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Chapter 4

# The Dyke-Pond Systems in South China: Past, Present and Future

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**Abstract.** In 1990 inland aquaculture accounted for about two-thirds of total aquaculture production in the world, of which about three-fourths came from pond culture in China. This chapter is an attempt to review the past, present and future of the dyke-pond system widely adopted in the southern part of China. There has been a long-term tradition of using organic wastes in inland aquaculture in most of the Asian countries, and some East European Countries such as Hungry. Manure served as pond fertilizer to enrich nutrients in the pond water, which facilitate algal growth. Fungal growth on manure particles is also enhanced. These organisms will in turn serve as food for different fish species with different feeding modes, and, therefore, all the substances derived from the manure could be fully utilized. However, the recent rapid socio-economic changes in the region have resulted in the discharge of a large volume of domestic and industrial effluent which is untreated. Single species of high priced fish (monoculture) is cultivated using high protein grains instead of polyculture using manure as the major energy input.

In addition, chemical fertilizer has been replaced by the use of animal manure. Other chemicals used in aquaculture operations including sediment and water treatment compounds, pesticides, disinfectants, antibiotics, vaccines, immunostimulants, vitamins, etc. all exert harmful effects on the cultured fish, occupational health, adjacent ecosystems, food safety and human health. It is commonly known that persistent organic pollutants (POPs such as total polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dichlorodiphenyltrichloroethane (DDTs)) and heavy metals and metalloids (such as lead (Pb), mercury (Hg), and chromium (Cr), arsenic (As)) can enter fish ponds and exert harmful effects. Antibiotics (such as streptomycin, chlortetracycline, oxytetracycline, tetracycline, etc.) included in feed additives are anticipated to end up in

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the environment. These chemicals may be taken up by fish, washed off into surface waters or leached to groundwater where they can adversely affect both environmental and human health. Investigations are needed to study the persistent behavior, distribution and ecotoxicological effects of these contaminants in the pond environment and adjacent aquatic ecosystems; the health risk due to the consumption of contaminated fish; and the possible evolution of antibiotic-resistant bacteria due to the overuse of antibiotics. This information will be useful for preparing the guidelines for "Good Aquaculture Practices" or "Organic Fish Farming" for aquacultural industries in our region.

## 4.1. Introduction

Aquaculture production was 21.8 million tonnes in 1998, which accounted for more than 55% of the total fishery production in China (Qi, 2002). Freshwater fisheries or inland aquaculture accounted for about two-thirds of the total aquaculture production, of which about three-fourths came from pond culture (Wang & Yi, 1995). These facts suggest that the future of aquaculture production in China will depend heavily on the pond aquaculture.

Being an agriculture based country, China has a long tradition of waste recycling and utilization. Recycling of wastes can utilize residual energy contained in the wastes, ease waste disposal pressure, and hence mitigate land and water pollution problems. Animal and human manure are mixed with plant residues such as rice straw to produce compost, which serves as soil conditioner and fertilizer for improving both physical and chemical conditions of nutrient deficient soils. Verimcomposting involves using earthworms to degrade organic materials, and the verimcompost produced also serves as a soil conditioner/fertilizer, in addition to the production of high-grade animal protein (earthworms). Anaerobic digestion of waste materials with appropriate C/N ratio fulfills the dual purpose of methane (biogas) generation for fuel, and maintenance of sanitation in the rural areas. The digested slurry is added to the fishponds as pond fertilizer for polyculture (rearing different fish species simultaneously) of fish, resulting in increased fish yields (Polprasert, 1996).

The "Feedlot" method using cereal grains or high protein feed pellets, rearing a single fish species (monoculture) is commonly practiced in Europe, USA and Japan. By contrast, there has been a long tradition of applying waste materials to freshwater fish ponds in China, most of the Asian countries and some of the East European countries such as Hungry. The use of wastes is due to the unavailability of grain feeds. The waste materials include animal and human excreta, kitchen wastes and other agricultural and industrial byproducts. Some of the waste materials such as kitchen wastes can be directly consumed by fish, whereas animal and human excreta serve as fertilizer to enrich nutrients in the pond water to facilitate growth of microorganisms such as fungi and algae, which in turn serve as food for higher trophic organisms, including some species of fish thriving in the pond. Polyculture involving different fish species, with carps as the major component, and waste materials as the major source of input has been practiced for almost four thousand years in China (Heilongjiang Aquacultural College, 1990). All the substances derived from the waste materials can be fully utilized by different aquatic organisms and fish species, with different feeding habits and digestive systems. This has led to very high fish yields.

