of 3000 persons/km^2 and are among the most densely populated areas on earth, whereas others, such as the tidal wetlands of southern Sumatra, have only 10–20 persons/km^2. Further, with a population of some 142 million (1980), which is growing at a rate of 2% a year, Indonesia is the fifth most densely populated country in the world.

The predominant agricultural transformation over the course of many centuries and at the hands of the local inhabitants on Java, Bali and Madura, together with those coastal tracts on the Outer Islands lacking wetlands, has been the conversion of pre-existing ecosystems into irrigated rice fields, either for mono-culture or in association with coconut plantations or coconuts interplanted with mixed secondary crops. Many local variants occur within this necessarily generalized picture, but none refutes it.

'Spontaneous migrants', principally Buginese from southern Sulawesi and Javanese and Sundanese from Java, who have migrated mainly as pioneer agriculturalists to the tidal wetlands of Sumatra and Kalimantan, have also followed the same agricultural practices, i.e. mostly rice and coconut farming or secondary crop–coconut agriculture. Few such migrants settle in coastal zones that lack tidal wetlands, probably because pioneering in the swamps yields higher economic returns. In contrast, most government-sponsored transmigrants are obliged to adopt the mono-culture of irrigated rice, although some have also taken up the cultivation of secondary crops combined with coconuts, partly in response to the poor economic returns from rice.

5.IV.2.1 Traditional Technologies for Wetland Transformation

Sophisticated, low-energy techniques for successful agricultural transformation of peat soils of tidal swamp areas in central and southern Kalimantan (Borneo) have been developed and expanded over many decades by Banjarese, Buginese and migrants from Java. All three groups employ systems based almost entirely on the Banjarese model.

Over some five decades Banjarese agriculturalists have employed and developed their system of sustained agricultural production in former tidal swamps (Collier, 1980). At Samuda Kecil Village, on the River Metaya of central Kalimantan, Banjarese pioneer agriculturalists select a small tributary stream and, by hand, deepen and widen it from a confluence with a larger stream to its source. At the source they 'dig a small canal which follows the natural drainage system' (meaning ambiguous).

The area destined for cultivation is then progressively opened and cleared in 1 ha lots. First, the small stream is canalized for some 50 m, then the trees in an adjacent area of 425 m^2 are felled during the July dry season (since in the wet the area is inundated to a depth of 1 m), sun-dried for three months, and finally cleared by burning either once or twice during September and October. In December and January seedlings propagated in a seedbed are transplanted to the new field. Since only a digging stick is used, the peat layer is hardly disturbed. At the same time residual stumps and logs are burned again. Finally, the only time that first- and second-year fields are weeded is during the transplantation period. More intense weeding is required in third-year fields and consumes 14–20 man-days per hectare per year of labour input. Weed infestation becomes progressively worse, and fourth-year fields, for example, require 30 man-days per year of weeding input for each hectare. Weed infestation and associated problems are the prime reasons for eventually converting rice fields to other forms of cropping. Only one crop *per annum* of local rice varieties adapted to the prevailing swampy conditions is cultivated. The crop is harvested in May.

After the second year of rice cultivation a drainage ditch 1 × 0.5 × 425 m is excavated across the centre of the field. Again, only hand tools are used.

During the third and fourth years of field use, coconut seedlings are interplanted with rice, at a rate of 135/ha, on small mounds made of the earth removed from the shallow drainage ditches that separate the rows of coconuts. The individual mounds must be built up and the ditches deepened biennially until the fifth year, when they are formed into continuous ridges. Coconuts, the principal crop, are then inter-planted with coffee, bananas and vegetables. Rice is cultivated in the shallow ditches between the rows for three more years.

Three years after inter-planting with coconuts, shade impedes rice cultivation, so that the village headman permits the clearance of an additional 2 ha of swamp forest, thereby initiating another 7–8 years of the agricultural transformation process. The Banjarese consider a 6 ha farm to be ideal, with 4 ha under coconuts and associated secondary crops and 2 ha planted to rice, given the time required for their system of swamp forest agriculture to reach maturity, together with the ability to recruit labour.

Under the Banjarese system, rice fields are converted to coconut and secondary crop production because the increasing labour costs required to weed older rice fields, in combination, perhaps, with lower yields, is not economically justifiable. This is particularly so when coconuts produce a higher rate of return.

Over several generations the Buginese from southern Sulawesi have developed a method similar to that of the Banjarese—from whom they might have learned it—for agriculturally transforming tidal swamps. The Buginese, who began migrating spontaneously to the swamps of Kalimantan and southern Sumatra early this century, cultivate mostly coconuts and other commercial crops, and plant rice for subsistence only, until their coconuts produce an income or until rice yields begin to decline on the newly cleared land.

Buginese pioneer settlers carefully select cultivable areas in swamps by judging the quality of the natural vegetation and noting the presence of indicator species. The soil is then checked; peats are cleared for coconuts inter-planted with sweet potatoes and soy-beans, among other catch crops, whereas rice is planted where peat is either absent or only a few centimetres thick (Collier, 1978; Collier *et al*., 1981).

These settlers obtain land from the local clan (*marga*), and clear it by cooperative labour. First, a primary canal is gradually excavated at right-angles to a river and leading towards the centre of a peat dome. Its length depends on the size of the area to be developed, but the depth is about 2.5 m and the width some 3 m. As canal excavation proceeds trees are progressively felled and economically valuable species sold for subsistence. Land is progressively cleared along the canal, and narrow strips, separated by secondary canals some 450 m apart, are divided into 2 ha plots and distributed among the pioneers.

After several years, increasing weed and pest infestation combine with declining soil fertility to reduce yields, such that rice cultivation is no longer economically feasible. New fields are then opened up to repeat the land reclamation process and the older fields converted to coconut plantations.

Successful pioneer swamp agriculturalists in Kalimantan also include 'spontaneous migrants' from Java. Their success stems from having directly copied the Banjarese system, although in their case final results are delayed since before their own fields become productive they must work for others as farm labourers to ensure family subsistence.

5.IV.2.2 Wetland Transformation Via the Transmigration Scheme

As a consequence of increasing land shortage combined with an ever-growing demand for goods and services, together with national and regional policies, many coastal zones of Indonesia that were hitherto perceived as wastelands, or at best as marginal areas, are becoming the foci of economic and social development schemes. Indonesia has a land surface of approximately 200 million hectares, of which only 17 million hectares (8.5%) is under permanent cultivation. Further, 65% of all Indonesians are concentrated on the agriculturally rich zones of volcanic and alluvial soils of the islands of Java, Madura and Bali, which together comprise a mere 7% of the national territory. This extreme concentration of population has been increasingly exacerbated by the better economic diversification and social infrastructure of those islands. Thus it is now widely maintained that the major development problem facing the nation is the concurrent reduction of pressure on the resources of Java, Madura and Bali and the development of those on the Outer Islands, a linkage that will be effected by differential capital investment and through implementation of the transmigration policy.

Transmigration, a basic tenet of Indonesian development policy, is an ambitious scheme to relocate large numbers of people. Massive infrastructural investments are now being made to reclaim coastal wetland tracts formerly regarded by planners as useless, to absorb the transmigrants.

Although initially seen as a means of reducing population pressure and the associated detriments of landlessness, lack of economic opportunity and the degradation of renewable natural resources and the environment on the three overcrowded islands, the continued in-migration to Java prompted a revision of the fundamental objectives of transmigration, which is now principally viewed as the promotion of regional development to the sparsely populated

Outer Islands. In addition to satisfying a strategic need for national defence, this would also serve, along with the BIMAS (Agricultural Intensification) Program, to both augment the national supply of foodstuffs and raw materials, as well as providing land for the landless. Transmigration schemes are also used to absorb populations displaced by either natural disasters or by development projects as well as communities that must be resettled to reduce pressures on damaged or fragile watersheds, particularly those upstream of critically important agricultural zones or densely settled areas.

Both government-sponsored schemes to geographically redistribute population, as well as 'spontaneous migration', are officially termed 'transmigration'. The history of both types is already well documented and merits no further reiteration here (see, for example, Peltzer, 1945; Hardjono, 1977; Collier, 1978; Hanson, 1980) (Table 5.IV.1).

