Contrasting strategies for inland fish and livestock production in Asia

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Summary

The development of inland fish and livestock production in Asia has been linked to the need for animal protein by the increasing population of the region. Reliable supplies of stock underpin both fish and livestock farming. The production and dissemination of fish seed, typically of wild or undomesticated strains, has been critical to the emergence of sustainable aquaculture. The source, form and application of nutrients used in production identify the level of intensity for both fish and livestock culture. Extensive systems, with only naturally occurring nutrients are still viable where the opportunity cost of land is low, but semi-intensive systems receiving supplementary fertilisers and/or feeds produce most farmed fish and livestock in Asia. Intensive systems, using complete formulated rations in feedlots, are most common for pigs and poultry and carnivorous fish and their development is linked to the dominance of agribusiness. Pest and hygiene management are key components of both fish and livestock production; traditional and modem practices share similar values and, increasingly, the same medicaments. Risks to public health through transfer of diseases, residues from treatment and direct pollution exist, although these may be independent of intensification or integration of livestock and fish culture. The aquatic environment has constrained both effective control of pathogens and the development of aquaculture systems. Livestock and fish production occurs in a range of culture environments from those similar to natural systems to highly modified, densely stocked systems. The economics of intensive systems, particularly the cost of feeds, has led to the integration of intensive livestock or fish culture with semi-intensive fish culture in some areas of Asia. Introduction of new species, both livestock and fish, has risks for both future food production and the wider environment. However, a major trend is the expected increase in the production of a fish exotic to the region, the tilapia, in both semi-intensive and intensive systems for both local and export markets.

Introduction

Aquaculture is now developing into a food production system of major importance in parts of Asia. Many aquatic products that include algae, molluscs, crustaceans and fin fish are farmed but the latter dominate inland production. Aquaculture, including stocking and harvesting of communal water resources, accounts for an ever increasing proportion of the fish that people consume in the region. Although there are great differences within Asia, more fish is consumed per capita in the region than in Africa or Latin America (Laureti, 1996). Aquatic products from inland sources are most important in the so -called 'rice -fish societies' of the region, in which the staple diet of rural people is rice and vegetables complemented with fish (Laureti, 1996). In contrast, food products derived from livestock comprise a smaller proportion of the diets of such people. Providing draft power is the main role of large ruminants, but asset accumulation and a source of fertiliser are also important reasons why pigs and poultry are raised in small numbers (McDowell, 1980).

The key importance of fish in the diet has provided a stimulus for the development of aquaculture, which is neither traditional nor widespread in most of Asia. Natural stocks of aquatic products, including frogs, crabs and various insects were, until recently, adequate for subsistence purposes in all but the most densely settled rural areas of Asia. Undeveloped markets for these highly perishable products probably also constrained commercialisation. Small game, both birds and mammals also complement subsistence rice–growing close to forest areas (Srikosamatara et *al.* 1992). The need to intensify either fish or livestock was therefore not considered by the majority of rural dwellers until quite recently.

The rise in importance of both aquaculture and intensive production of monogastric livestock is driven by two major forces: overexploitation of natural stocks and increased human population. The latter has also led to modification or destruction of habitat and increased demand for food. There is a rising demand for farmed products by both rural and urban consumers. As most Asians will be urbanised by 2000 (Simpson, 1979) demand will increase further.

This article explores some of the basic similarities and differences in the development of fish culture and livestock farming in the region. Differences in the nature of the aquatic environment, and how they affect development of farming aquatic, compared to terrestrial animals, are considered. Concepts and definitions are followed by the historical development of traditional culture systems. Then the essential characteristics of intensification that both aquaculture and livestock production share are outlined, *i.* e., the development and use of germplasm, changes in the source, form and application of nutrients, the management of pests and hygiene, and system development. The importance and increasing scarcity of water means that aquatic-based food production is intimately linked with surrounding farming and livelihood systems; aquaculture has the potential both to pollute and to become sustainably integrated and these issues are also explored. Finally, we speculate on future developments in fish culture in the region and a comparison with the recent history and trends for livestock is useful to predict the species and systems that will supply the region's fish into the next millennium.

Concepts and definitions

Comparison of livestock and fish production is facilitated by a schema (Figure 1) for the probable evolution of farming systems from traditional, crop–dominated systems (Settled Agricultural Phase I), through mixed farming in which the importance of livestock was enhanced through their integration with crops (Settled Agriculture Phase II), to industrial agriculture characterised by monoculture (Settled Agriculture Phase III, Edwards et *al.* 1988). The latter system includes the 'green revolution' of developing countries (WCED, 1987). Livestock and fish production in systems are generally extensive within the first category, receiving no or few nutrient inputs above those available naturally: they are semi-intensive in Phase II, receiving nutrient supplements as fertilisers or feeds; or they are complete feeding systems (Phase III). The 'green revolution' in which new genotypes and agro-chemicals boosted the yields of staple cereals and pulses, has no direct parallel in livestock or fish production, although it has supported the development of both semi-intensive and intensive livestock and fish production.

