Urban Aquatic Production[1]

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Introduction

The cultivation of fish and aquatic vegetables is widespread throughout many cities in South and Southeast Asia and is found to a lesser extent in Africa, Europe, Latin and North America. Despite growing recognition concerning the roles of urban agriculture, including aquatic production, the importance and potential of growing fish and edible aquatic plants in and around cities remains largely unknown. Urban aquatic production is often intrinsically linked with the livelihoods of a significant number of poor people. Urban aquaculture encompasses a broad array of activities, varying from large-scale extensively managed culture-based fisheries like those in the East Kolkata Wetlands to intensive and high-tech production of freshwater and marine fish in tanks. However, in many Asian developing countries, the production systems involved are frequently semi-intensive utilising wastewater directly from the city as a source of nutrients to increase production.

The proximity of aquatic farming systems to urban areas presents a number of problems. These may be especially severe if contamination, through urbanisation and industrialisation, of waste resources traditionally exploited to enhance production causes the quality of fish or plants being cultured to deteriorate or negatively affects productivity. Faced with pollution problems, some farmers opt to intensify production depending less on exploiting human waste resources, and more on utilising feedlot livestock waste or inorganic fertilisers and supplementary feeds to enhance production. However, as with intensification in other agricultural sectors, there are risks associated with adopting such an approach. These will be discussed further.

Other farmers adopt alternative strategies to mitigate hazards and minimise risks associated with urban aquatic production, but in many cases it seems that the scale and complexity of problems that face urban producers means it is almost impossible for them to address the underlying causes. Foremost amongst these is the sheer rate and scale of physical transformation that characterises many urban centres; much of this change inevitably alters social and economic as well as physical landscapes.

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Productive and viable farms may be converted to concrete and tarmac in the course of just a few years. Such dynamic settings can however offer new opportunities for aquatic farming. Limited coordination amongst urban and rural government agencies, weak and ineffective governance, and limited resources mean that urban producers and their problems are often overlooked or ignored. Despite such constraints, urban aquatic production systems provide food and employment, particularly to the poor, whilst there are many other environmental and social benefits that are assessed in the following sections.

Urban aquaculture is defined here as the practice of aquaculture occurring in urban environments, or areas subject to urbanisation, incorporating by definition peri-urban situations. However, demographic and economic processes giving rise to urbanisation do not occur evenly around urban areas, and many factors influence the rate and extent of urbanisation. Furthermore, urbanisation is not always directly associated with development around pre-existing urban centres. Aquaculture activities (defined in Box 1) undertaken in both urban and peri-urban settings share many characteristics. However, we propose that as communities or environments become more urban in nature and the competition with other resource uses develops, then the management of aquaculture must become more intensive, though exceptions and limitations exist. Little and Bunting (2005) provide a more detailed review concerning the basis for development of urban aquaculture.

Box 1 Aquaculture defined

Aquaculture can be broadly defined as the farming or culture of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants where according to FAO (1995) ‘farming implies some form of intervention in the rearing process to enhance production, such as the regular stocking, feeding, protection from predators, etc.’ The FAO definition also notes that farming ‘implies individual or corporate ownership of the stock being cultivated’. However, based on a more practical understanding of the diverse settings in which aquaculture has evolved Beveridge and Little (2002) note that ‘if there is intervention to increase yields and/or ownership of stock or controls on access to and benefits accruing from interventions that this should be classed as a form of culture’; this definition encompasses all types of ownership, including that of households, families, communities, co-operatives and governments that all engage in aquaculture activities. This is of particular importance in the context of urban aquaculture where the equitable management of scarce natural resources is often likely to depend upon community-based organisations retaining ownership, or at least the right to exploit aquatic plants and animals cultured using common property resources.

Urban aquaculture systems

Considering the range of urban aquaculture systems, this overview covers the most significant and widespread activities, including aquatic plant production. With many urban centres located in coastal areas, it is also important to note that urban aquaculture, although probably dominated by freshwater production, may also include production in brackish water and marine environments. In this review we build on the aquaculture systems typology proposed by Coche (1982) to better characterise the nature of aquaculture occurring in urban areas and to demonstrate that the intensity at which urban aquaculture is managed varies in response to external pressures and incentives for producers. Coche (1982) defined aquaculture production systems as extensive, semi-intensive and intensive. The main characteristics of systems managed at these different intensities are outlined in Table 1.