In the Outer Islands an estimated 40 million hectares of potentially productive agricultural land, a large percentage of which is tidal wetland, is considered to be available for development, particularly for irrigated rice (IBRD, 1974). The definition, and therefore the estimates of the area of Indonesian tidal wetlands, vary considerably, and accurate assessment of their

Table 5.IV.1 Summary of agricultural planning for development of coastal wetlands off Java (1880–1976) (Hanson, 1980)

Year	Event
1880–90	Opening of the first in a series of canals in southern Kalimantan for navigation through swamplands. Canals gave Banjarese access to new agricultural lands by digging simple drainage systems emptying into the main canals.
1914–22	Rice shortage during the First World War focused colonial government's attention on outer island land potentials. Some field development started in 1920 in Kalimantan.
1935	Improvement of 1880 original canals in Kalimantan and further settlement in their vicinity.
1936–40	Extensive feasibility studies and soil surveys for massive agricultural development and transmigration to turn Kalimantan swamplands into a 'rice-bowl' in which mechanized agriculture would play a substantial role. First transmigration project initiated in 1937.
1948–52	Kalimantan Polder Plan developed under the direction of H. J. Schophuys and agreed to by the government of Indonesia. Over a 15-year period 840 000 ha of swampland would be employed with proper drainage and pumping systems. Pilot canal development initiated in 1950 on four areas totalling 40 000 ha conducted through regional Polder Corporations directed by government.

Table 5.IV.1 (*contd*)

Year	Event
1953	First 5-year plan was to begin in Polder development but by 1970 only 2 pilot projects totalling 8700 ha were near completion.
1957	Tidal irrigation project to convert 1.5 million ha of Kalimantan and Sumatra coastal swampland to ricefields over a 5-year period announced by Ministry of Public Works. Minister P. M. Noor had formerly been directly associated with the polder plan but shifted emphasis from pumping systems to lower cost open systems in which Public Works would Plan primary and secondary canals in areas under the influence of tidal back-up. A 700 km canal was proposed for Kalimantan.
1960–63	Project supported by government decrees including a 1963 Presidential decree declaring it a vital state project. Actual implementation was limited to minor developments in Kalimantan and, in 1963, the project was reduced in size.
1964–65	Work committee for tidal and polder systems established by Minister of Public Works, resulting in publication of 'Proyek Kanalisasi'. Among other projects proposed was a canal running most of the length of Sumatra.
1967–68	Ministry of Public Works announced a new tidal irrigation project to open 5 250 000 ha of land over a 15-year time span. Considerable exploratory work on possible projects by foreign consultants working for private companies and by FAO.
1968	FAO–Dept. of Agriculture Land and Water Resource Development Project established in south-east Sumatra as an outcome of mission activities. Emphasis on Musi river water basin.
1969–74	Public works tidal irrigation project reduced to 500 000 ha over a 5-year period (REPELITA I 1969–74). Actual area opened over this period was 13 198 ha for 7180 transmigrant families. Three sites (including Delta Upang) were developed in Sumatra and three in Kalimantan. Indonesian universities became involved in planning and design in 1969.
1974	By presidential instruction a plan, developed by the Ministry of Public Works, to open 1 000 000 ha of coastal swampland between 1974–79 (REPELITA II) adopted. Survey activities, training and massive equipment purchases initiated quickly.
1975	Canal excavation started in areas adjacent to REPELITA I pilot projects.
1976	Downward revision of land opening projection to 250 000 ha by 1979.
1975–76	Request to World Bank for design and survey assistance resulted in 3.2 million dollar loan for studies on 300 000 ha at two sites in Sumatra; complemented by 3 million dollar hydrological studies and training from government of the Netherlands.

extent and type is severely hampered by a dearth of scientific knowledge about them. Relatively recently it was estimated that there are some 43.5 million hectares of swampland in the country, excluding that of Irian Jaya (*ibid*.). Excluding the latter, the estimated area thought to have agricultural development potential ranges from 10.5 to 2.2. million hectares (*ibid*.). Further, the area of Indonesian wetland directly or indirectly influenced by tides is also subject to various estimates: Soeriaatmadja (1978) placed it at 5–7 million hectares.

Despite various changes in programme design, the overall scope of the transmigration schemes is large, the Third Five Year Plan (1979–84), for example, aiming to relocate 2.5 million people to some 250 resettlement sites, mostly in Sumatra, Kalimantan and Sulawesi. As one of the major loci for its transmigration projects, since 1968, with the organization of the 'Project for Opening Tidal Swamps for Rice Production', it has become an integral part of government policy to reclaim areas of tidally influenced peat soils as zones for rice production. So important has tidal swampland become in the overall scheme that between 13% and 20% of all transmigrants are now asigned to such areas. However, it is noteworthy that to 1976 some 300 000 ha of tidal swampland has also been converted to agricultural production by spontaneous migrants (DBP, 1978), more than double that developed under government-sponsored schemes to 1980.

5.IV.2.2.1 Agricultural Land Use on Wetland Transmigration Schemes

The geographical location of transmigration schemes situated in tidal wetlands is shown in Figure 5.IV.1. The following description and later analysis of problems encountered is based mostly on one typical such site, that in the Upang Delta of south-eastern Sumatra.

Government-sponsored transmigrants live in official settlements of several hundred families in the centre of a former swamp area previously drained and partially deforested by government contractors. They are given land that has been opened up with an artificial drainage infrastructure excavated by heavy machinery, and the forest has been partially felled, sun-dried and either already removed or made ready for burning by the settlers. Commercially valuable species are first removed. Part of the assigned land remains to be cleared of timber and scrub by the migrants during the slack period of the agricultural cycle. The first rice crop of such newly opened land may be anticipated in either one or two years. Most official transmigrants on the scheme are Javanese and Sundanese, from Java, and a few are Balinese.

During 1970 and 1971 each transmigrant family arriving in the Upang Delta received 2.75 ha of land. Official plans required that 0.25 ha be used for a dooryard garden, 0.75 ha for various dryland crops, and 1.75 ha planted to tidally irrigated rice. This has not been adhered to, since many settlers have

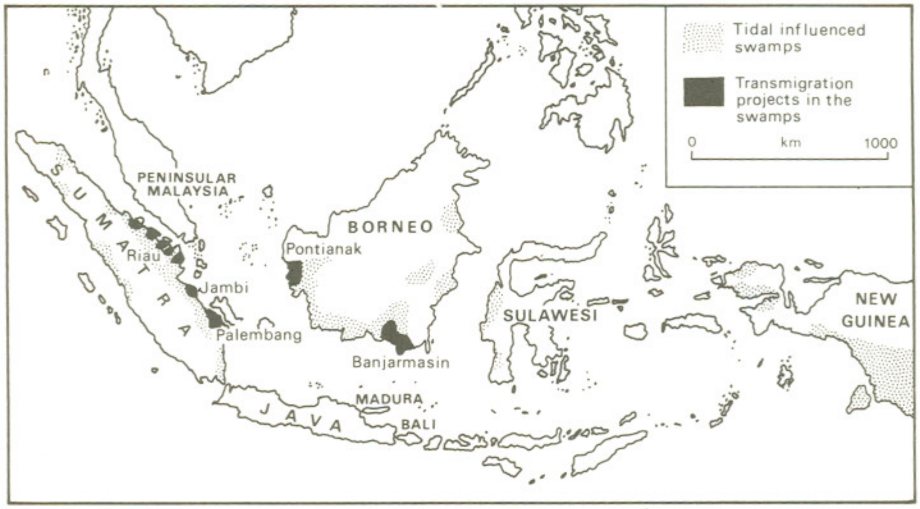

Figure 5.IV.1 Location of official transmigration projects in the tidal wetlands of Indonesia

acquired additional land away from the scheme. Further, since the tidal irrigation system has failed to function as designed, rice production depends almost entirely on rainfall. Hence only a wet-season crop can be taken, and dooryard gardens are almost entirely devoted to rice for household subsistence needs.