Polycultures, systems in which more than one product is grown in the same unit (field or pond), are suitable for both extensive and semi-intensive systems dependent mainly on a variety of natural foods, in contrast to single species monocultures typical of intensive systems. However, the three-dimensional aquatic environment (water column, sediments and margins) generally has a larger range of ecological and production niches than the terrestrial environment. Feeding habits are similarly more diverse. The carnivorous nature of some popular wild and cultured fish species has no direct comparison with livestock which are omnivorous or herbivorous (Tacon, 1996). The use of animal-protein supplements is common to more intensive forms of both aquaculture and livestock however. Social and economic aspects of people's relationships to livestock and fish also show similarities across the continuum. From being a minor but important part of a variable complex of activities in Phase I, livestock and fish farming become highly specialised at the level of industrial farming. The knowledge required, and the extent and type of resources needed (land, water, labour) change with intensification as do the purpose and fate of the outputs which increasingly develop from a subsistence to a cash orientation, and from local to distant markets.

Figure 1 Schema showing the evolution of farming systems for livestock and fish

Category	**Evolutionary stage/trend**		
System definition	Traditional crop dominated	Mixed farming	Agro-industrial
Intensity level	Extensive	Semi-intensive	Intensive
Descriptor	Settled Agricultural Phase I	Settled Agricultural Phase II	Settled Agricultural Phase III
Livelihood	Part of a complex of activites	→	Specialised activity
Knowledge	Indigenous	→	Scientific
Resource[1] use	Land, water[2], labour intensive	→	Cash, fossil fuel energy intensive
Market	Rural, subsistence, local	→	Urban, cash, export
Cultured species	Polyculture	→	Monoculture

[1] per unit fish/livestock output
[2] based on pond fish culture

Historical development of tropical aquaculture

Aquaculture has evolved in Asia as wild fish stocks have become insufficient to meet needs. Traditional systems therefore first developed in the densely populated, flood plain areas of China and the Indian Sub Continent where demand was high and wild fish seed for stocking was available from major rivers. Herbivorous and omnivorous species that feed low in the food chain, Chinese and Indian major carps, characterise culture in those two regions. Aquaculture is more recent in other parts of Asia and has been introduced from China (Edwards *et al.* 1988, 1997). Management of Indian major carps was limited to stocking and harvesting of wild seed (Tripathi and Ranadir, 1982), but complex systems in which fish culture was well integrated within the farm characterise Chinese aquaculture systems. This was facilitated by the complementary 'grazing' feeding ecology of the riverine carps typically stocked in static water ponds and rice fields. Limited amounts of human and livestock manure were supplemented by grasses and other fodder that the dominant grass carp (*Ctenopharyngodon idella*) consumed; their inefficient digestion resulted in fish manure being probably the most important source of nutrients for the food web through production of planktonic and benthic organisms which supported the growth of different fish species (Little and Edwards, 1994). Fish such as the silver and bighead carps in turn promoted recycling of nutrients within the pond (Milstein, 1992).

Many of the native fish most prized in Asia are carnivorous and a range of species is now cultured. Traditionally, however, these depended on the availability of small wild fish from artisanal fishing, rather than being integrated within rice-based farming systems. Artisanal cage culture of high-value carnivorous fish such as pangasid catfish and snakehead is found in Cambodia and Vietnam but its extent has been limited by the feed resource base, which is both seasonal and competes directly with human consumption (Chhouk, 1996). Overall production of carnivorous fish is thus far lower than from fish raised in semi-intensive systems.

Traditional systems encompass the full range of intensification, *i.* e. extensive (unfertilised, traditional Indian major carp culture), semi-intensive (Chinese carp polycultures) to intensive (cage culture of carnivorous fish). There are similarities to the evolution of livestock farming systems with extensive pastoralism comparable to extensive aquaculture, and mixed farming or settled Agricultural II comparable to the integrated farming of Chinese carp polycultures. Traditional-style intensive cage culture is most analogous to 'cut and carry' feedlot systems used to intensify livestock production in which feeds were collected in and around the farm prior to the emergence of modem feedlots. Fishers collected and used trash fish while animal husbandry used vegetable fodder for ruminants.

Major changes have occurred in both livestock and aquaculture over the last half-century as the era of settled Agricultural Phase III, or industrial monoculture has dawned. However, the dominance of vertically integrated agribusiness is highly variable in Asia. Modem poultry is dominated by such concerns in many countries, swine to a lesser extent; but ruminant and fish production are largely still in the hands of small entrepreneurs and farmers. Intensification of crop production, the so-called green revolution, has had both direct and indirect effects on livestock and fish production. Whereas fossil fuel-based mechanisation and use of agro-chemicals undermines the traditional position of livestock and fish on the farm, the food surpluses created can support intensified farming of both. Feedlots produce large amounts of animal protein in small areas through the feeding of diets mainly composed of food grains and their by-products.