Conventionally, extensive aquaculture is characterised by the dependence of stock on natural food, however, in most urban and peri-urban settings it can be assumed that natural production in water bodies where extensive aquaculture is practised is enhanced indirectly through nutrient-rich runoff and drainage water. Semi-intensive production routinely involves fertiliser applications to enhance natural food production and / or the provision of low-protein supplementary feed; in urban settings waste resources (agricultural and food processing by-products, offal, hotel and restaurant waste) and direct wastewater applications are exploited.

Table 1 Characteristics of urban aquaculture systems managed at different intensities

	Management intensity		
Characteristic	Extensive	Semi-intensive	Intensive
feed source	natural production enhanced indirectly through nutrient rich surface runoff and drainage water	exploitation of waste resources and fertiliser applications to enhance natural production and / or the provision of basic supplementary feed	dependence on externally supplied high-protein feed; which in some cases may have been produced using by-products e.g. tubifix worms, fly larvae
access, ownership and tenure	open access, common property resources	private, cooperatives, leaseholders, community-based management	private, commercial, research and development, vertically integrated
markets	subsistence, local retail markets	subsistence, local and regional wholesale and retail	high value food and ornamental species, regional and export oriented, food products processed to add value
constraints	variable productivity; access may be denied to poorer community members and new entrants; urban sprawl; competition with other user groups; theft and poaching	contamination of waste resources and pollution may inhibit production and affect consumer sentiment; urban sprawl; limited control over environmental perturbations	high capital costs; inherent financial risks; susceptible to disease outbreaks, technical failures, changing market conditions and competition
opportunities	poorer community members may benefit through continued access or cheaper food from low investment systems	where hazards can be minimised, local production of fish and plants from urban systems can contribute to food security, enhanced livelihoods and environmental protection	investment opens up access to new and larger markets; possibility of higher returns from money and resources invested

Intensively managed systems, whether in rural or urban settings depend on externally sourced inputs of high protein (>20%) feed; but in urban areas entrepreneurs have seized upon opportunities to utilise by-products and waste resources to culture high protein feeds such as tubifix worms and fly larvae to supply aquaculture producers. Practically, however, these distinctions can become blurred. Many peri-urban culture systems benefit from enhanced natural food production as a consequence of nutrient disposal rather than purposeful fertilisation. Furthermore, in contrast to formal semi-intensive sewage-fed aquaculture, production of aquatic vegetables in nutrient-rich water bodies and canals uses sewage-derived nutrients but there is no control over its concentration, as would be the case in the formal system. Nutrient inputs into many systems may be more or less unregulated although the harvest of products such as fish or plants may be highly managed.

Extensive urban aquaculture
Extensive aquaculture is practised in a number of urban settings; the most notable approach consists of stocking fish in reservoirs and large urban water bodies, followed by recapture after a period of 1-2 years. Accounts of stocking and harvesting fish from urban reservoirs have come from cities such as Brasilia, Brazil (Starling, 1998); Hanoi, Vietnam (Sy and Vien, 2002) and Wuhan, China (Liu and Cai, 1998). Culture-based fisheries in Donghu Lake, Wuhan, which covers 1,500 ha are dependent on stocking millions of silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) seed, and providing nursery areas in dammed coves, net-barred bays and net cages to ensure fingerlings are only released when they are sufficiently large to avoid predation. Predatory fish are also controlled to help limit mortality, whilst bulk harvesting is undertaken after a year when fish are around 1 kg in weight. Owing to enhanced management, production increased from 180 t in 1971 to 1,840 t in 1995. The manipulation of fish stocks in urban reservoirs, through selective stocking and harvesting, has also been employed to control eutrophication, but with variable success (Starling, 1998).