However, due to the rapid socio-economic development during the past 20 years in the southern part of China, chemical fertilizer and high protein feed lots are used instead of waste materials, and very often monoculture of high priced fish is practiced, instead of polyculture. This coupled with the deterioration of water quality due to the contamination by nutrients and pesticides, casts doubt on the fish quality and the health of consumers. In fact our studies indicate that the human breast milk collected from Hong Kong and Guangzhou (the biggest city in South China) contained high concentrations of DDT and PCBs, which are related to their diets, with a high consumption of fish (Wong et al., 2002a,b). However, little is known about the relationship between the operation of pond aquaculture and environmental pollution in our inland aquatic ecosystem.

The objectives of this chapter include the review of (1) the dyke-pond system in South China; (2) the traditional practice of using waste materials for aquaculture; (3) the recent socio-economic changes in South China related to the freshwater aqucultural industries; and (4) recommendations for tackling the problems.

## 4.2. The Dyke-Pond System in South China

In the southern part of China including Hong Kong, a large part of swamps around the Pearl River Delta were gradually reclaimed for productive use some six centuries ago. Wetlands have been transformed to ponds separated by cultivable ridges (dykes) for growing different crops. Components of the system include mulberry, silkworm, vegetable and sugar cane, etc. Ponds are managed in a rotation of harvesting and stocking, with 4/5 fish species, and carps served as the major components. The organically enriched mud at the bottom of the pond is dredged regularly to fertilize the dyke soil for crop production. Due to the favorable climate and water resources, the region has been known as "homeland for rice and fish". Table 1 compares the fish production of selected Asian countries.

Chinese fish farms produced two third of the world's yield of farmed fish in 1990 (FAO, 1992). The average rates of sustained production throughout most of the world were in the range of 300-500 kg/ha, while it has been demonstrated in both

Table 1: Inland and coastal aquaculture production in some selected Asian countries/ regions in 1990.

| Country/region | Total production (t) | Inland production (t) | Coastal production (t) |
|---|---|---|---|
| Bangladesh | 169,758 | 151,161 | 18,624 |
| China | 7,200,383 | 4,204,728 | 2,995,655 |
| Hong Kong | 10,256 | 5,525 | 4,731 |
| India | 1,011,136 | 982,136 | 29,000 |
| Indonesia | 558,795 | 242,625 | 316,170 |
| Korea, DPR | 208,670 | 11,200 | 196,470 |
| Korea, Rep. of | 789,765 | 15,823 | 773,942 |
| Malaysia | 47,876 | 7,007 | 40,869 |
| Pakistan | 40,057 | 40,016 | 41 |
| Philippines | 672,316 | 81,127 | 591,189 |
| Sri Lanka | 5,700 | 5,000 | 700 |
| Taiwan | 343,954 | 148,795 | 195,159 |
| Thailand | 253,326 | 92,466 | 160,860 |
| Vietnam | 155,000 | 123,000 | 32,000 |

Source: FAO, 1992.

China and Israel that, it is possible to achieve experimental production rates as high as 18,000 kg/ha/year (Advisory Committee on Technology Innovation, 1981).

### *4.2.1. Integrated Agricultural and Aquacultural Systems*

Common waste materials include municipal wastes, sewage sludge, agricultural wastes, coal ash, toxic, hazardous and difficult wastes, but not all of them are suitable for recycling in aquaculture. Waste materials that could be used as fish feeds include both agricultural (such as rice bran) and industrial (such as food processing wastes and brewery wastes). Manure can be regarded as pond fertilizer because nutrients such as nitrogen and phosphorus will be released upon decomposition to facilitate algal growth. In addition, fungi can also make use of manure as their growth substrate. These microorganisms will in turn serve as food for different fish species. Some species such as tilapia may consume manure directly.