With an average of 17.5 quintals/ha (field dry weight), transmigrants obtained higher rice yields in the mid-1970s than either the Buginese (12 quintals/ha) or the local Sumatran population (15.5 quintals/ha) (CNRMES, 1978). This, however, does not indicate the relatively greater success of the transmigration scheme, since both the Buginese and the local population undertake many alternative and complementary economic activities which absorb much of their time and capital, whereas the transmigrants are limited almost exclusively to rice production.

Planners have generally assumed that tidally irrigated rice fields in reclaimed wetlands could be eventually double-cropped. But such optimism is not merited by the evidence. Increasing problems of pest infestation, together with the lessons of the long Buginese and Banjarese experience, make it doubtful whether the agricultural system envisaged for use by transmigrants, based exclusively on irrigated rice, will ever be either ecologically or economically viable. Nor will it permit double-cropping. A further constraint is imposed by water shortages in the dry season, a crop-destroying drought caused by rainfall failure being likely every five years (*ibid.*).

A comparison of local residents, spontaneous migrants and officially sponsored transmigrants cultivating irrigated rice on reclaimed tidal wetland soils in several areas of Sumatra and Kalimantan reveals many of the practical problems involved in the effective reclamation of such areas for agricultural use (Collier, 1980). Compared with rice cultivators on Java, all three groups obtain lower yields per hectare and harvest only one annual crop (as opposed to two on Java), and therefore experience far lower economic rates of return per unit area cultivated. Further, they received (1980) an average monthly income of only Rp12 000 (US$20) from all sources (i.e. rice fields plus complementary activities). This was too low to support a household. By the mid-1980s it is likely that incomes will decline owing to decreasing crop yields and the greater probability of crop loss. Production costs are probably higher in the reclaimed swamp than on Java because of greater weed and pest infestation, and the risk of catastrophic flood or drought is greater than on Java (Hanson and Koesoebiono, 1979).

5.IV.2.2.2 Problems and the Future of Agriculture on Reclaimed Tidal Swamps

An estimated 17–19 million hectares of the Indonesian coastal zone supports lowland peat soils (Pons and Driessen, 1975; Soepraptohardjo and Driessen, 1976). Tidally influenced peat, or tidal swamps, cover about 5 million hectares, mostly as dome-shaped, interfluvial structures, or shallower riparian deposits, approximately 300 000 ha of which have already been developed for rice, coconut and vegetable cultivation by Banjarese or Buginese spontaneous settlers.

Some 5% of the lowland peat soils of Indonesia are chemically rich eutrophic peats that are organically highly productive when managed properly (Pons and Driessen, 1975). Most such peats are already under cultivation (*ibid.*), since for the most part the Banjarese and Buginese have carefully selected them for their spontaneous agricultural settlements. Peat areas that remain available for settlement are mostly the relatively nutrient-poor, interfluvial oligotrophic peats.

The traditional agricultural technology of the Banjarese and Buginese, developed empirically in coastal wetlands over many decades, if not longer, does not appear to be deleterious in eutrophic peat soils; but even the minor perturbations that such technologies can induce in oligotrophic peat cause major and rapid deterioration (Driessen and Suhardjo, 1975). Further, earlier efforts to reclaim oligotrophic peats and areas underlain by potentially acid sulphate soils (estimated to amount to 2 million hectares) in Indonesia (Pons and Driessen, 1975) have a dismal record, several hundred thousand hectares of wasteland having been created as a result (*ibid.*).

As has been demonstrated (Soepraptohardjo and Driessen, 1976), reclamation of infertile tidal swamplands is problematical even where acid sulphate potentials are absent, and such soils remain marginal economically when reclaimed. However, problems can be avoided if soils remain permanently inundated, as under normal swamp forest conditions, and undrained peats can be used to produce sustained yields of sago palms (*Metroxylon* sp.) (Kueh, 1976; Ruddle *et al*., 1978). Rice can also be produced on undrained peats; but results have been disappointing, and poor plant growth and weed infestation need to be overcome by sophisticated and expensive reclamation, drainage and continuous leaching measures (Driessen and Suhardjo, 1975).

In reclaimed tidal swamplands, drainage is the single most important factor required to promote conditions suitable for agriculture. But unless carefully designed, implemented and managed, drainage can lead to high rates of peat subsidence as well as to undesirable and irreversible changes in the reclaimed area. Subsidence in swampland, however, is an inevitable and continuous result of drainage, a consequence that can be controlled but never entirely halted.

Two classes of subsidence have been recognized. 'Initial subsidence', a reorientation and denser packing of peat content (Driessen, 1977), follows the lowering of water tables by drainage and may attain rates in deep peat of 0.6 m a year, as in Sarawak (Tei and Kueh, 1979). 'Continuous subsidence' then follows at lower and more gradual rates: it usually results from the gradual decomposition of peat accelerated by agricultural practices (Driessen, 1977; Chambers, 1979), and at rates determined by them in combination with climatic conditions and biophysical factors inherent in the peat (Driessen, 1977; Chambers, 1979; Tie and Kueh, 1979). Rates of continuous subsistence are generally difficult to estimate, although those of 2–5 cm a year which occur in the Upang Delta Transmigration Project area, in south-eastern Sumatra, would threaten the viability of the project, since little peat would remain by the mid-1980s (Chambers, 1979).

The impact of subsistence on the reclaimed swamp is determined by a combination of factors, the principal of which are such physical elements as shrinkage, settlement and compaction, biochemical oxidation, together with burning and the removal of organic matter during land clearance and subsequent agricultural activities (Driessen, 1977). As a consequence, irreversible changes may occur in the colloidal structure of soils, which affects their capacity to retain water, as well as the degradation of the organic matter into a fine power which is susceptible to accelerated erosion and is of low agricultural value (Tie and Kueh, 1979).

Initial subsidence can be controlled by maintaining water tables as high as crops will tolerate (Driessen, 1977; Tie and Kueh, 1979); hence wet rice is the usual crop planted on peat soils. Reduction of continuous subsistence depends on minimizing the exposure of the reclaimed surface to direct sunlight, usually by cover crops. Rates of peat loss could also be greatly reduced by eliminating burning and by up-grading other agricultural practices.

Lowland tropical peat soils are usually acidic. Typical estimated pH values for those in Indonesia are 3.69–3.55 (Suhardjo and Widjaja-Adhi, 1976). Further, many shallow lowland peat soils are underlain by mineral soils with acid sulphate potential, which on aeration causes acid sulphate conditions and renders them virtually useless for agriculture. In Indonesia many such areas reclaimed by both traditional as well as modern technologies have been abandoned as wastelands (Pons and Driessen, 1975), since once such soils have been formed it is both extremely difficult and often prohibitively expensive to either leach out or neutralize excess acid over many years—an effort that may not be economically justifiable when balanced against the risk of crop failure and low yields from treated lands (Brown, 1972). Even the frequently advocated cultivation of wet rice to reclaim acid sulphate soils is no longer recommended, owing to the difficulties of managing irrigation (Gersie, 1979).

Toxic concentrations of aluminum and iron, together with low nutrient levels, inhibit crop production more than does low pH (Moorman and Pons, 1975). Acid sulphate soils are also phosphate-retentive (Watts, 1969). Management of soils with an acid sulphate potential is directed, via careful management of the water table, either at preventing oxidation and subsequent acid production or at ameliorating conditions by leaching with fresh or brackish water (FAO, 1982). The acidity of shallow peats not underlain by soils with acid sulphate potential can be corrected by the application of lime. Liming must be carefully controlled and requirements are crop-specific (Tie and Kueh, 1979). Moreover, applications that raise the pH values beyond 5.5 have been demonstrated to reduce the availability of trace elements—particularly boron, manganese, phosphorus and zinc (Lucas and Davis, 1961). Draining and ridging for agriculture can result in the formation of acid sulphates. In tropical areas with a pronounced seasonality of rainfall, oxidation can penetrate deep into the soil profile, leading to an annual regeneration of acid sulphates. But depending on the acid sulphate potential as well as on climatic, hydrological and other factors, such acid-tolerant dryland crops as oil palm, coffee, pineapple, cassava and coconuts can be grown successfully on wetland soils reclaimed by draining and ridging, if water tables are carefully managed to prevent acids and salts from reaching root-zone level.