A serious constraint to aquaculture in urban reservoirs is the multiple uses of such water bodies by various groups, often with conflicting interests. The openness of such systems also makes it difficult for those farming fish to monitor hazards such as possible pollution sources, or to keep an eye on the activities of other users. The use of cages or pens may constitute an opportunity for farmers to secure access to parts of common property resources, but access of this type may be difficult to negotiate and is likely to cause conflicts and possibly disadvantage poorer sections of communities. There is a growing body of literature concerning common property resources, and guidelines and best management practices proposed for aquatic resources may be useful in developing equitable access and management strategies for urban aquaculture (see for example Bromley, 1992). Continuous cropping of fish from eutrophic urban water bodies is probably one of the most productive and beneficial systems accessible to the poor in Asian cities. Mara, Edwards, Clark and Mills (1993) predicted that a yield of 13 t ha per year would be achieved through the continuous stocking and harvesting of tilapia from extensive lagoon systems managed for wastewater aquaculture, which is significantly higher than production levels in most semi-intensively managed traditional pond based-systems.

Cage culture is practised on a large scale in the Saguling-Cirata-Jatiluhur chain of reservoirs downstream of Bandung, Indonesia (Hart, van Dok and Djuangsih, 2002);

estimates suggest some 4,425 fish cages, producing a total of 6,000 tonnes per year of tilapia (*Oreochromis* sp.), are present in the Saguling Reservoir. However, cages and pens are open to the wider environment and as such susceptible to water quality problems. This *de facto* privatisation of the common pool resource inevitably requires capital assets less available to the poor, who can therefore be quickly excluded from production activities.

It is important to note here that urban wastewater, through nutrient enrichment of receiving water-bodies, can enhance production of wild fisheries. However, little work has been done to quantify the extent and significance of this relationship, whilst most attention is given to ensuring that nutrient enrichment in receiving water bodies does not exceed the environmental carrying capacity, degrading the environment and actually harming capture fisheries. Considering the widespread lack of wastewater treatment facilities in many developing countries, it is likely that drainage water from cities in many countries is flowing to rivers, ponds, lakes and rice fields in urban and peri-urban areas, however, little work has been done to document or quantify this, or to assess the costs and benefits of informal wastewater reuse through aquaculture. Moreover, the environmental, animal and public health risks associated with indiscriminate discharges of wastewater to the wider environment and the subsequent capture and consumption of wild aquatic products require consideration (see the Bangkok case study).

Semi-intensive urban aquaculture

Unlike aquaculture in reservoirs and large lakes, pond-based aquaculture offers farmers greater control over management and permits better surveillance, enabling producers to guard against theft, predation and contamination. Recent accounts of semi-intensive pond-based aquaculture in urban settings have been reported for several counties, including Cuba, Ghana and Tanzania (Abban and Cudjoe, 2005; Coto, 2005; Rana, Anyila, Salie, Mahika, Heck and Young, 2005).

Around Kolkata, West Bengal, India, urban aquaculture is practised in ponds covering an area of approximately 3,500 ha where the majority of production is based on wastewater inputs from canals draining the city. Various historical reasons and government interventions have contributed to the scale and distribution of land holdings in the area. The landowners are commonly absentee landlords and management of the fisheries is largely undertaken by the leaseholders; others are operated by cooperatives and groups of fishermen and a small number are under government control. Recently it was estimated that these urban ponds produce ~18,000 tonnes per year of fish for sale in urban markets, many of which serve poor communities. Bunting, Kundu and Mukherjee (2005) present a detailed account regarding the management of the system and the constraints facing producers (see the Kolkata case study for further information). A similar system has evolved in Thanh Tri District close to Hanoi, Vietnam. Phuong and Tuan (2005) reported that the total area of fish production in peri-urban Hanoi was 3,348 ha with an annual yield of nearly 9,000 t, and that 52% of this production was from Thanh Tri district. However, Edwards (2005) noted that owing to land use planning changes outlined by the authorities the fish culture area in Thanh Tri (now Hoang Mai district) was destined to decline and change from traditional semi-intensive systems to intensive or organic farming, with the emphasis on producing high-quality seed and high-value aquaculture species.

Aquatic vegetable production in semi-intensive and intensive systems is widespread and commercially significant around many cities in Southeast Asia. According to Phuong and Tuan (2005) in Hanoi, water spinach (*Ipomoea aquatica*) is produced throughout the year, whilst water mimosa (*Neptunia oleracea*) is cultivated only in the summer (April to August) and water dropwort (*Oenanthe stolonifera*) and water cress (*Rorippa nasturtium-aquaticum*) are produced in the winter (September to March). Most production occurs in flooded fields, some of which were converted from rice production to generate a higher income; water spinach is also cultivated floating on canals within the city. Water mimosa and water spinach production is reported from peri-urban provinces around Bangkok (Yoonpundh, Dulyapurk and Srithong, 2005). Around Ho Chi Minh City, Vietnam, many farmers in Binh Chanh District have combined water mimosa cultivation with fish production in separate ponds; mimosa providing a daily income whilst the fish consume the duckweed that grows alongside the mimosa (Hung and Huy, 2005).