In some areas, the effluent from waste stabilization ponds is introduced to fishponds where herbivorous fish species are cultivated, and sometimes these fish are also cultivated in the stabilization ponds themselves, in order to remove algae and to upgrade the effluent (Schroeder, 1975). Our early study (jointly with the Agriculture, Fisheries and Conservation Department) rearing a mixture of freshwater fish (silver carp, big head, common carp, grass carp, tilapia and black bass) in four fishponds receiving polluted river after it has been treated by sedimentation and aeration, indicated that all fish (except grass carp) grew to marketable size within one year (Liang et al., 1999a).

The integrated agricultural and aquacultural system with animals such as pigs and ducks reared in the vicinity of the fishponds enables the easy delivery of manure, avoids nutrient loss during transportation, and cuts down transportation cost. Ducks release manure directly to the ponds, and also keep the water surface clean by consuming algal blooms and higher plants such as duckweeds. Combined fish and duck culture is widely practiced in Eastern Europe, especially Hungary, with improved feed conversion, increased fish yield, as well as improvements in both duck quality and yield (Advisory Committee on Technology Innovation, 1981).

### *4.2.2. General Principles of Using Manure in Polyculture of Fish*

The common fish species used in polyculture include the following, each with distinctive feeding mechanism: (1) Grass carp *Ctenopharyngodon idellus* eats all kinds of food, although higher plants, submerged grasses and detritus are its major food items; (2) Silver carp *Hypophthalmichthys molitrix* is also a filter feeder, mainly consuming phytoplankton; (3) Big head, *Aristichthys nobilis* is able to trap zooplankton whilst swimming with its mouth wide open; (4) Common carp *Cyprinus carpio* is omnivorous and eats plants and snails; (5) Black carp *Mylopharyngodon piceus* eats snails, aquatic insects and crustacean; and (6) Mud carp *Cirrhinus molitorella* feeds on benthic organisms such as worms, shrimps and detritus. Cultivation of different carp species is of a great interest not only in terms of available food utilization but also with respect to the utilization of all the ecological niches available in the pond system, as surface feeder, column feeder or bottom feeder (Table 2). Sometimes tilapia *Tilapia mossambicus* (also omnivorous and eats detritus, plants and plankton) is added as the association of carp, and tilapia may increase the growth of carp (Hepher, 1988).

The use of a polyculture of mixed fish species, which is adapted to feed on various organisms can fully utilize all the substances derived from the wastes. The synergistic interactions among fish species reared in polyculture are clearly explained by Milstein et al. (1995): faecal pellets, rich in partially digested phytoplankton, are discharged from silver carp than consumed by the common carp which otherwise could not use these algae. The common carp in turn recirculates nutrients into the water column by stirring up the mud, and interferes

Table 2: Feeding habits and ecological niche of the different carp species.

| **Species** | **Feeding habits** | **Ecological niches** |
|---|---|---|
| Grass carp, *Ctenopharyngodon idella* | Macrophytes | Surface |
| Silver carp, *Hypophthalmichthys molitrix* | Phytoplankton | Surface |
| Big head, *Aristichthys nobilis* | Zooplankton | Mid-water |
| Common carp, *Cyprinus carpio* | Benthos + detritus | Bottom |
| Black carp, *Mylopharyngodon piceus* | Benthos | Bottom |
| Mud carp, *Cirrhina molitorella* | Benthos + detritus | Bottom |

with the development of filamentous algae and higher plants, thereby raising phytoplankton production and hence food for silver carp. Understanding of the dynamics of the natural food web is deficient, because most studies have been related to pond fish culture based on the gut contents of fish, or measurements of primary production and the standing stock of plankton.

#### *4.2.3. Nutrient Dynamics of Fish Ponds Using Manure as the Major Input*

The high yield of fish using this system is mainly due to rational use of manure, good management practices, suitable climate and water supply. Fish grow rapidly in warm weather, and wastes can replace the need for feeds. This gives rise to higher yields of high-grade animal protein at a lower cost, with a better (lower) food conversion ratio in comparison with other farmed livestock (Table 3). In addition, it is envisaged that the accumulation of metabolic waste in polyculture fishponds is less than monoculture ponds.