Peats deeper than 2 m in the tropical coastal zone are generally so lacking in nutrients and so difficult to manage that the capital investment required to reclaim them for agriculture is not economically sound (Pons and Driessen, 1975). Since chemical fertilizers are expensive, the surface peat is commonly burned to liberate plant nutrients (Satari, 1979), to raise pH values (Coulter, 1957), to reduce pests and diseases, or to destroy toxic compounds. Opinions vary on the value of this practice. Certainly it is deleterious on shallower peats, where there exists a danger of exposing the underlying soils with an acid sulphate potential.

Any major landscape transformation resulting from radical alteration of biotic and physical assemblages consequent on a change in water–land interactive relationships through wetland reclamation opens broad new niches for a wide variety of organisms. Once wetland soils are drained and chemically treated, for example, conditions for micro-organisms—some beneficial and others not—are enhanced (Tie and Kueh, 1979). Similarly, weeds (especially *Scirpus* sp.) in rice fields, as well as mammalian and insect pests, can reduce crop yields by competition and consumption, or destruction, respectively (Hanson and Koesoebiono, 1979). Further, the alteration of the tidal wetland habitat also creates new niches for the vectors of malaria and other arthopod-borne diseases in humans, since one general aspect of the ecology of human diseases is that their vectors are to be found in man-made or man-modified environments (Ruddle and Manshard, 1981). The large-scale clearance of mangroves, for example, in many parts of the Asian tropics creates conditions suitable to the breeding of malaria vectors (Kunstadter, 1978a). On the other hand, malaria vectors are not endemic in south-east Asian mangroves that are relatively undisturbed or where clearings are small or temporary (Kunstadter, 1978b).

5.IV.2.2.3 Evaluation of Peat Soils for Development

Although the methodology for assessing the biophysical and biochemical capabilities of organic soils in the tropical coast zone is now fairly well established (Soepraptohardjo and Robinson, 1975; Soepraptohardjo and Driessen, 1976; Maas *et al.*, 1979)—but not always applied too rigorously in feasibility studies—as is that on farming systems and management requirements, among other of the more important techno-economic considerations, little attempt has been made to assess the sustained investment, capital or manpower requirements needed to maintain agricultural output from reclaimed peat soils. One such attempt, from Sarawak, questions the wisdom of reclaiming tidal swamps by suggesting that the enormous investment costs that underwrite environmentally deleterious methods of reclamation, coupled with the inherent limitations of former swampland soils, are at best difficult to justify economically (Tie and Kueh, 1979).

But such an argument presupposes that the principal reason for developing such lands is to increase national levels of agricultural production. That is not necessarily the case. In Indonesia, for example, the reclamation of tidal wetlands seek to fulfil diverse political objectives, of which increased agricultural production is but one, and not necessarily the most important one at that.

Development plans for both the Central Islands (Java, Bali and Madura) and the Outer Islands have always been linked by the paired concepts of transmigration and irrigated rice production. Yet, ironically, even were it feasible to develop the full extent of Sumatra's tidal wetlands alone by transmigration—some 4 million hectares—the population problem on Java would be far from solved. Further, it is being increasingly demonstrated that tidally irrigated rice production is not suitable for the areas being reclaimed.

Planning for the swampland transmigration schemes in Indonesia is relatively simple in that the only crop envisaged is irrigated rice. But this is flawed since the areas are unsuited to sustained rice mono-culture, as the long experience of the Banjarese and Buginese reveals. Rice production is constrained by several major inherent biophysical problems, among which are edaphic characteristics, flood frequency and height, saltwater intrusion, and drought. Further, planning is complicated by the long-established communities of other ethnic groups in the areas designated for reclamation. These original southern Sumatran inhabitants, together with spontaneous migrants, exploit diverse and complementary resources that are protected and managed by traditional systems of customary rights and administration. The result has been a complex and confusing multiple and uncoordinated allocation of the same resources to different groups and for different purposes.

In conclusion, it is clear that sustaining the agricultural productivity of reclaimed organic soils of former tidal wetlands continues to be problematical, even for the better-adapted traditional practices of the Banjarese and Buginese. The relative success of spontaneous migrants from these two ethnic groups probably derives from their careful selection for reclamation of the shallower and richer peats, as does that of the relatively more successful transmigration schemes.

Monitoring of progress on the wetland transmigration project in south-eastern Sumatra reveals a generally decreasing trend in soil fertility, increasing peat management problems and decreasing rice yields from the reclaimed land. Further, rice production via double-cropping is now unlikely owing to a lack of water in the dry season. On the contrary, outright failure of the rice crop is seen as a distinct possibility, owing to rainfall fluctuations (CNRMES, 1978).

At least in its tidal wetland component, the Indonesian transmigration scheme must necessarily be viewed as an expensive experiment, and lamentably one undertaken in advance of an adequate knowledge of the long-term ecological, economic and social costs. Further, the opportunity costs of equal investment foregone in alternative locations has never been properly considered.

5.IV.3 AGRICULTURAL TRANSFORMATION OF WETLANDS BY LARGE-SCALE INTEGRATED FARMING SYSTEMS

5.IV.3.1 The Zhujiang Delta, People's Republic of China

The transformation of tidal and other wetlands through the application of integrated agro-ecosystems, such as the joint operation of agriculture and aquaculture, is an ancient, widespread and enduring practice in south-east Asia. Systems are based on livestock, fowl and fish husbandry in combination with a range of seasonally rotated crops. Small numbers of pigs and ducks, together with fish, provide the household with animal protein and often a small cash income; while aquatic macrophytes, crop residues and kitchen leftovers feed the livestock, the manure of which, together with systematically collected human excrement (at least in the Chinese case), fertilizes the fishpond and eventually the cultivated field. Such diversified and integrated systems have sustained small-scale farm households for centuries. In the more sophisticated variants of such systems nutrients and energy are cycled continuously, little waste results, and an ecological balance is preserved. Whereas many if not most such farming systems are small and usually oriented towards family subsistence, that in the Zhujiang (Pearl River) Delta of southern China is an old-established and highly elaborate integrated system of intensive agriculture combined with poly-culture of carps and other freshwater fish. It

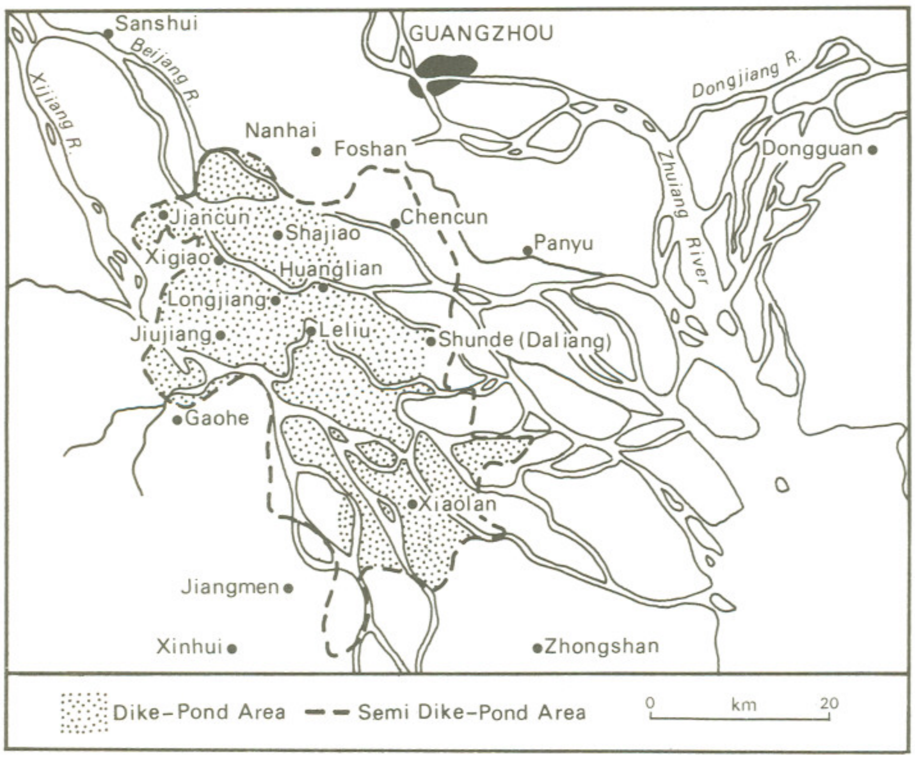

Figure 5.IV.2 Location of the dike–pond area in the Zhujiang Delta (Ruddle *et al.*, 1983)

has evolved over the past two millenia. There, integrated agriculture is operated on a geographical and economic scale unmatched elsewhere in the world (Ruddle *et al.*, 1983).