Duckweed (*Lemna* and *Wolffia* spp.) are commonly removed from aquatic vegetable crops in both Vietnam and Thailand for use locally as fish feed. Water spinach is grown in converted rice fields in Thu Duc District utilising wastewater, in some cases water spinach leaves are used to feed cultured fish species such as giant gourami (*Osphronemus gouramy*) and kissing gourami (*Helostoma temmincki*) that can readily digest and benefit from them. The operating costs for aquatic vegetable production may be lower than for fish culture, the risks from environmental perturbations less and the potential returns higher. However, aquatic vegetable production in many areas is threatened by land use change and the environmental, animal and public health impacts of applying large quantities of agrochemicals during production remain to be quantified. Relatively, aquatic vegetables may be more robust for urban aquaculture than fish; the investment costs tend to be lower and the vegetable crops tend to be less sensitive to acute loss from pollution than fish.

Semi-intensively managed ponds are frequently observed in towns and cities throughout Asia. Production from urban aquaculture however is not usually considered separately from rural production in regional or national statistics, and consequently it is difficult to assess its extent and relative importance. The considerable production of freshwater aquatic plants is also not generally acknowledged even in national statistics. Risks, costs and benefits associated with small-scale urban aquaculture are poorly defined and understood and this may prohibit investment of time, money or resources in developing enhanced approaches. Risk assessment in relation to household aquaculture practices in urban settings is required if sustainable practices are to be identified and promoted, and is discussed further on in this paper.

Describing semi-intensive aquaculture production in ponds close to Kumasi, Ghana, Agyapong (1999) noted that tilapia (*Oreochromis niloticus*) and catfish (*Heterobranchus* sp.) are farmed in ponds ranging from 12 to 54,000 m^2. Poultry manure is widely used to fertilise ponds and supplementary feeding with maize bran, groundnut husk and paste, leaves and coconut fibre is routine. Production from 94 fish farms in the area has been estimated at ~150 tonnes per year. Aquaculture practices that utilise food processing and agricultural by-products, such as poultry manure, are widespread and diverse, and aquaculture has an important role in recycling organic wastes from industrial and urban activities. For example, in Thailand, by-products from chicken processing plants are used to feed catfish (*Clarias gariepinus* x *Clarias macrocephalus*) grown in urban aquaculture systems stocked at high densities (Little, Kaewpaitoon and Haitook, 1994). Little and Edwards (2003) provide a framework for the interaction between livestock and fish production in peri-urban conditions, as opposed to rural environments.

Integration of aquaculture with wastewater treatment using stabilisation ponds and lagoons is widely advocated and several operational systems have been developed; Mara et al. (1993) describe a rational design approach for lagoon-based wastewater treatment that optimises both wastewater treatment and fish production. Lagoon-based systems have been developed for small municipalities in West Bengal, India (Mara, 1997); design and management approaches for these systems have been derived largely from the traditional urban aquaculture practices close to Kolkata. In Lima, Peru, treated wastewater has been used to produce tilapia and studies have demonstrated that fish cultured in this way are acceptable to consumers and that the proposed approach is economically viable (Moscoso, 2005).

Intensive urban aquaculture

Intensively managed aquaculture operations in urban areas are being developed by entrepreneurs in several countries. Although less land may be required per unit of production for intensive as compared to semi-intensive production units (Bunting, 2001), investment costs associated with establishing intensive systems are comparatively high. The advantage of intensively managed farms is that operators can exert greater control over the operation of the system, better regulating factors such as water quality, feed delivery and stock management. More intensive, less open systems also offer producers greater control over public, animal and environmental health hazards. However, due to high capital and operating costs of intensive systems, in many cases it is only feasible to produce high value products, which are often destined for specialist markets.