Table 3: Efficiency of feed utilization of various animal species per 1,000 g of feed intake.

| **Species** | **Live weight gain (g)** | **Food conversion ratio** | **Energy gain (kcal)** | **Protein gain (g)** |
|---|---|---|---|---|
| Chicks | 356 | 2.8 | 782 | 101 |
| Pigs | 292 | 3.4 | 1,492 | 30 |
| Sheep | 185 | 5.4 | 832 | 22 |
| Channel catfish | 715 | 1.4 | 935 | 118 |
| Brown trout | 576 | 1.7 | 608 | 75 |

Source: Hastings & Dickie (1972).

Direct consumption of manure usually results in lower yield due to the lower energy and protein contents contained in the manure. The advantage of applying manure to fishponds is mainly its role as a pond fertilizer for autotrophic production via photosynthetic production of plankton, or as a base for the heterotrophic production of bacteria and protozoa which are utilized by pelagic and bottom-feeding fish. There seems to be insufficient information relating to the flow of manure and its metabolic products through the fishpond ecosystem, therefore, more information on various pathways of the natural food web would aid the understanding of nutrient dynamics in the system. Nevertheless, it is understood that the advantages of using manure in fish culture include: (1) stocking and harvesting different fish species in a rational manner; (2) decreased hazard of fish killed due to anoxia; (3) more efficient use of nutrients; and (4) stable water quality due to higher oxygen concentration and higher pH; and all of these factors contribute to higher fish yields. In other words, ecological balance is achieved between production and consumption. Algae, bacteria, and fish form symbiotic relationships in a well function waste-fed fishpond (Bhattarai, 1985).

It is commonly known that the use of raw or untreated organic waste imposes adverse effects on treated organisms, mainly due to the release of ammonia, and other volatile substances. Pretreatment of wastes is, therefore, essential. Anaerobic digestion involving the mixture of pig manure and rice straw can (1) generate biogas for fuel, (2) sanitize the manure as the high temperature of the digestion process destroys eggs of parasites, and (3) treat the manure so as to avoid harmful substances such as ammonia being released into the pond water. Aerobic decomposition involves a group of microorganisms including bacteria, fungi and actinomycetes, and by providing suitable temperature, moisture and aeration, the digested materials should be free of harmful substances, and can be recycled in the pond system.

## 4.3. Recent Socio-Economic Changes and Their Effects on the Aquacultural Industries

### *4.3.1. South China and Persistent Organic Pollutants (POPs)*

Being the first "economic zone" in the whole of China, the region of Hong Kong and South China has undergone rapid socio-economic change during the past 20 years. Population growth, urbanization and industrialization resulted in the deterioration of water quality in most streams and rivers, due to the discharge of untreated domestic and industrial effluent. The change of land use is also an important problem as good agricultural land has been used for the constructions of highways and housing estates. Marginal land, which has been reclaimed for agricultural purpose, has required a large amount of chemical fertilizer, so that the runoff results in eutrophication along coastal areas (Neller & Lam, 1998). The traditional practice of organic waste recycling in both agriculture and aquaculture is diminishing. These include the declining use of waste materials for biogas generation. The accumulation of waste materials, especially animal manure, therefore, results in further land and water pollution problem.

Since the adoption of the Stockholm Convention on POPs, worldwide attention by scientists, policy-makers, industries, NGOs, and the general public on environmental health and management issues relating to POPs has been increasing. The 12 Stockholm POPs include pesticides (such as aldrin, endrin, DDT, etc.), industrial chemicals (such as PCBs) and unintentional by-products (such as dioxins/furans). Most of these chemicals are toxic, long-lived, can travel long distances, and move from warm areas to colder areas. Due to their affinity to lipids, they are absorbed by the fatty tissues of animals and humans and are bioaccumulated and biomagnified through the food chain. There is a severe lack of information related to the sources, fates and effects of POPs in our region (Wong & Poon, 2003).

Heavy metals, fuels and lubricants originating from industrial activities, dumps or human settlements near fishing farms, as well as pollutants from non-point sources such as pesticides from agricultural run-off can be present in the ponds, usually due to non-intentional contamination (Boyd & Massaut, 1999). Freshwater sediments collected from the inland river systems and fish ponds in the Pearl River Delta were grossly polluted by various heavy metals, PCBs, HCHs and DDTs, which resulted in higher concentrations of these chemicals in fish collected from inland rivers as well as from fish ponds, with fish collected from inland rivers having higher concentrations of these contaminants (Zhou et al., 1998, 1999a; Zhou & Wong, 2000). It is also alarming to discover that the PCB concentrations in muscle tissue of grey mullet (*Mugil cephalus*) collected from a nature reserve (Mai Po Marshes), a remote area, exceeded the guideline of 0.01 μg/g wet weight basis, imposed by US EPA for human consumption (Liang et al., 1999b).