Four major aspects of intensification, discussed below, are common to livestock and fish production:

- germplasm development
- nutrient source, form and application
- pest and hygiene management
- system development

Germplasm development-the introduction of fish seed production technologies and new species

In contrast to livestock production which is dependent on a handful of domesticated species (although a plethora of strains), aquaculture in Asia is characterised by a large number of cultured species. Most fish species have been cultured only relatively recently, and almost all are essentially 'unimproved, wild strains. This is a fundamental difference between livestock and fish production reflecting the pioneer status of aquaculture. Furthermore, Asia has a rich natural fish fauna with a huge array of potential species for culture.

Again in contrast to livestock, a major constraint to the spread of aquaculture from its origins in the flood plains of Asia is that most commonly cultured fish species do not breed spontaneously under culture conditions. An exception is the longest and most widespread species cultured, common carp (*Cyprinus carpio*), that will spawn with simple environmental stimulation. This trait, together with its generally highly favourable cultural characteristics, have allowed this species to be cultured in a wide range of traditional and modern systems throughout Asia. Similar advantages have made its close relative, the ubiquitous Koi into a global ornamental. The development and dissemination of induced breeding techniques to the private sector has been critical for the more widespread culture of riverine carps and catfish-two classes of fish which together constitute nearly 80% of all cultured fin fish in Asia (FAO, 1995).

A major comparative advantage of aquaculture to animal husbandry is the high fecundity of most cultured fish species. This both reduces the cost of production and accelerates growth in the number of farmers that can enter aquaculture. It has also allowed both rapid introduction and dissemination of new species. Movements of the major groups of carps (Chinese and Indian Major carps, west and east, respectively) have had enormous impacts. Chinese carps, particularly the phytoplankton-consuming silver carp, are now highly favoured by commercial hatcheries and constitute an important part of farmers' polycultures in India and Bangladesh. In contrast, the native carps of Bengal, rohu and mrigal, make up more than half the output of many hatcheries in North Vietnam (Little and Pham, 1996). This has happened in little more than a decade and is the net result of importing a mere few hundred small fish, as breeding animals, in each direction.

An emerging contradiction is the exotic tilapias. Since their introduction to Asia as recently as the 1940s to 1960s, they are now having a major impact, despite much lower fecundity than the carps. Dubbed as the 'aquatic chicken' (Maclean, 1984), comparison with the chicken is apt because of its comparable bland white flesh, low cost of production and suitability for intensification. A natural poultry-like habit of brooding their own eggs has constrained the development of methods to mass-produce seed. Whereas a skilled technician can produce millions of seed from a few dozen carps, tilapias produce relatively few eggs on each occasion they spawn due to the advanced parental care that female tilapias lavish on their eggs and young by incubating them in the mouth. These propensities together with an aseasonal and asynchronous spawning habit are serious problems for hatchery managers used to carps. However, intensified management of breeders and artificial incubation can revolutionise hatchery efficiency in a similar way to poultry (Little, 1989).

Improved management of breeding fish, including selection, is constrained by the nature of aquatic culture systems, the high fecundity of most fish species and poorly developed marking systems. Inbreeding and bottlenecking can occur rapidly in isolated populations and through poor hatchery practices (Eknath and Doyle, 1985). When these problems have become acute they have been overcome by new introductions from the field although novel, practical techniques for farmers are being developed (Brzeski and Doyle, 1995). The lack of 'improvement' in the past has raised expectations that selection can bring returns similar to those achieved by animal breeders. Selective breeding programs are already well developed for the common carp (e.g. Kirpichnikov et *al.* 1993), channel catfish (Brooks *et al.* 1982) and the Atlantic salmon (Gjedrem, 1983). However, impacts in Asia to date have been minimal although a major effort has begun with the Nile tilapia (Eknath *et al.* 1993).

In general, these programs appear to have most relevance for intensive, commercial aquaculture. The complexity of designing and managing selection programs tends to focus efforts to produce fast growth in optimal and homogeneous environments: 'improved' breeds are selected for performance under intensive conditions. As with monogastric livestock, the sustained performance of 'improved' breeds of fish by small–scale farmers may be harder to attain, particularly without upgrading the culture system. The role of local institutions, seed trading networks and the farmers themselves must all be considered, in addition to production of improved germplasm under controlled conditions in well-funded centres.

Nutrient source, form and application

Extensive Systems

Naturally occurring feed that supports extensive production of fish and livestock may occur within the system or be based on nutrients brought in with water flows, such as occurs in seasonal flooding. Typically the boundaries of the production unit are indistinct as there may be reliance on common property resources, whether conventional pasture or ponds, or in some form of ranching for both livestock and aquaculture. The ranching of fish in which rivers and water bodies are stocked is well-established in developed countries. It is also developing to sophisticated levels in freshwater lakes in Bangladesh around the organisation of fishermen's groups (Middendorp *et al.* 1996). The issue of legal ownership, easily settled with branding of 'wild' and 'semi-wild' stocks of livestock, has been a major constraint for fish stocks, which the use of sophisticated genetic tools now promises to overcome. Complex social issues often affect the use of communal water bodies for aquaculture, constraining any form of intensification although they may still be of major importance in terms of household nutrition (Lorenzen, in press; Little *et al.* 1996a).