In Europe, and North America intensive urban aquaculture systems have been used to produce high value fish such as eel, sea bass, shrimp and tilapia (Browdy and Moss, 2005; Bunting and Little, 2005; Zohar, Tal, Schreier, Steven, Stubblefield and Place, 2005). Often, this is only possible where investment costs are reduced through using redundant buildings or waste heat, for example from power stations, to subsidise operating costs. Further to producing food, examples of urban aquaculture from Europe, North America and other regions demonstrate that the practice is used to produce ornamental species, to create visitor or tourist attractions, or is included as part of social development and educational schemes. In developing countries, intensive urban aquaculture systems do exist, for example, producing ornamental species for regional and export markets, a practice that is being encouraged by the local government around Ho Chi Minh City in response to growing pressure on land resources (Hung and Huy, 2005). Intensive production of catfish has been reported from small areas around Lagos, Nigeria (Rana et al., 2005); in Cuba, the Ministry of the Fishing Industry promotes the concept of ‘family aquaculture’ which includes intensive fish production in urban systems (Coto, 2005); waste from hotels, cafeterias and factories is used in Bangkok to culture catfish intensively (Little and Bunting, 2005). Other intensively managed farms producing high-value food fish and high-quality seed are destined to emerge in other urban and peri-urban settings in response to market demand, rising land prices and concerns over environmental, animal and public health.

Dynamics

In peri-urban areas, access to larger markets and more consistent and reliable demand, mean that producers are more likely to invest in a wider range of semi-intensive management strategies. The greater availability and concentration of domestic waste, in particular wastewater from urban drainage systems, and by-products from food processing and marketing, mean that producers are also able to exploit such resources, reducing their expenditure on fertilisers and feeds. Apparent subsidies to peri-urban farmers in the form of waste resources offer them a significant advantage over producers with limited access to such production enhancing inputs. In selected examples access to such resources has led to dramatic growth in peri-urban aquaculture and widespread benefits for producers. For example, tilapia seed producers utilising sewage near Ho Chi Minh City have a valuable competitive advantage over other producers in the Mekong Delta, even after including transportation costs (AIT/CAF, 2000). However, despite the benefits of being located close to markets and being able to access waste resources, there are potential constraints associated with undertaking aquaculture in urban areas (which are discussed in the following sections).

The transition from extensive to semi-intensive may be attributed to various factors, of which greater demand from markets combined with improved marketing channels often constitutes an important driver for intensification. Control of resources, more access to production enhancing inputs, for example, waste resources, food processing by-products and credit to purchase additional seed, feed and labour can also stimulate intensification. In urban settings the transition from semi-intensive to intensive production appears to be driven largely by financial considerations and increased competition for resources, in particular land, but also solid organic and wastewater resources, labour, credit and markets. Intensification also appears to offer producers greater control, enabling them to better safeguard and enhance the quality of products, addressing concerns expressed by consumers regarding possible health hazards. Despite the competitive advantage associated with intensification, several barriers to such a transition can be identified; transaction costs may be high, whilst limited access to knowledge, training, credit, markets and institutional support limit the options and opportunities available to producers. Insecure tenure and poorly defined property rights can also mean that producers are unwilling or unable to invest in intensification or improved management approaches.

Benefits of urban aquaculture

Employment, income generation and food security constitute important and tangible benefits of urban aquaculture, in particular, for people from poorer communities. However, wider benefits afforded to society such as managed waste reuse leading to improved public and environmental health protection, economic benefits such as increased tax revenue and subsidised waste management, non-renewable resource recovery; additional functional and non-functional values may also be attributed to urban aquaculture.

Food security and meeting market demand

Reliable and high level demand for aquatic products in urban markets is a primary driving force behind the development of many urban aquaculture activities. Farmers engaged in urban aquaculture have a number of advantages over rural producers, most notably their proximity to markets means that they, or intermediaries, are able to deliver fresh products in a timely fashion to consumers, potentially securing a market premium. Consumers in many Asian countries prefer to buy live fish as a guarantee of freshness, and for urban aquaculture producers it is possible to supply live fish to the market at little extra cost. Increased supplies of aquatic products to markets from urban aquaculture can also help lower the cost of such commodities, thus making them more accessible to poorer communities. Considering aquaculture at the peri-urban interface of cities such as Hanoi and Kolkata, having access to wastewater means that farmers are able to supply fish throughout the year to urban markets. This is important as many of the markets supplied serve poor communities (Morrice, Chowdhury and Little, 1998) and there is a growing recognition (Punch, Bunting and Kundu, 2002) that in some situations urban aquaculture makes a significant contribution to food security in poor households and communities.