The uptake of contaminants by fish seemed to depend on their feeding modes, with carnivores having higher concentrations. Table 4 indicates that black bass, which are located in the highest trophic level, contained the highest levels of DDTs, PCBs and Hg (Zhou et al., 1999b; Zhou & Wong, 2000). The quality of fish and their safety for human consumption has recently become a controversial issue. Our recent study revealed that the higher concentrations of organochlorine pesticides (DDT, DDE and HCH) and PCBs contained in human breast milk collected from two populations (Hong Kong and Guangzhou, the largest city in South China) were related to diet, especially fish consumption (Wong et al., 2002a,b). This may well be harmful to the next generation, as infants borne to

Table 4: Contaminant concentrations in fish species related to their feeding modes.

| Species | DDTs (μg/g, lipid) | PCBs (μg/g, lipid) | Hg (ng/g, dw) | Feeding habits |
|---|---|---|---|---|
| Black bass, *Micropterus salmoides* | 0.760 | 3.4 | 56.7 | Carnivorous, shrimps and mosquito fish |
| Tilapia, *Oreochromis mossambicus* | 0.090 | 3.1 | 13.7 | Omnivorous, algae, detritus, benthic invertebrates, small shrimps |
| Common carp, *Cyprinus carpio* | – | – | 18.9 | Omnivorous, benthic invertebrates, aquatic insect larvae |
| Big head, *Aristichthys nobilis* | 0.040 | 0.87 | 33.8 | Filter feeder, zooplankton |
| Silver carp, *Hypophthalmichthys molitrix* | 0.038 | 1.6 | 20.8 | Filter feeder, phytoplankton |
| Grass carp, *Ctenopharyngodon idellus* | 0.087 | 2.1 | 26.3 | Herbivorous, macrophytes |
| Shrimps | – | – | 13.3 | Algae, zooplankton |

– indicates not tested; Zhou et al., 1999b; Zhou & Wong, 2000.

mothers with high body concentrations of dioxin-like PCBs can experience low birth weight (Brouwer et al., 1998). In our region, bioaccumulation and biomagnification of persistent toxic substances within aquatic ecosystems will increase the risks to inhabitants with a strong preference for consuming freshwater fish.

#### *4.3.2. Environmental Impacts of Inland Aquaculture*

Basically the different environmental impacts caused by inland aquaculture can be described in terms of the amount of excreted metabolites and uneaten food, and of the chemicals used during fish production (Papoutsoglou, 1992). However,

Table 5: Adverse environmental impacts of aquaculture on the environment.

| Physicochemical and biological changes | Reference |
|---|---|
| Modification of water temperature and flow rate profiles | Billard & Perchec (1993) |
| Increased concentration of suspended solids, BOD, COD, forms of N (including $NH_3$), P | Warrer-Hansen (1982) |
| Reduced concentration of DO | Bergheim & Silvertsen (1981) |
| Alteration of drinking water by use of chemicals and antibiotics | Buchanan (1990) |
| Generation of organic-rich sediments | Holmer (1992) |
| Occurrence of algal blooms in eutrophic waters | Gowen et al. (1990) |
| Modification of the biotic index (based on invertebrate communities) | Gowen et al. (1988) |
| Genetic pollution | Hepher & Pruginin (1981) |
| Increased risk of disease spread | Hubbert (1983) |
| Conflicts with other usages: fishing, agriculture and recreational activities | Gowen (1992) |

the impacts on the surrounding environment are more diversified, and include causing physicochemical and biological changes to the surrounding areas, as well as conflicts with other economic and recreational activities (Table 5).