Linkages between extensive livestock and fish culture are typically weak, through the limited amounts of manure, which are valued for use elsewhere in the farming system (Little and Edwards, 1994). However, the multipurpose nature of farm ponds means that livestock may utilise ponds for wallowing and defecation with positive effects on fish production.

Semi-intensive systems

Both the theory and practice of fertilisation of terrestrial and aquatic systems are at different stages of development because aquaculture has a relatively recent and weak scientific base (Edwards *et al.* 1988). A wide range of organic wastes is used in aquaculture today, ranging from the manure from feedlot livestock to human waste in the form of sewage or nightsoil and by-products of agro-industry. Fertilisation of fish ponds with organic manure, the basis of traditional Chinese integrated farming systems involving aquaculture, is still largely the result of farmer experience rather than scientific principles. It has been appreciated for a long time that the pond could not economically be only the stall, but rather the 'stall and pasture' in traditional production of common carp in Europe (Schaeperclaus, 1933).

The direct use of inorganic fertilisers is less widespread in aquaculture than in agriculture although fertilizer use is being promoted (Edwards ***et al.*** 1996). On resource-poor farms where livestock are typically few, the use of inorganic fertilisers to supplement on–farm wastes may be the only realistic means to produce yields that meet farming households' needs, given typical constraints of land, water and labour (Edwards, 1993; Edwards ***et al.*** **1996a,b**). The more widespread and intensive use of inorganic fertilisers in aquaculture does raise issues of sustainability. Alternative sources of nutrients produced on farm such as nitrogen fixing *Azolla–Anabaeba* may have potential in certain contexts (Caguan, 1994) but are generally land and water intensive. Green manure in the form of terrestrial legume leaves from nitrogen–fixing perennial bushes such as ***Leucaena spp.*** and ***Sesbania spp.*** may also be used as partial inputs to semi-intensive fish culture. However, given the need to harvest and transport them, their strategic use as ruminant feeds or conventional green manure (Aye *et* ***al.*** 1994) probably has more potential (Little ***et al.*** 1995).

A major difference between semi-intensive livestock and fish production is the possible likelihood of greater exploitation of feeding niches in aquatic systems through polyculture. Many fish species have broader feeding niches than macrophagous ruminants. This is fortunate because the food supply in a fertilised pond varies much more than that from a conventional terrestrial **pasture.The** microalgae that typically dominate fertilised ponds in association with zooplankton, bacteria and benthic animals are subject to periodic succession and change in an unpredictable and uncontrollable manner. Fish culturists cannot sustain continuous algal cultures in large open systems whereas practical improved pasture and range management are well established for ruminants. Some types of microalgae are known to be nutritionally superior to fish that can extract and digest them but the scientific understanding of how fish utilise natural feeds is rudimentary. The basis of the Nile tilapia's digestion of the blue-green alga ***Microcystis aeruginosa*** was described only in the 1970s (Moriarty and Moriarty, 1973).

Many fish species are versatile and opportunistic feeders. For example, the silver barb (***Puntius gonionotus*)**, although known to be primarily macrophagous, is extremely insectivorous given the opportunity. This provides both a dilemma and an opportunity since the food organisms within fertilised pond are likely to be highly diverse and their availability cyclical. Large amounts of phytoplankton-derived detritus are believed to the major source of nutrition for a variety of fish species besides silver barb that would otherwise filter feed them with difficulty. The detritus-bacterial aggregate has been proposed as a major under exploited niche for further intensifying low-cost systems that could utilise farm–produced detritus of low value (Schroeder, 1978; Schroeder ***et al.*** 1990). Unfortunately, use of large amounts is constrained by their effect on water quality, particularly on dissolved oxygen (Colman and Edwards, **1987**), and the low availability of nutrients, especially nitrogen, in such wastes that tend to be refractory. Several important aquaculture systems are largely detrital-based, however, including snakeskin gourami (*Trichogaster pectoralis*) ***in*** Thailand (Boonsom, 1986) and red swamp crayfish in the southern USA (Caffey ***et al.*** 1996) . Fish such as common carp and Nile tilapia stocked in rice fields generally appear to graze periphyton-detrital aggregate (Chapman, 1991). This may be a more efficient strategy than filter feeding alone, even in principally microphagous fish such as the Nile tilapia (Dempster ***et al.*** 1993). Fish also graze on a range of meiofauna, insects and crustacea in their various life stages, in and around the sediments, in the water column (planktonic or motile) or attached to natural or artificial substrates (Shrestha and Knud Hansen, 1994).

Feeds that supplement natural feeds produced in the system, whether plankton or detritus, are commonly given to raise fish yields in fertilised systems in the same way that supplements are provided for grazing ruminants and scavenging pigs and poultry. In small–scale farming systems the use of common supplementary feeds such as rice bran produced in village rice mills may be limited in both quantity and quality. Their use in fish culture may also compete with livestock (Little ***et al.*** 1996b; Little and Edwards, 1994). Improving the quality of on-farm produced feeds is possible through using mixtures of available ingredients. Upgrading locally available by-products to improve their feeding value for fish in fertilised systems is also technically feasible (New ***et al.*** 1993; Edwards ***et al.*** 1996b). The production and feeding of on–farm green fodder to fish, rather than to ruminants, appears to be limited, partly by anti–nutritional factors (Yakupitiyage, 1993). An additional major constraint is that only a single species, grass carp, feeds voraciously on a range of green fodder. In practice the land and labour required to grow, harvest and transport fodders may constrain their use (Edwards ***et al.*** 1996b). The highest quality green fodder such as water spinach (*Ipomoea aquatica*) also has an opportunity cost for human and livestock foods.