Employment and income

Urban aquaculture can provide employment for large numbers of people. Jobs are created directly as a result of stocking, harvesting, maintainance and management, and indirectly in associated activities such as producing and supplying seed and feed, making nets and boats and transporting and marketing harvested products. Estimates suggest that urban aquaculture around Kolkata provided direct employment for 8,000 people, whilst employment in associated sectors servicing the farms was put at over 20,000 people (Kundu, 1994). Employment of one family member, either directly of indirectly, as a result of aquaculture may provide a valuable source of income, but it cannot be assumed that benefits are divided fairly amongst household members (Harrison Stewart, Stirrat and Muir, 1994). Furthermore, where urban aquaculture is practised on family farms, inequality within households may mean the distribution of tasks unfairly burdens particular individuals. As noted in the previous section, many urban aquaculture systems operate throughout the year, and consequently workers employed in such activities are less vulnerable to seasonal labour demands. However, it should be noted that a seasonal demand for additional labour does occur in some situations, and employment for even short periods may constitute an important component in the portfolio of activities that make up poor livelihoods (Punch et al., 2002).

Resource recovery

Reusing wastewater and by-products from agriculture and food processing in urban aquaculture offers a possible solution to the problem faced by many farmers in developing countries of limited access to nutrient inputs and water resources. Ensuring the maximum possible benefit is derived from appropriated water resources and nutrients contained in both solid and liquid waste will reduce pressure on the remaining renewable freshwater resource and non-renewable mineral resources. This may contribute to reduced conflict over controversial dam building and mining schemes, and limit environmental degradation. Furthermore, compared to prevailing approaches to disposing of wastewater and solid organic waste in many developing countries, productive reuse of waste resources in urban aquaculture offers a greater degree of environmental protection.

Financial returns generated by urban aquaculture, and in particular where wastewater or agricultural and food processing by-products are employed, could potentially subsidise the development and maintenance of formal collection, treatment and delivery strategies for the waste resources. Mara and Cairncross (1989) noted that for Trujillo, Peru, the approach recommended for development of a lagoon-based wastewater treatment facility was to charge construction costs to the municipality and to charge the local farmers who irrigated their crops with treated wastewater with land and operation costs. Responding to a survey, the local farmers indicated that this was an equitable solution, with the cost of treated wastewater expected to be half of what some of them pay for groundwater.

Household and community health and benefits

Urban aquaculture can help facilitate the managed reuse of waste resources and according to Mara and Cairncross (1989) wastewater reuse through aquaculture, which occurs predominantly in urban settings, could be an important component in the sanitation strategies of poor communities in developing countries. Providing sanitation is an important component of development, and is recognised as being of prime importance in improving the general health of the population, reducing infant mortality and the incidence of severely malnourished individuals with associated physical and mental health problems whilst increasing life expectancy (World Bank, 1992; Ahmed, Zeitlin, Beiser, Super and Greshoff, 1993). Inadequate sanitation results in the degradation and contamination of groundwater and surface water. This in turn leads to a need to boil contaminated water, a process that uses large amounts of fuelwood, and results in atmospheric pollution, and possibly increases in respiratory disease (Birley and Lock, 1999). Nutritional and food security benefits associated with urban aquaculture were noted in the previous section.

Distributing benefits from urban aquaculture to the wider community can occur through the presentation of fish to family and friends as gifts; a custom which was observed to be widespread in the town of Saidpur, Bangladesh (Bunting, 2004). Furthermore, by distributing some fish at harvest time to community members residing closest to the ponds, a pond owner found it was possible to reduce the proportion of missing fish. This was attributed in part to either a reduction in poaching by the recipients or greater vigilance of his neighbours reducing the incidence of poaching and predation; enhanced flood control was another factor cited by the owner.