A number of chemicals such as fertilizers, liming material, disinfectants, antibiotics, algaecides, and herbicides are used in pond aquaculture for improving soil and water quality, and for controlling biological problems such as phytoplankton blooms, aquatic plant infestations, disease vectors, and the proliferation of wild fish (Boyd & Massaut, 1999). The most common chemicals used in inland aquaculture fall into three classes, according to Alderman & Michel (1992):

(1) Topical disinfectants including a wide and diverse range of compounds, such as malachite green, formalin, salt, copper sulphate, potassium permanganate and quaternary ammonium compounds, used in the treatment of topical parasites (including some bacteria, protozoa and fungi).
(2) Organo-phosphates, primarily dichlorvos, for eliminating crustacean predators of fish fry in cyprinid nursery ponds.
(3) Antimicrobials which include a wide and diverse range of compounds listed in Table 6.

Pesticides are intentionally applied to ponds in order to kill unwanted organisms before stocking with fish or shrimp. For example, organophosphate pesticides that

Table 6: Major antimicrobial drugs used in aquaculture.

| Drug | | Route | Dose/application interval | Indication |
|---|---|---|---|---|
| *Antibiotics* | *Product* | | | |
| β Lactams | Ampicillin | Oral | 50–80 mg/kg 10 days | Gram-negative bacteria |
| | Amoxycillin | Oral | | |
| Aminoglycosides | Neomycin | Oral | 50–80 mg/kg 10 days | Gram-negative bacteria |
| | Kanamycin | Bath | 20 mg/kg | |
| Tetracyclines | Tetracycline | Oral | 50–80 mg/kg 10 days | Gram-negative bacteria |
| | Oxytetracycline | Bath | 20 mg/kg | |
| | Doxycyline | | | |
| Macrolides | Erythromycin | Oral | 50 mg/kg 10 days (bathe eggs in 2 mg/kg 1 h) | Bacteria kidney |
| Non-classifiable | Chloramphenicol | Oral | 50–80 mg/kg 10 days | Gram-negative bacteria |
| | | Bath | 20 mg/kg | |
| *Synthetic antibacterial* | *Agent* | | | |
| Sulphonamides | Sulphamethazine | Oral | 200 mg/kg 10 days | Gram-negative bacteria |
| | Sulphadimethoxine | | | |
| | Sulphaguanidine | | | |
| Potentiated sulphonamides | Trimethoprim + sulphadiazine | Oral | 50 mg/kg 10 days | Gram-negative bacteria |
| Nitrofurans | Furazolidone | Oral | 50–80 mg/kg 10 days | Gram-negative bacteria |
| | Furaltadone | | | |
| | Nifurpirinol | Oral | 10–50 mg/kg 10 days | |
| | | Bath | | |
| Quinolones | Oxolinic acid | Oral | 12 mg/kg 10 days | Gram-negative bacteria |
| | Flumequine | | | |

Alderman & Michel (1992).

are used against trematodes or mysids pose a major threat to exposed non-target crustaceans (GESAMP, 1997). In a Norwegian study, Egidius & Møster (1987) demonstrated that Neguvon (active ingredient: trichlorfos) treatment in salmon farms was the likely agent that caused the death of lobsters and the disappearance of crab populations adjacent to salmon farms. The heavy metals which present the greatest threat to contamination of aquaculture products are lead, mercury, arsenic, beryllium, cadmium, chromium, manganese, silver, and zinc (Boyd & Massaut, 1999): these substances can be toxic to the cultured species, and they can contaminate the harvested product thus imposing potentially adverse effects on human health.

Due to the socio-economic changes, high priced fish are in greater demand, leading to monoculture and the use of high protein feed grains. Antibiotics are very often used to increase the immunity of fish in order to help them survive in poorer water quality. As in other countries, the main groups of antibiotics used in pond aquaculture are tetracyclines, sulfonamides and chloramphenicol (Migliore et al., 1993). These are applied through the feed or by simple addition to the water. Most of the antibiotics in excess feed end up in the sediments where they are either degraded (Lai et al., 1995) or slowly leached back into the surrounding water (Smith & Samuelsen, 1996). It has been estimated that about 70% of the antibacterial agents applied in fish farming are released into the environment (Schneider, 1994).