Intensive systems

Nutritionally balanced complete feeds for livestock and fish raised in feedlots are based largely on materials derived from agro-industry, and are dependent on fossil fuels (Preston, 1990). The development of fish and shrimp feeds, typically by agribusiness that produces livestock feeds, has proved a key factor in the intensification of aquaculture. As poultry and swine feed production pre-date fish feed manufacture, with every stage of feed development found in Asia (New and Wijkstrom, 1990), feed companies identify the latter as a key area in which to grow and diversify their business.

The development of complete feeds for fish was limited until the early 1950s by a poor understanding of the nutritional requirements of the largely carnivorous, mainly salmonid, fish raised in North America (Rumsey, 1994). Once the special importance of vitamin B_{12} and folic acid was understood, the formulation of nutritionally complete diets became possible. Developments in production of feeds that float or sink, depending on requirements, and are water stable, have occurred over the following 40 years for a wide variety of species.

The biggest single stimulus for the development of pelleted feeds in Asia was the boom in coastal rather than inland aquaculture when culture of black tiger shrimp (*Penaeus monodon*) began to develop rapidly in the 1980s. Hatchery development that allowed juvenile shrimp to be produced to demand spurred intensification away from a reliance on natural seed and feed. Taiwan with well-developed aquaculture and feed infrastructure set the pace, and Taiwanese companies remain active around the region. However, Thailand's fish feed business was already established to supply a large domestic catfish (*Clarias spp.)* industry before shrimp farmers became the main source of demand and has since developed a large range of feeds. The latest trend in the rapid development of the shrimp culture business is a move inland to raise this species in new unpolluted sites. This practice is expected to lead to new conflicts, particularly regarding resource use and potential adverse environmental impacts.

The feed business has allowed intensive aquaculture to become a year-round operation and to expand to regions without suitable feeds. Intensive aquaculture no longer need rely on seasonal fluctuations in the availability of small wild fish for feed. Formerly, intensive farms raising trout far from the sea used fresh meat (Schaeperclaus, 1933) or maggots raised on slaughterhouse waste (Rumsey, 1994). Old horses, the pre-eminent form of draught power, were probably the single major source of fish feed. Traditional trash fish-based systems described above have increasingly been replaced with dry feed formulations based on marine fish meal, except in certain exceptions in which some fish species feed only on moist feed formulations containing fresh fish (Czavas, 1989).

The continuing dependence on fishmeal, especially for the high valued marine shrimp and fin fish, has changed overall demand for fishmeal with consequences for livestock production and fish consumers alike (New, 199 1). Increases in demand for fishmeal in shrimp caused knock-on effects in Thailand where higher feed costs led to increased consumer prices and a slump in chicken exports (New and Wijkstrom, 1990). In general the livestock sector has responded to increased fishmeal scarcity as there is a major difference in the proportion of fishmeal used in livestock and fish feeds. The level of fishmeal in poultry rations has been reduced by more than 80% in the US over the last two decades by substitution with alternatives (Rumsey, 1993). Aquaculture is already estimated to absorb in excess of 12% of the world supply of fishmeal (Pike, 1990) and this is expected to increase further.

Attempts to reduce levels of fishmeal inclusion in feed for carnivorous fish from the levels of 30–70% typical of salmonids have been less successful. Fish acceptance of such feed declines although many species of carnivorous fish have been shown to tolerate high dietary levels of soybean meal experimentally (New and Wijkstrom, 1990). It is also likely that increasingly the small, marine pelagics used for fishmeal will be used for direct human consumption (Tacon, 1996). Processing to surimi and use of fishmeal for speciality and value–added feed products such as pet foods and rumen bypass diets is likely to increase (Rumsey, 1993).

The experience of the livestock feed industry could indicate likely developments in aquaculture, and thereby avoid the so-called 'fishmeal' trap (New and Wijkstrom, 1990), *i.e.* dependence on a finite and declining resource by an expanding market. Substitutes for fish diets will follow as the price of fishmeal continues to rise in real terms and processing techniques to improve the value of plant-based protein sources are further refined. Furthermore, cultured fish species that are omnivorous or herbivorous and can tolerate low little, or no fishmeal in complete diets, such as channel catfish (*Ictalurus punctatus*) and Nile tilapia, will become more competitive. Currently herbivorous and omnivorous fish, although comprising nearly 90% of farmed fish globally, consume less than 10% of the fishmeal used in fish feeds (Tacon, 1996).

Intensive food production, irrespective of dependence on fishmeal or soybean has high social and environmental costs. Large amounts of nutrients and fossil fuels are required to harvest ingredients and/ or to produce or transport them. Moreover, the tendency for high-density production to pollute the environment remains a major unresolved issue.