Burbridge (1994) presents a valuable summary of the most important functions attributed to wetlands. These include biomass production, sediment and carbon storage, filtration and cleansing of water, providing pathways or linkages between ecosystems, acting as buffers and regulating the rate of surface-water flow and groundwater recharge within catchments. Preliminary assessment suggests that a similar range of benefits may be attributed to agro-ecosystems supporting urban aquaculture close to cities such as Kolkata, Hanoi, Ho Chi Minh and Phnom Penh (Bunting, 2004; Little and Bunting, 2005).

Management of wastewater and by-products as inputs for urban aquaculture could be regarded as a subsidy provided by the farmers to society, reducing the demand for resources placed on local authorities. Depending on their design and operation, urban and peri-urban fishponds receiving wastewater inputs are likely to facilitate a range of physical, chemical, bio-chemical and biological contaminant removal processes similar to those observed in wetlands and lagoons (Watson, Reed, Kadlec, Knight and Whitehouse, 1989; Mara, 1997). Furthermore, assessments by Breaux, Farber and Day (1995) and Brix (1999) demonstrate that constructed wetlands constitute an ecologically sound and cost-effective means of sanitation, especially when compared with conventional waste treatment and management strategies.

Constraints to urban aquaculture

In the case of extensive and semi-intensive urban aquaculture practices, several factors threaten their continued operation and constrain development of more refined management strategies. The main factors implicated are described in the following sections. In contrast, however, there appear to be opportunities for intensively managed operations.

Urbanisation

Processes of urbanisation, in many cases, constitute the most significant threat to the viability of urban aquaculture. Rural-urban migration continues in many developing countries and migrants looking for employment increase the demand for new settlements and temporary housing, and slums may encroach on agricultural land, but more often become established on embankments, roadsides and derelict land. Conversion of land under for urban aquaculture is related to higher-value residential and industrial developments. Unregulated sprawl at the urban fringe is often seen as an irresistible force, leading to a general reluctance to invest in enhanced management practices and maintaining infrastructure, and generating feelings of insecurity among the inhabitants that have been linked to problems such as vandalism, theft and poaching (Little and Bunting, 2005; Kundu, 1994). Ineffective planning and irregular enforcement of regulations by poorly coordinated and resourced authorities exacerbates the problem.

Labour migration

Following an investigation of problems affecting the operators of farms in peri-urban Kolkata, Kundu (1994) noted that the loss of labour to more highly paid employment represented a constraint to continued operation. Enhancing benefits derived by the poor from urban aquaculture though increased wages and more secure employment arrangements may contribute to the retention of skilled labourers; an alternative would be to support the more effective transfer of skills to new employees. Where dynamic labour markets exist, with people commonly moving from farming activities to more attractive urban employment, this would create opportunities for under-employed community members and recent migrants.

Competition for markets

When threatened by development during the 1950s, a key argument for retaining a network of ponds and paddy fields in the Salt Lake region to the northeast of Kolkata was its ideal location from which to supply fresh produce to urban markets (Kundu, 1994). With the advent of new roads and increased access to public and private transport, urban markets become accessible to more distant producers. Surveying fish markets in Kolkata, Morrice et al. (1998) noted that the large Indian major carp had mostly been imported from other States, from Uttar Pradesh by truck and from

Madras, Orissa, Gujarat and Punjab by train. Market studies from Hanoi and Ho Chi Minh City, Vietnam, have identified an increasing demand for high quality aquatic products from urban consumers, but also note that competition from other producers threatens the market for products from traditional urban aquaculture activities (Hung and Huy, 2005; Phuong and Tuan, 2005).

Changing access patterns for inputs

Inadequate access to wastewater has been identified as a major constraint to continued urban aquaculture in the East Kolkata Wetlands. This situation has arisen due to siltation in the canal network conveying wastewater to the fishponds and the inappropriate management of sluice gates regulating the distribution of wastewater. The priority of the local authorities responsible for urban drainage is to ensure that wastewater is drained effectively and safely from the city, and they are under no obligation to supply the needs of the urban fish farmers. The farmers may find themselves in this position as they do not pay for the waste resource, whilst Kundu (1994) noted that competition between farmers exploiting the wastewater resource could be preventing effective distribution. As a consequence of these problems, the farmers are increasingly employing more manageable, but costly, inorganic fertlisers to sustain production and limit their dependence on unpredictable access to wastewater.