In 1991, the Japanese Health Authority found unacceptable levels of oxytetracycline in farm raised shrimps imported from Thailand (Weidner & Rosenberry, 1992). In a study conducted in 1990-91, 8% of the shrimps *Penaeus monodon* (over 1400 samples) obtained from Bangkok markets contained residues of tetracyclines, quinolones, sulphonamides and penicillins (Saitanu et al., 1994). In the USA, analyses for chloramphenicol in imported shrimps have been conducted regularly. From 1992 to 1993, it was found that five samples (three were obtained from Thailand and two from China, 3.2% of the samples tested) contained measurable amounts of chloramphenicol (Weston, 1996).

Tetracyclines, oxolinic acid, several sulpha drugs and trimethoprim are all known to be persistent, with varying results in degradation studies depending on temperature, depth in sediment, etc. (Halling-Sørensen et al., 1998; Weston, 2000). Several antibiotics, e.g. oxytetracycline, oxolinic acid and flumequine, have been found in sediments 6 months after treatment (Weston, 1996; GESAMP, 1997). The half-life of oxytetracycline was estimated to be 10 weeks in anoxic sediment (at 4–8°C) in a model of a fish farm bottom (Jacobsen & Berglind, 1988). There is a lack of local information concerning the presence of antibiotics in fish ponds and adjacent aquatic ecosystems.

It is widely recognized that the extensive use of antibiotics in agricultural animal production contributes to the development of antibiotic-resistant pathogens, and that these microbes can infect both humans and domesticated animals (Willis, 2000). Development of resistant pathogens in aquaculture environments was documented (Sørum, 1999), and evidence for transfer of resistance encoding plasmids between aquaculture environments and humans was presented (Rhodes et al., 2000). Accumulation of antibiotics in sediments may interfere with bacterial communities and affect the mineralization of organic wastes (Stewart, 1994). Digested pig manure has been traditionally used as pond fertilizer for culturing different carp species (polyculture of common carp, grass carp, big head, etc.) in the region, and the effect of antibiotics associated with animal manure on pond culture is unknown. In addition, a large amount of antibiotics has been used for monoculture of some species (such as mandarin fish, a carnivore) with a higher economic value

Some recent studies also indicate that several of the antibiotics, e.g. ciprofloxacin, oxolinic acid, chlortetracycline, oxytetracycline, tetracycline, tiamulin and trimethoprim, are acutely toxic to algae and aquatic invertebrates (Halling-Sørensen et al., 1998; Wollenberger et al., 2000). The toxic effect data of antibacterial agents on various aquatic species reported in the literature (Macri et al., 1988; Migliore et al., 1993), show values in the mg/l range. To make an ecotoxicological risk assessment, the concentrations of potentially hazardous chemicals in the environment should be compared with concentrations of chemicals for which biological effects have been reported.

## 4.4. Good Aquacultural Practices and Organic Fish Farming

A recent survey on the state of world fisheries and aquaculture by FAO (2002) recognized that China is the world's largest producer of farm-grown aquatic products today, and that the main challenges to further development are the limited supply of good quality seeds for some fish species; the oversupply of traditionally cultured species; the under exploitation of high value species; outdated farming technologies; water pollution; the limited availability of suitable land for expansion; and frequent fish disease outbreaks. To overcome these, it was recommended to (1) develop industrialized farming systems by improving the design and upgrading production, employ the latest technology and select the best combination of species to respond to market conditions in China and abroad; (2) raise the market share of high-value freshwater species suitable for export, and achieve production efficiency through the adoption of large scale industrial farms; (3) pay emphasis to the production of high quality seed by making use of modern biotechnology; and (4) establish an integrated scientific system and network of fish breeding and seed production for high-quality indigenous or endemic species, as well as fish health management to improve disease prevention, diagnosis, control and treatment.

All the aforementioned factors should be explored using the existing models available in China, taking into consideration agricultural and aquacultural development, land use and coastal management, pollution control, and food quality and safety. Aquaculture is an ancient practice and until recently has developed mainly on a trial and error basis. However, it is commonly recognized that the addition of aquaculture into the mix of farm enterprises can greatly raise the efficiencies of bioresource flows and profitability (Ruddle & Zhong, 1988), and there are different successful models of ecologically integrated freshwater systems available in different parts of the world (Table 7).