The Zhujiang Delta, a densely populated region of some 12 000 km^2 focusing on the city of Guangzhou (Canton), is the economic and cultural core of south-east China. This delta has been built-up by several large rivers that converge in the region, principally the Zhujiang, Xijiang and the Beijiang (Figure 5.IV.2). Soils have developed from the recent alluvium of former tidal wetlands and are rich in organic matter and only slightly porous. Those in the central delta, for example, were primarily paddy soils with some tracts of meadow-boggy soils; but after centuries of intense cultivation and irrigation under a dike-pond system distinctive classes of silty soils have emerged. The climate is warm, temperate and rainy (Köppen *Cfa*) and is affected by the monsoonal circulation. It is characterized by an annual mean temperature at Shunde, in the central delta, of 22°C and an average annual range of 15°C, with mean temperatures in the warmest months of 28.7°C (July) and 28.4°C (August), and in the coldest months of 13.0°C (January) and 14.7°C (February).

Southern China is subject to damaging climatic hazards, principally Spring drought and monsoon and typhoon flooding (Luo *et al.*, 1980). Since 1949, however, their impact has been increasingly controlled by major infrastructural projects (Ruddle *et al.*, 1983).

5.IV.3.2 Evolution of the Zhujiang Dike–Pond System

About 1000 years BP, when the coastline in the Zhujiang Delta met the Xijiang, some 60–80 km inland of its present position (Li, 1657), the swampy coastal lowlands supported little agriculture, owing to continual flooding and acid sulphate conditions. Village economies were based mostly on the capture and collection of marine and estuarine resources. At higher elevations, however, fruit cultivation, especially of litchi (*Litchi chinensis*) and longan (*Euphoria longana*), had developed rapidly since its beginning during the Han Dynasty, some 2000 BP.

During the mid-fourteenth century water control began in the wetlands around Jiujiang, when smaller watercourses were dammed and diked to make fish ponds. Ponds were dug to create agricultural land and the excavated soil used to construct dikes. These early artificial ponds were devoted mainly to commerical fry rearing. As a consequence of the region's long experience with fruit cultivation, together with the large market demand throughout China, the first commercial crops grown on the dikes were fruits, particularly litchi and longan. Fruit cultivation may also partly have been a response to declining local water tables caused by the rapid seaward progradation of the delta, and which, when added to the impossibility of retaining water on the dikes, ruled out rice growing. At that time, however, there was apparently little or no conscious organization of an integrated fruit dike–fish pond system via linked flows of materials and energy, although both activities might have been undertaken on the same farm unit.

Mulberry cultivation, silkworm breeding and silk spinning have a history of about 2000 years in the Zhujiang Delta, and were initiated to produce goods for home consumption or to pay taxes. But by the seventh century AD a substantial industry had developed to satisfy the trade that developed rapidly when Guangzhou was opened to international commerce, 1200 years ago. Mulberry growing and silkworm rearing remained separated both geographically and conceptually from fish cultivation, since even by the thirteenth century few dikes were planted to mulberry. By the 1620s, however, mulberry was being widely cultivated on the dikes between the fish ponds, experience having shown that the economic returns from integrated mulberry dike–fish pond systems were greater than those obtained from cultivating fruit. Moreover, pond mud enriched with silkworm excrement and other wastes that had first been utilized to fertilize the pond and feed the fish, was found to be a superior fertilizer for the mulberry bushes than was the raw silkworm excrement applied hitherto, and which when applied to excess damaged the mulberry leaves. With this discovery an integrated dike–pond system that was found to be beneficial to both mulberry and fish, and far better than growing rice, quickly evolved (Zou, 1894). Thus by the 1650s farmers in the area around Jiujiang and Xiqiao began to replace old fruit trees with mulberry and hemp over some 70–80% of the dike area (Li, 1657). This process continued until around 1800, by which time most parts of Shunde County were devoted exclusively to the integrated dike–pond system.

Added impetus to the widespread adoption of this system occurred in the 1750s, when the Qing government closed all ports except Guangzhou to foreign trade, and at the same time limited the export of Hu (Taihu) silk. Thus the demand for Yue (Guangdong) silk increased abruptly and prices soared. Conversion of paddy fields to dike–pond systems continued apace and was extended beyond the areas of tidally influenced wetlands, the transformation to productive use of which was the main objective of the system.

A further boost to silk production occurred after the mechanization of the reeling process, in 1866. With the opening of the first local modern filature the integration of mulberry and fish entered a new phase. Not uncommonly, rice cultivation was abandoned as an increasingly larger area was converted to ponds and dikes. Shunde County, which now accounts for 75% of the Delta's silk production and has the most fish ponds, had converted 6700 ha of paddy fields into integrated mulberry dike–fish ponds farms by the end of the nineteenth century. By the end of the Qing Dynasty (1911) the Zhujiang Delta had some 66 700 ha devoted to this kind of agro-ecosystem; and by 1925, the apogee of Guangdong silk production, 93 000 ha of dikes was planted to mulberry.

Sugar cane has been cultivated in the Zhujiang Delta for about 2000 years, mostly on the higher and drier slopes of the uplands, and since the twelfth century Panyu County has been one of China's important sugar-growing areas. But a relatively poor quality product, with fluctuating yields, Guangdong sugar was grown mostly to satisfy local demand, and the industry was slow to develop. During the 'Great Depression' silk prices fell dramatically, large areas of mulberry dike were left uncultivated, and about one million silk workers were jobless. Seeking a profitable replacement for mulberry, entrepreneurs introduced improved varieties of sugar cane from south-east Asia, and converted abandoned mulberry dikes to sugar-cane growing. When the region's first sugar refinery was established in Shunde County in 1936, the focus of Guangdong sugar cultivation shifted from the uplands to the dike–pond region. Other former mulberry dikes were planted to mixed vegetables or rice, and yet others remained derelict.

Under the Japanese wartime occupation (1938–1945) local silk prices declined precipitously. During that period, too, rice prices increased dramatically, and because little food grain was cultivated in the Zhujiang Delta rice had to be imported from elsewhere in China or from abroad. Unable to purchase expensive rice with the now meagre earnings from their silk, farmers rapidly abandoned the dike–pond system to cultivate rice and other foodstuffs.

Although excavation of fish ponds and dike construction was historically considered to be the best way of transforming formerly marginal and natural hazard-prone wetlands into a productive agricultural region, until 1949 cropping patterns on the dikes were dictated by market prices rather than by the ecological considerations that are the essence of traditional integrated farming systems. But since 1949, although market demand in the guise of fixed production quotas has remained an undeniable force in determining patterns of resource use in the dike–pond region, integrated resource use based on fundamental ecological principles has evolved hand-in-hand with the exigencies of economic dictates. As a consequence, the components and processes of the dike–pond system have become progressively more tightly integrated in terms of complementary inputs and outputs; the system has become more elaborate in terms of the crops and animals raised and in the spatial and temporal patterns of inter-cropping, inter-planting and rotation; and overall system productivity has been raised and energy losses as a result of waste or by-products or niches not exploited, minimized. However, further refinements and improvements that demand a more rigid linking of the various components of the system are still forthcoming.