Pest and hygiene management

Livestock and fish health

Pests and diseases can undermine the success of more intensive forms of livestock and fish husbandry. Close confinement at high density and resultant stress is an important predisposing factor for disease organisms in farm animal systems and aquaculture alike. However, improved management of stock in intensive systems can also make control of diseases or competitive organisms more cost effective than in more open, extensive production systems.

Some concepts of pasture management, both traditional and modem, have been adapted to aquatic culture environments. Fallowing, to 'rest' land for natural recovery of fertility and to break pest cycles, is still common practice in Asia (Grigg, 1977). This is part of an annual cycle when conditions are unsuitable for production such as winter or dry season, or for longer periods of time such as shifting cultivation. Crop rotation, principally between pasture, fodder and grain crops was a major factor in intensification of livestock into 'mixed farming' in the West (Settled Agricultural Phase II). The cost of constructing fish ponds and the high opportunity cost of land on Asia's generally small farms constrains fallow as an option in most cases, although pond preparation should involve exposing sediments to sunlight, and if possible, thorough drying.

Agricultural lime has played a major role in enhancing the productivity of acidic arable land. Liming of fish ponds both to kill pathogens and adjust pH when constructed on acid sulphate soils is also common during their preparation. Control of predators in nursery ponds in which extremely small and vulnerable fish larvae are stocked and raised until fingerling size is particularly well developed. Sanitising agents such as rotenone, derris, mahua and tea seed cakes are used to control predatory fish and insects. Similar plant-derived products have been use for traditional and modern–day control of parasites in livestock (Peacock, 1996). Some commonly available products are used as home-made remedies for backyard fish and livestock alike. Diesel oil is used to control air-breathing larvae of predatory insects as well as mites on village poultry (Swan, persp. comm.). Organo–phosphates are used to manipulate food supply in intensively fertilised fish nursery ponds in addition to their use to control insects and helminths in livestock. Low doses are used to control predatory and competitive zooplankton, thereby stimulating the preferred first feeds of fish larvae (Horvath et *al.* 1984).

In general, the fluid aquatic environment makes treatment of infected fish more problematic than for terrestrial livestock. Apart from the difficulties in controlling working concentrations of medicarnents used in feeds or as baths, dips or flushes, treatments have to provide for maintenance of adequate dissolved oxygen. The use of chemotheropeutics in aquaculture is hindered by a rapid loss of active substances from treated feed (Bergheim and Åsgård, 1996) or water in systems with high water exchange. As with feeds, a well-established veterinary infrastructure for livestock typically quickly diversifies to support intensive aquaculture. Anti–bacterials and parasiticides are given to virtually all types of livestock to prevent and control disease and their use, particularly in intensive aquaculture, is therefore hardly surprising (Weston, 1996). However their use in aquaculture has caused particularly acute concern because of its recent and rapid adoption in some sectors, the lack of effluent treatment and the lack of reliable data (Weston, 1996). Antibacterials have chiefly been used in intensive mariculture, especially salmonids, yellowtail and penaeid shrimps. Inland production has been less affected, although the highly intensive systems of hybrid *Clarias* catfish are frequently treated in Thailand (Tonguthai et *al.* 1993). To date only a small fraction of antibacterials used in agriculture have been regularly used in aquaculture.

Maintaining high stock densities in 'open' systems makes it difficult to control pathogens in both livestock and fish. The ready transfer of parasites and opportunistic organisms in water is particularly difficult to control for fish raised intensively in cages suspended in rivers or reservoirs. In North Vietnam, the raising of grass carp intensively in cages in rivers has led to the widespread dissemination of disease problems on a level rarely present in the livestock business. Fish become infected in cages throughout river systems as well as those stocked in ponds that depend on the river for their water supply.

Control of infectious disease has been a crucial part of the intensive poultry industry, with immunisation being critical. Although much less well developed in aquaculture, vaccines are now regularly used for a range of diseases in salmonids (Weston, 1996). As inland aquaculture in Asia intensifies, it is likely that fish vaccines will become similarly important.

Public health

Threats to public health from both livestock and aquaculture are diverse. Throughout history infectious diseases have (largely) entered human populations through animals (Morse, 1990). Modem-day society is threatened with both ancient, as the recent outbreaks of anthrax in Australia and Thailand indicate, and novel risks such as the rise of BSE in the UK. A pundit recently questioned the virtue of the World's future fish supplies being dependent on intensively raised fish fed fishmeal and risking an epidemic of PSE (Piscine spongiform encaphaly)! Prophylactic use of antibiotics and growth promoters in intensive fish feeds rival their use in the livestock industry and are creating similar problems in terms of public health and consumer resistance. Legislation governing the use of these compounds in different countries is threatening international trade.

Both intensive livestock and aquaculture can pollute valuable surface water and affect human health. Both can be involved in passive or active transfer of a range of parasites and diseases. Fish are intermediate hosts for a range of human parasites. However, the use of human and livestock waste in semi-intensive fish culture, subject to certain safeguards, can generally be considered positive in any holistic assessment of risk (Edwards, 1993).