Although guidelines are available for the use of different chemicals in aquaculture, and for the residual levels of different antibiotics and synthetic antibacterial agents in aquacultural products in China (Standards on Agricultural Industries of P. R. China, 2002), very often they are not fully enforced. Regulation is also needed to control the impact of aquaculture development on the environment. The approaches to the regulation of aquaculture for environmental protection should include: (1) development permits, specifying size and/or location of the fish farm; (2) environmental quality standards which could be achieved through nutrient loading limits and other conditions related to discharge; (3) waste minimization regulations, related to feeding management; and (4) discretionary requirement for environmental impact assessment. In order to reduce operational costs, and promote "green" marketing opportunities, it is essential to adopt environmental management systems consisting of environmental review, environmental policy, system design and implementation, and environmental audit in order to offer a strategic framework for the control of environmental impact from inland aquaculture, and for improving environmental performance in the aquaculture business (Milden & Redding, 1998).

Like "organic farming", the demand for "organic fish farming" is increasing worldwide, e.g. production of organic salmon in Scotland. Some of the regulations stipulated for organic salmon farming (Costa-Pierce, 1988) included: (1) density of fish should be less than 10 kg/m$^3$ (compared with traditional salmon farming of 20 kg/m$^3$); (2) fish feed has to come from certified feed manufacturers, and must contain no genetically modified ingredients, no artificial colors, no fish meal from industrial fishing (fish meal produced from fish processing wastes is used), and all cereals used have to come from organic farming; (3) fish should be fed by hand; (4) no carbon dioxide is allowed in slaughtering; (5) no anti-fouling chemicals are allowed in treating nets; and (6) no polystyrene boxes are allowed for marketing the fish (waxed cardboard or reusable plastic boxes are used). Most important of all is the close monitoring on the use of chemicals, and on the quality of the

Table 7: Some examples of ecologically integrated freshwater systems.

| Systems descriptions | Reference |
|---|---|
| Chinese dike-pond aquaculture ecosystem integrates aquaculture, plant and animal agriculture, silviculture and sericulture, sustainably producing 20–40 t/ha/yr | Ruddle & Zhong (1988) and Korn (1996) |
| Silvofisheries: integrated mangrove forest aquaculture systems, e.g. dyke-pond system in South China including Hong Kong | FitzGerald (1988) |
| Polyculture of carps, mullet and prawns, with effluents irrigating a mixed tropical orchard | Costa-Pierce (1987) |
| Mixed intensive tilapia culture in tanks integrated with hydroponics producing commercially viable fish and plant yields and using sludges for pastures | Rackocy & Hargreaves (1993) |
| Reuse of saline aquaculture effluents to irrigate halophytes suitable for forages | Brown & Glenn (1999) |
| Effluents from channel catfish ponds coupled with bulrush, cutgrass and maidencane aquatic wetlands achieved excellent removal of all nutrients, BODs and solids | Schwartz & Boyd (1995) |
| Biculture cage ecosystems (one species being grown in a culture system receiving formulated feeds placed above or at higher elevation from a second system below it holding species that are unfed) | Costa-Pierce & Hadikusumah (1990) |
| Tilapia aquaculture integrated into irrigation schemes in the US southwest | Olsen & Fitzsimmons (1994) |

aquacultural products which are relatively free of contaminants, and thus safeguard environmental and human health.

## 4.5. Conclusion

In view of the recent socio-economic changes in South China, it is essential to utilize organic wastes as much as possible. Integrated farming systems involving agriculture as well as aquaculture should be encouraged. Organic wastes should be applied to land in order to improve both the chemical and physical properties of poor soils, and as pond fertilizer in fish polyculture. Nevertheless, waste and wastewater treatment facilities should be constructed in South China, together with close monitoring of pond water quality. Laws relating to the use of chemical fertilizer, pesticides and other undesirable chemicals, such as antibiotics and growth hormones, should be established and then enforced within in the region through joint agreements between the Guangdong and Hong Kong governments. The availability of more data and information on the chemicals used in fish farming would be valuable for effective environmental and public health management. It is likely that the use of antibiotics and hazardous chemicals could be significantly reduced, without decreasing production yields, by disseminating correct information among farmers about the safe and effective use of antibiotics and other chemicals in fish farming. "Good Aquaculture Practices" and "Organic Fish Farming" should be established, in order to safeguard the health of inhabitants in the region, as well as to ensure that export products meet the standards imposed by other countries.

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