5.IV.3.2.1 The Fish Pond (Figure 5.IV.3)

Much of the success of freshwater aquaculture in south-east Asia results from the poly-culture of several different yet compatible species in the same body

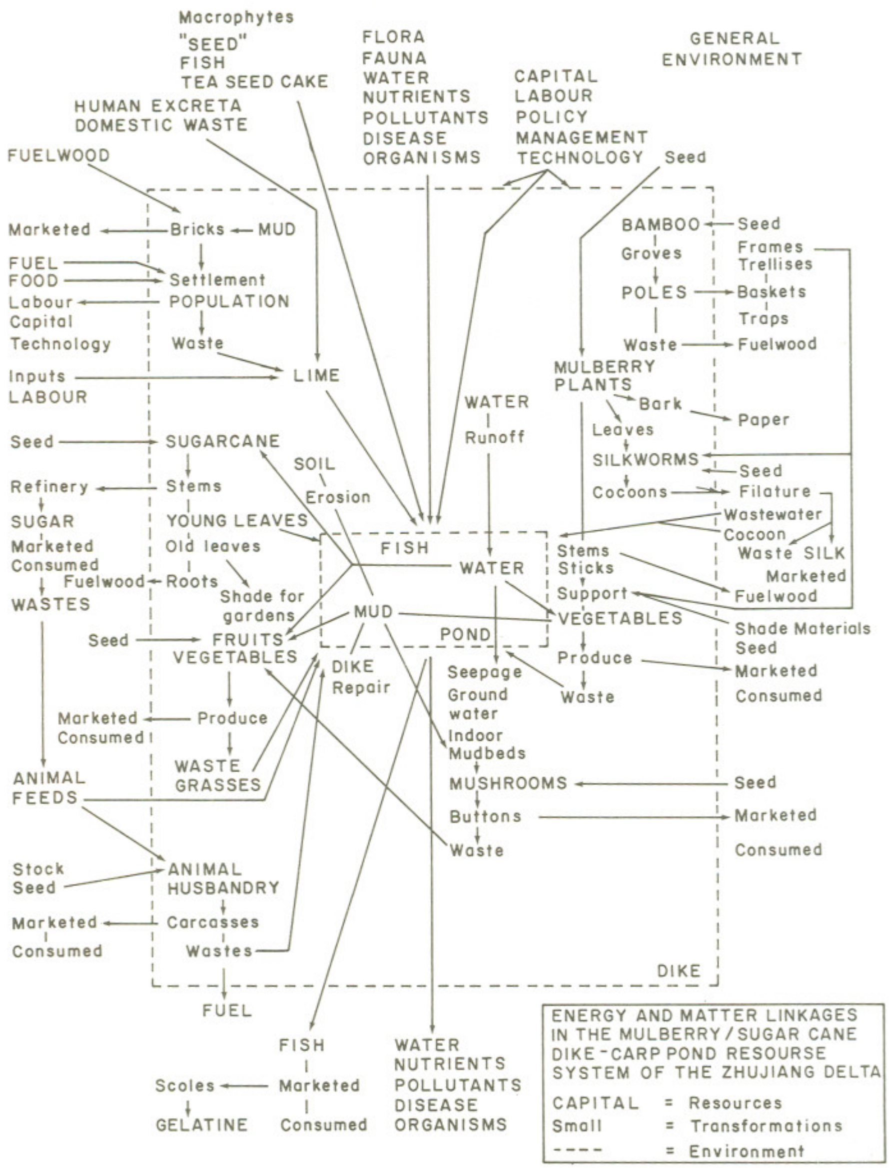

Figure 5.IV.3 Energy and matter linkages in the dike–pond system of the Zhujiang Delta (Ruddle *et al.*, 1983)

of water. This is the most efficient technique for using a limited pond area since the complementarities among the species, particularly in feeding habits, permit the harmonious exploitation of available ecological niches and the optimum use of the foods available at the various trophic levels of the complex aquatic food chain.

All fish ponds in Shunde County are devoted basically to carp culture: the Grass carp (*Ctenopharyngodon idellus*), the Silver carp (*Hypophthalmichthys molitrix*), the Bighead carp (*Aristichthys nobilis*), the Black or Snail carp (*Mylopharyngodon piceus*), the Mud carp (*Cirrhinus moitorella*), and the Common carp (*Cyprinus carpio*). Each species has distinct feeding habits and each occupies a different level within the pond.

Most production ponds in Shunde County are rectangular or square in shape, thereby permitting more efficient natural or mechanical aeration of the water and facilitating mechanization of pond operations. Ponds range in size from 0.2 ha to about 0.5 ha, although the majority are less than 0.5 ha. An area of 0.26–0.33 ha is regarded as ideal, but in zones of porous soils production ponds of 0.66 ha are not uncommon. Ponds are preferrably aligned east–west to maximize the available hours of sunshine, and with a length to width ratio of 6:4 to minimize dike erosion by wave action and to optimize fish and crop production. Apart from public sewage ponds used to collect the communities' faecal matter and urine, ponds are not constructed in the lee of tall buildings or trees, thus minimizing the interception of solar radiation and wind.

Pond water depths range from 2 to 3 m, with a preferred depth of 2.5–3 m. If the water is too shallow strata are not deep enough to optimize poly-culture or to rear large numbers of fish, and over-heating and eutrophication problems can also arise. Conversely, when the water is too deep temperatures and light in the bottom layers are low, bottom waters may become de-oxygenated, and plankton production reduced.

In the Zhujiang Delta the main fish species raised is the Grass carp, combined as environmental conditions and the availability of inputs permit with Bighead, Silver, Black, Mud and Common carp, and sometimes with Bream and Tilapia. Fish cultivation continues to be based on the traditional mixed-age or mixed-size poly-culture, the larger fish being selectively harvested in quantity every 3–4 months, with three or four, and in some places five or six, harvests each year. During the rearing period the pond is selectively restocked with younger individuals; thus in any given pond there are fish at various stages of growth. Although densities and species composition vary within the region, stocking rates of 15 000 per hectare are not uncommon.

Because stocking densities are high, extremely heavy fertilization of ponds and feeding of fish is practised; but since the system is so tightly integrated this presents few if any logistical problems. Only organic fertilizers are applied to both ponds and crops. Of these the most important is pig manure, applied at rates up to 230 t/ha per year. Commonly, pigsties (as well as latrines for humans) are built adjacent to the pond, on the dike, so that manure enters the pond directly. When available, chicken manure is used as fertilizer, at a rate of 15 t/ha per year. 'Fertilized water', which consists of 77% residues of soybean curd and 23% of other fermented wastes from the local food-processing factories, is applied to ponds at a rate of 200 kg per 1 kg of Silver carp per year. Additional pond fertilization is provided by the decomposition of fish excrement and fish food remains.

Fish are fed with organic materials produced on the associated dikes, in some cases after these products have been processed in local factories. Fish do not normally receive high-protein supplements of animal origin. Grass carp is the principal species raised and is fed mainly with grasses, sugar-cane husks, leafy vegetables and aquatic macrophytes grown on the dykes or in proximate water bodies. In general, such rough plant material constitutes 99.6% of fish feed, the balance being fine food consisting of various bean-cake residues and rice bran. The natural fertility of the pond water, enhanced by manuring, promotes the growth of plankton, the principal food of Bighead and Silver carp. Common and Mud carp are detritus feeders, whereas the Black carp feeds on snails. On this basis it has been determined empirically that the crops from 1 ha of dike can provide the feed for fish in the same area of associated ponds.

The principal environmental problems of concern to Shunde fish farmers occur in the pond micro-environment as a result of the extremely high organic loading of the water. Pond fertilization and fish feeding are therefore carefully controlled and water quality strictly monitored, especially to assess the dissolved oxygen content in the hours just prior to sunrise. This is particularly critical in these ponds since they are relatively deep by usual standards. Dissolved oxygen levels are monitored by observing fish behaviour. Optimum levels for ponds in this region are 5 mg/litre; when they decline to 1 mg/litre fish start to surface, and when they fall below 0.2 mg/litre large-scale fish mortality results (Zhong *et al.*, 1965). Serious oxygen depletion is indicated when the bottom-dwelling species come to the surface—a rare occurrence in this region, where good management is the norm.

5.IV.3.2.2 The Crop Dike

Since the single most important commodity produced by the dike–pond system is fish, crop patterns on the dikes are geared basically to the feed requirements of the fish and the fertilizer needs of the ponds. The relative emphasis placed on mulberry and sugar cane, the main commerical crops cultivated on the dikes, is also a response to both domestic and international market demands for silk and sugar. Balancing market demand and pond input requirements, and thus deciding on the main dike crop, results in a fluctuating ratio of the different crops.