A major issue raised recently has been the possible connection of livestock and fish in the emergence of influenza pandemics, a story which has led to heated debate in both the scientific and popular literature (Scholtissek and Naylor, 1988; Edwards et *al.* 1988; Edwards, 199 1; Skladany, 1996). It has been claimed that the farming of pigs, poultry and fish together on the same farm is predisposing Asia and the World to the emergence of new virulent strains of influenza virus. The known transfer of such viruses from poultry to pigs, which act as 'mixing vessels' for the virus to undergo 'antigenic shift', is not questioned by aquaculturists, but rather the role of aquaculture in the process. Modem, integrated systems in which both poultry and pigs are raised together on the same farm with fish are rare for logistic reasons whereas traditional farming of poultry and pigs together on farms without fish is common throughout the developing world and especially in China. Home to many of the world's poultry and pigs, China is also the putative source of origin of new strains of influenza.

System development

Physical containment-modified environments

Understanding of reproductive and feeding habits of fish has been handicapped by the practical difficulties of direct observation. Behaviour of terrestrial livestock is readily observable but limited knowledge of fish behaviour has greatly hindered the development of optimal management for aquaculture. Only recently has the use of underwater video improved our understanding of salmon behaviour in cages.

Intensification of livestock and fish production relies on high performance in highly modified culture environments. A range of intensities has been described for both livestock and fish (Little and Edwards, 1994). Culture environments may be little changed from natural conditions (deepening natural pools to maintain year-round water for swamp fish) or the maintenance of natural ecosystem complexity in traditional and modem agro-pastoral systems. The other end of the spectrum is exemplified by modern battery chicken egg production systems or modified light regimes which are used to maintain breeding stock in animal husbandry and aquaculture, respectively. The aquatic environment has unrivalled opportunities for intensification because densities of fish can exceed 80 kg/m^3. Moreover, the movement of water in systems such as tanks and raceways facilitates handling, grading and harvest. Broiler chickens in contrast rarely exceed standing stocks of $20kg/m^2$.

Another aspect common to the intensification of fish and livestock is the trend towards specialisation within the production cycle. Seed production of fish is increasingly becoming specialised with separation of nursery, grow–out and fattening of fish in the same way that breeding, ranching and fattening of cattle are commonly distinct operations. Commercial systems, apart from greater levels of inputs, are also characterised by improved stock management. Enhanced survival through careful husbandry of the young and maintenance of optimal densities are as important to semi-intensive fish production as to managing ruminants on pasture. Developments of closed cycle production, both in terms of the life cycle of the cultured species and insulation from the external environment, are common trends for both livestock and fish. In tropical Asia, temperature control to maintain appetite and performance are critical for livestock. Low temperature becomes a problem in aquaculture in Asia at higher altitudes and latitudes but water quality, particularly the need to maintain dissolved oxygen and remove nitrogenous wastes, is a paramount concern for fish culture everywhere.

Intensification of both livestock and fish production has become a major issue in developed countries of Asia and elsewhere in terms of pollution of surface waters. Industrial agriculture, both terrestrial and aquatic, typically results in a 'breach in the flow of nutrients' (Borgstrom, 1973). Extensive and mixed livestock or fish production systems are typically nutrient-limited, with wastes recycled at their site of production. In contrast, local reuse of nutrients frequently becomes impossible at the concentrations typical of intensive systems. Pollution control in intensive aquaculture is particularly problematic as nutrients are usually removed in effluent waters in pond systems with major exchanges of water, or continuously enter the surrounding waters in cage culture. Low concentrations of pollutants at high flow rates characterise wastes from intensive aquaculture operations (Cripps, 1994), whereas the relatively low moisture livestock wastes can be collected and often stored before treatment. In contrast, fertilised semi–intensive ponds have little environmental impact (Edwards, 1993) with most nutrients being retained in the pond sediments. This is the basic rationale behind the promotion of intensive feedlot livestock within mixed farms in Asia. By balancing the scale of intensive livestock production and associated waste with the nutritional needs of surrounding fish and cropping systems, pollution is not only avoided but wastes are recycled. Practically, however these systems are often complex, difficult to manage and risky, particularly with regard to input supply and marketing (Little and Muir, 1987), and become the preserve of entrepreneurs rather than small-scale farmers. Such systems, however, are having major impacts on the supply and price of fish and poultry in certain countries in Asia (Little and Satompanit, 1997). Generally, more intensive and urbanised aquaculture and livestock cannot be integrated in this direct fashion but farmer entrepreneurs are developing methods that are both technically and economically viable. These include the use of invertebrates, such as the green bottle fly larvae (*Lucilia sericata)* to 'pre-treat' odorous, bulky manures prior to their use as live feeds for valuable, carnivorous fish (Nouv et *al.* 1995). Much larger amounts of feedlot livestock manure can be 'treated' by aquaculture in this way, whilst residue manures are reduced in moisture and rendered more valuable (Little and Edwards, 1994). Processing wastes produced by livestock abattoirs are also being locally recycled into feed ingredients by fanners in peri–urban areas, where the two activities are often located (Little et *al.* 1994)

Polycultures and integration

'Polyculture' defined in a broader sense to include not only different species linked in terms of feeding or spatial niches within a culture system, but with other roles or components of a larger network, has great potential. Manufacturing industries of the future are being designed to have negligible impact on the environment by using materials that can be recycled, and by physical integration allowing consumption of each other's waste. These traditional agricultural principles should also be followed by intensified, industrial food production. The adoption of 'organic' concepts by intensive agriculture involves the use of managed polycultures. Fish are increasingly stocked in flooded rice fields for their role in integrated pest and nutrient management in addition to diversifying outputs (Lightfoot et *al.* 1992). Egg-laying ducks are used to control both insect and crab damage in rice, while muscovy ducks are more economic at fly control in feedlot dairy units than conventional insecticides (BOSTID, 199 1). Cattle are used to maintain pond bank–side compaction and vegetation control in commercial catfish farms in the USA, and also in small-scale farms in Asia.

Introduced species and biodiversity

The introductions of new species for culture and their roles in loss or maintenance of biodiversity have been long-standing issues in livestock production, and more recently in aquaculture. In contrast to livestock and irrespective of the type or management of aquaculture system, escapees are impossible to prevent completely. The impacts of escaped and introduced exotic fish on indigenous ecosystems have been reviewed (Beveridge and Philips, 1993; Arthington and Blühdorn, 1996) but are often poorly chronicled and contradictory. Moreover, the potential risks from establishing new species or altering indigenous gene pools are now considered to be some of the most damaging and least reversible of environmental impacts (Pullin, 1993). Disturbance of local habitats has been well described in relation to the introduction of the common carp into Australia where, for its nuisance value, it should probably be termed the 'aquatic rabbit'. Additionally, new species have been associated with predation, competition, introduction of diseases and parasites and genetic degradation of local stocks (Beveridge and Phillips, 1993). Clearly, some environments are more sensitive, and some fish species more likely to cause adverse consequences than others. Many introductions, as with livestock, have bought short and long term costs and benefits that defy simplistic analysis (Welcomme, 1988).

The imminent loss of habitat and stocks of wild fish of potential culture value through environmental degradation and modification has no immediate equivalent in livestock, although genetic resources of various non-conventional species including various micro-livestock may be threatened if not more fully appreciated and conserved (BOSTID, 1991). The disappearance of once common indigenous strains of livestock throughout the World should be a clear message to countries to safeguard these resources.

Future trends

Aquaculture has undergone a rapid increase in global growth over the past two decades of almost 10% per year, which has and much faster than any other food commodity. More than 80% of global production came from Asia. Inland aquaculture production was about half of this total, with fin fish providing more than 99% of this farmed output (FAO, 1995). Semi-intensive production of carps and tilapias, the bulk of the production., will continue to expand in areas where water and land have low opportunity value. Growth in intensive livestock will provide inputs to many of these systems, particularly in peri–urban areas. In rural, resource-poor areas, the use of inorganic fertilisers will often be the most rational choice of inputs (Edwards et *al.* 1996a).

Certain catfish species (*Clarias spp.) will* also grow rapidly along with agro–industry in peri–urban areas of the region; these fish can be raised extremely intensively and are highly tolerant of poor water quality. Co-location of this type of fish culture with slaughter houses to utilise fresh processing by-products is now common in Thailand, a pioneer in the development of integrated culture systems.

A gradual shift from carps to tilapias is also likely, especially in the most economically dynamic and warmer parts of developing Asia. Tilapia is less bony and can yield more in semi-intensive systems than carps (Hossain, 1995), although their relative intolerance of low temperatures has restricted their adoption in sub-tropical areas. Its importance as a food for the poor, particularly in polycultures with indigenous and introduced carps, will continue to grow. Tilapia can be cultured in brackish water as well as freshwater and has the ability to produce high yields in fertilised water supplemented by pellets without fishmeal. Culture in semi-intensive ponds and cages suspended in community water bodies will have the greatest relative advantage in terms of production cost. Hatchery constraints have been largely overcome and the mass production of monosex seed capable of reaching a predictable market size is now a commercial reality (Little *et al.* 1997).

On the threshold of being a major international commodity, tilapia will also be the favourite for intensification and export as frozen fillets. Experience gained in the vertically integrated poultry business will be vital and countries and companies with experience are already developing production capacity. A major problem has been the difficulty of scaling up production to meet consistent quantity and quality standards. An important issue, however, is whether development of the corporate sector will undermine 'backyard' tilapia production (Pullin et *al.* 1994). As for livestock production, research, development and funding agencies need to accelerate resources for improving the productivity of small-scale systems appropriate for the majority of rural people.

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Acknowledgements

The concepts outlined in this article reflect the nearly two decades that both authors have worked in the region and the quality of the people with whom they regularly interact. The Agricultural and Aquatic Systems Program at AIT comprises active educational, research and outreach components in Indochina. Colleagues at AIT and throughout the region have contributed to the formulation of these ideas. The authors are both seconded to AIT by the Overseas Development Administration, UK.