Four principal types of dike are recognized: mulberry dikes, sugar-cane dikes, fruit dikes and miscellaneous-crop dikes. Compared with those in other regions of integrated farming systems, dikes in the Zhujiang Delta are exceptionally large and varied, both in morphology and function. For the integrated system practised in this region, level-top dikes 6–10 m in width and 0.5–0.7 m in height above the pond surface are considered ideal. Dikes range in width from 6 to 20 m. Cultivation on narrow dikes is inefficient, whereas on the widest it is difficult to provide enough pond mud as fertilizer. Medium-height dikes, 0.5–0.7 m above the pond surface, absorb enough water from the pond to maintain a soil–water content ideal for most crops cultivated. Low dikes—those less than 0.5 m above the pond surface—suffer from waterlogging in the root-zone and are flood-prone in the wet season, whereas dikes higher than 10 m are incapable of absorbing enough pond water.

In the Zhujiang Delta year-round cultivation on the dikes and in the associated waterways presents a complex picture of seasonal and biennial rotation and of inter-cropping. There is no agricultural slack season and the dikes are under continuous cultivation. Cropping is closely connected with the husbandry of mammals, fish and silkworms. The principal commerical crops cultivated are mulberry (*Morus atropurpurea*), sugar cane (*Saccharum officinarum*), various fruits (especially litchi and longan, together with bananas and plantains [*Musa* spp.]) and a wide range of other plants for domestic use, fish feed and for marketing.

In the Zhujiang Delta, 9400 ha of dike is devoted to the cultivation of mulberry, the leaves of which are fed to silkworms (*Bombyx mori*). Mulberry leaves are harvested eight or nine times a year, between March and late-November. In this region 1 ha of dike yields an annual average of 22 500–30 000 kg of leaves, which results in a yield of 1875–2250 kg of silkworm cocoons. Shunde accounts for 90% of the cocoons produced by Guangdong Province (unpublished statistics).

Climatically this region is well-suited to both mulberry cultivation and silkworm rearing. Mulberry grows best at temperatures of 25–30°C, whereas its growth is hindered below 12°C and it cannot survive drought at temperatures greater than 30°C. Thus in this area the mulberry shrubs are pruned in late-November and the dike inter-cropped with various winter vegetables until February of the next year. Rainfall is sufficient for mulberry growth, and without irrigation dikes of medium height absorb enough pond water to maintain adequate moisture at an average depth of 35 cm, the root-zone of the mulberry plant. In drought periods dikes can be irrigated easily from the adjacent ponds.

Temperatures and humidity are important factors in sericulture. Silkworms grow only at temperatures between 15 and 32°C and die in drought periods at temperatures above 40°C. They require a relative humidity of 70–80% for optimal growth. Except in winter, when dry Mongolian air occasionally intrudes, relative humidity in the Zhujiang Delta is always high. From May to September high temperatures and high relative humidity are detrimental to silkworm growth but are mitigated by using bamboo frames constructed for the silkworms in the rearing sheds.

In the Zhujiang Delta mulberry shrubs are pruned after the last harvest of leaves and the dikes are inter-planted with an assortment of vegetable crops. This has the additional advantage of improving mulberry yields. To reduce plant diseases and insect pests the dike is planted alternately with mulberry and sugar cane, which also has been demonstrated locally to increase the yields of both crops as well as to improve soil quality.

With 15 300 ha of dike under sugar cane and an average yield of 75 t/ha, the delta produces 12.5% of Guangdong's sugar and is one of China's leading sugar-producing regions. Sugar cane is well-adapted to annual temperature and rainfall regimes in the region: its greatest water demand occurs in the period June–September, coinciding with the months of highest precipitation, and the second period of high water demand occurs in January–April, when again there is enough water. Mean monthly temperatures normally satisfy the requirements of sugar cane, the growth of which is retarded below 20°C and which stops altogether below 10°C. Frost damage is rare in the Zhujiang Delta. Dikes are planted to sugar in the Autumn and the crop requires 16 months to reach maturity.

In early-Spring, before the mulberrys come into leaf, mulberry dikes are inter-planted with soy-bean (*Glycine max*), mung-bean (*Phaseolus aureus*), taro (*Colocasia antiquorum*), peanut (*Arachis hypogea*), and other vegetable crops, which are harvested in the period May–June. Along the dike edge, bananas, plantains and fruits are cultivated. In Summer and Autumn, at the very edge of the dike, melons and gourds are trained on trellises that hang over the pond, thereby shading the water and preventing excessively high temperatures from endangering the fish. Each November, after the last mulberry leaf harvest, dikes are inter-planted with Chinese cabbage (*Brassica pekinensis*), cabbage (*B. oleracea*), leaf mustard (*B. juncea*), carrot (*Daucus carota*) and radish (*Raphanus sativus*), which provide two harvests, the last being in February. For feeding fish, Elephant grass (*Pennisetum purpureum*), maize (*Zea mays*), sorghum (*Sorghum sp.*) and sweet potato (*Ipomoea batatas*) are planted on all available spare land, including dike slopes, road-sides and along watercourses. To feed fish and pigs aquatic macrophytes such as water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichhornia crassipes*) are cultivated in canals, rivulets and associated water bodies.

The mulberry dike–carp pond represents a highly intensive, integrated system of agriculture and aquaculture in which many outputs of sub-systems constitute inputs for other sub-systems. In this way not only is the medium for the growth of fish and crops provided, but so too is the environment from which their food and fertilizer requirement can be met. The system thus yields for all commodities produced a wider range of products per unit area of land and water than could otherwise be obtained, and lower costs for inputs, which, in the absence of integration, would be imported from outside the system, usually at considerable expense in terms of capital, time and labour. In conventional, semi-intensive aquaculture, for example, under systems not integrated with either animal husbandry or crop production, supplementary feed usually accounts for 50% of the total farm operating budget (Schroeder, 1979) and pond fertilizers and other inputs for the field crop comprise a large item of the budget of a non-integrated farm. In addition to the economic benefits afforded by integrated systems, integration is also beneficial to the environment in that it solves the problems of organic waste disposal in a sanitary manner and obviates *in situ* toxicity and downstream residue problems that arise from the incorrect use of organic fertilizers. In the dike–pond system of the Zhujiang Delta, integration exists exogenously among the pond, dike and general environment (*vide supra*) and endogenously within each of these elements.

Systems such as that of the Zhujiang Delta exhibit many obvious advantages over those that lack integration. Principal among them is that the pond fertilizers and fish needs are produced locally and at low cost, thereby almost eliminating the uncertainties of supply and greatly reducing the costs commonly associated with the use of compounded feeds and inorganic fertilizers. Hence profits from the cultivation of fish are increased by as much as 30–40% in the People's Republic of China (FAO, 1979). By using pond mud as a fertilizer for the crops, soil fertility and crop yields are raised without the expense of inorganic fertilizers. In national terms these savings are considerable when it is realized that an estimated 30% of all agricultural fertilizers used in the PRC are derived from fish ponds (*ibid.*); and, as a consequence of integration, the human consumer is assured a regular and balanced diet as well as a high degree of self-reliance in a wide range of foodstuffs and raw materials.

The different types of agricultural activity involved in complex integrated agro-ecosystems call for a diverse range of skills; and, on the scale practised in the Zhujiang Delta, also requires a large, well-organized labour force. Moreover, integrated systems of such complexity can only be operated on a large scale. Under such systems the economic returns from any one component are not viewed as important. Instead, maximizing the return from the whole system is the objective.

Thus the dike–pond system is ideally suited to the densely populated Zhujiang Delta and to the social and political organization of the PRC. Further, in biological and physical terms the region is well-suited to the assemblage of animals and crops that together form the mulberry dike–carp pond system.

This two millenia-old, ecologically sound system of reclaiming tidal wetlands and transforming them to a flourishing agricultural landscape continues to operate in southern China, with the reclamation of tidal wetlands along the seaward margin of the rapidly prograding Zhujiang Delta. This is a continuous process and is implemented using a field–pond variant of the dike–pond system used in the upper and central deltas. Unlike the dike–pond system, where the ratio of ponds to dikes is 6:4 or 5:5, the field-pond system is dominated by larger fields (replacing the ponds) and relatively few fish ponds, the ratio being 9:1 or 8:2.

In Doumen County, on the seaward edge of the Zhujiang Delta, 50% of the cultivated area is composed of low-lying fields with an average elevation of 0.2–0.7 m above sea-level. It is usually inundated during the rainy and typhoon seasons as well as being subject to salinization during the Winter-season high tides. Such fields are planted with rice and sugar cane, but yields have always been poor. Since 1974 some low-lying fields have been excavated to a depth of 2.5–3 m for use as fish ponds, and the soil removed used to elevate surrounding fields. In addition to providing soil to build up fields, the pond also serves as a drainage basin to lower field water tables. As a consequence, crop yields have risen dramatically and an integrated system of farming has begun to emerge there too (Zhong *et al*., 1982). Gradually the landscape of the inner areas of the delta edge is coming to resemble that of the longer-developed central delta, as an increasingly larger area is converted into fish ponds and the field–pond system evolves slowly but surely toward the dike–pond system.

5.IV.4 THE FUTURE OF WETLAND AGRICULTURAL TRANSFORMATION

To many planners the vast wetlands that dominate large tracts of the coastal zones of many developing nations in the humid tropics represent wastelands that when reclaimed with the appropriate combination of technological inputs supported by a large investment of capital will become a cornucopia of agricultural products, principally rice. This attitude persists despite the failure of many such ambitious reclamation and development schemes to attain planned levels of productivity. Such partial or outright failures, which are not uncommon, do not demonstrate the inherent impossibility of effecting modern transformations in tropical wetlands—rather they highlight the folly of incomplete planning and hurried project design predicated on a narrow knowledge base. They also demonstrate a total failure to evaluate pre-existing and perhaps, in the Western scheme of things, unconventional resource systems that have attained acceptable levels of agricultural productivity and that with careful consideration and planning could be transformed to a modern purpose.

Tropical wetlands are rich in an enormous range of renewable natural resources and their seemingly easily irrigable and largely level surfaces appear to offer ideal locations for extensive rice fields. This belies the potential fragility of such wetlands, the resource base of which can so easily be destroyed by ill-conceived and improperly implemented land transformation schemes.

Given that inherent fragility of wetlands combined with the scanty and uneven state of scientific knowledge regarding the types of transformations to which they should be subjected, large-scale schemes that call for radical environmental alteration are best deferred until such time as planning can be far better informed.

With that in mind, developing nations would be far better advised to consider schemes to rehabilitate for agricultural and other primary production degraded watersheds (such as those reduced to an *Imperata* cover by maladaptive shifting cultivation), as well as seeking ways of extracting higher yields from lands already under cultivation. The failure to consider the opportunity costs of investment in wetland development while not doing so in other areas undoubtedly represents a major squandering of precious development capital.

The focus of large-scale development schemes on the mono-culture of rice is a mistake. The dominant natural characteristic of wetland ecosystems is the all-pervasive and intimate interaction of terrestrial and aquatic components. Almost without exception this characteristic has been reflected in time-honoured resource systems traditionally used by wetland populations, and that yield on a sustained basis a wide range of complementary crops together with harvests of naturally occurring plants and animals. Mono-cultural systems introduced to wetlands are likely to eventually prove maladaptive, whereas properly designed, integrated poly-cultural systems of agriculture–aquaculture–livestock are likely to produce long-term sustained yields.

By definition coastal wetlands are the recipients of the entire up-stream discharge of linked hydrological basins. All too frequently the fundamental implications of this linkage are not considered when wetland development is being planned. The agricultural transformation is planned out of its total context without reference to up-stream uses of resources that can (and invariably do) have deleterious impacts on down-stream resource systems.

The integration of aquaculture and agriculture is an ancient, widespread and enduring practice in south and south-east Asia. Nevertheless, the structure, functions and management of such systems have been little appreciated outside those regions until relatively recently. Almost without exception such traditional and sophisticated resource systems have been overlooked by development planners, perhaps because they have been regarded as small-scale subsistence operations ill-suited to fulfilling the urgent food and raw-material needs of developing nations. As a consequence, few data are available to refute this reasoning, virtually nothing is known of the techniques and technologies used, and data on levels of productivity and farm economy are seriously deficient, if available at all.

Traditional Asian systems of aquaculture and agriculture, particularly those in the People's Republic of China, where such systems have been best developed and applied on the widest geographic and economic scale, have recently aroused major interest among Western scientists and development planners. While this trend is to be applauded, a note of caution is in order. Most integrated farming systems remain in large measure based upon the empirical wisdom of many generations of local farmers. Although Chinese scientists, such as those engaged in the artificial propagation of carps, have recently brought a more analytical approach to bear upon the subject, for the most part the scientific bases for system integration remain to be properly ascertained. This, in turn, has led to the acceptance as proven of many assumptions about integrated systems, a dangerous situation since much basic work remains to be done before integrated resource systems can be transferred with a reasonable assurance of success to other parts of the developing world. Further, virtually all attempts to improve the scientific understanding of traditional integrated systems have concentrated on extremely detailed micro-studies of various biological, physical, technological and economic aspects—such as the nature of the animal waste linkage between livestock and fish from the perspective of fertilizing the pond and feeding the fish—particularly as they concern poly-cultural pond systems. There has been little attempt to relate these detailed studies to the larger-scale relationships such as those between the pond and the dike, or those between the pond–dike system and the general environment within which the integrated resource system functions.

The constraints inhibiting a fuller scientific understanding of integrated systems—and thus their improvement, development and wider dissemination—lie as much in the social as in the natural sciences. The major factors that affect the performance of integrated systems—energy, materials, spatio-temporal considerations and information diversity—are not, as a whole, well-known, and the socio-economic aspects of such systems, which are complex and little understood, are in particularly urgent need of analysis.

The relatively small-scale Banjarese system that has permitted successful transformation of some Indonesian wetlands, together with the large-scale dike–pond system of the Zhujiang Delta of the PRC, when contrasted with the relatively disappointing results of Indonesian wetland transmigration projects, clearly shows the value of both a slower and incremental approach to wetland transformation, as opposed to a rapid and radical change, and the importance of the alternative models exemplified by these non-Western systems. The empirical wisdom—which, granted, in every situation may not be particularly wise—that underpins such systems is of itself a valuable resource that should be distilled and applied to modern techniques and technologies to effect wetland transformation. It has the intrinsic merit of tempering a rampant 'can-doism'. This is not to advocate a species of nativism but rather to suggest an alternative, low-cost path to obtaining the required information to plan adequately for wetland transformation, since it is starkly apparent that budgets will never be sufficient to permit totally comprehensive and fully satisfying scientific pre-development studies of the complex ecosystems that comprise tropical coastal wetlands. And lack of information suitable for planning is probably the largest single constraint on wetland development.

Since successful adaptive strategies in tropical wetlands have largely been based on non-Western concepts, the development of such areas should be based in large part on the adaptation of such systems for larger-scale application and transfer to other regions. The first priority, then, is for information on which to plan for system transformation. This requires sound data on the traditional system to be adapted and its compatibility with proposed innovations. This should be assembled in terms of energy and materials flow, the optimum use of farm (or other minimal unit) space, the temporal synchronization of the various integrated farm activities, information diversity (particularly in management and socio-cultural inputs) and linkages with other off-farm resource systems. Since a wide range of adaptations to wetlands exists throughout the tropics, a large number of crop and animal species should be tested for use in integrated farming systems. Basic research is required on crop (including livestock and fish) biology, seed supply, stocking and planting rates and densities, particularly for candidate species that are hardy and tolerant of the extreme seasonal changes that characterize wetland environments. Research is also urgently required to overcome the principal constraints on integrated systems in wetlands. Of the utmost importance is that on land preparation and soil capabilities, crop requirements, fertilization rates, pest and disease management, weed control and the provision of an adequate and regular water supply. Finally, basic economic research through the cost–benefit analysis of a range of existing systems and proposed introductions and changes is a *sine qua non* for the successful transformation of tropical wetlands.

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