Introduction of a pricing system may be one approach to optimising waste resource use, although care should be taken not to disadvantage poor producers. The potential of developing markets for waste resources in stimulating improved supply channels was highlighted by Furedy, Maclaren and Whitney (1997) who suggested that where traditional waste reuse practices have declined, establishing markets for organic waste may promote separation and collection, increasing the value of this resource to farmers and providing income for those involved in processing. Where formal markets are established, such recognition may in turn demand proper regulation to ensure environmental, animal and public health protection. The use of livestock waste in predominantly fish culture and horticulture areas to the south and east of Bangkok are examples of the networks that develop between producers and users of waste in an environment where communications and infrastructure are well developed (Little and Edwards, 2003).

Contamination

Contamination of surface water resources with domestic and industrial pollution constitutes a widespread threat to urban aquaculture. Biswas and Santra (1998) noted that the heavy metal content of fish purchased from urban and suburban markets in Kolkata was higher than similar products from rural markets. Referring to urban aquaculture in Hanoi, Vietnam, Edwards (1997) noted that water from the Set River is widely used, with water from the To Lich River no longer being suitable owing to industrial pollution. The entire wastewater reuse system in Thanh Tri district was apparently in decline, with the canal network that had fallen into disrepair and rubbish dumped in the canals compounding the problem. Problems of contamination are also reported for the Chinese wastewater aquaculture systems in Han Kou region where accounts suggested that fish produced here smelt and tasted of phenols; grow-out ponds are now used as nurseries for small fish, removing problems of consumer acceptance. Where wastewater or other waste resources are used for urban aquaculture the risks posed by contaminants demand careful assessment and monitoring. Bunting and Little (2003) discuss the implications of this and other potential sources of contamination in urban aquaculture in more detail. Source separation could provide one practical approach to dealing with growing concern over the contamination of wastewater destined for reuse.

Public health concerns

A number of authors have also described potential health hazards associated with urban aquaculture, and in particular those activities where wastewater reuse is practised (Mara and Cairncross, 1989; Strauss, 1991; Edwards, 1992; Edwards, 2001; Howgate, Bunting, Beveridge and Reilly, 2002). Although several of these reviews make hazards associated with aquaculture explicit, it is much harder to quantify the associated level of risk. For example, the risks associated with products grown using waste resources vary, depending on characteristics of the waste resource, the degree of treatment prior to use, the design and operation of the culture system, husbandry and processing practices, subsequent handling and preparation and susceptibility of the consumer. Reviewing health hazards associated with aquaculture employing wastewater reuse, Mara and Cairncross (1989) identified four groups of people at risk: field workers, crop handlers, local residents and consumers. Bunting (2004) provides a more detailed review of the hazards faced by these different groups, describes factors that influence the degree of risk and outlines potential strategies for mitigation. An emerging threat that requires greater attention is the possible relationship between aquaculture operations, where poultry waste is used as a fertiliser, and the transmission of bird flu to humans (see Box 2).

Despite possible health hazards associated with exploiting waste resources in urban aquaculture, it should be noted that adopting formal waste reuse practices incorporating treatment components and procedures for monitoring product quality represents a significant improvement on unregulated informal waste reuse practices. Pal and Das-Gupta (1992) demonstrated that water samples and organs from fish cultured in conventional rain-fed ponds contained certain pathogenic bacteria at concentrations two orders of magnitude greater than similar samples from fishponds receiving wastewater from Kolkata. However, risks posed by urban aquaculture, especially in systems reusing wastewater, should not be underestimated and those responsible for managing such farms should be provided with knowledge on limiting health risks. Schemes for risk identification and evaluation have been proposed by a number of authors (Blumenthal, Strauss, Mara and Cairncross, 1989; Mara and Cairncross, 1989; Strauss, 1991; Shuval, Lampert and Fattal, 1997), however, the development of appropriate materials and tools for operators and local authorities may assist in implementing such measures.

Changing social expectations and perceptions

The changing expectations and perceptions of operators, consumers and society may be responsible for the decline observed in once productive urban aquaculture systems. As mentioned previously, migration of skilled and experienced employees represents a possible constraint to the continued operation of traditional systems. However, it is important to acknowledge that the expectations of managers and employees are not limited to financial considerations; socio-cultural factors such as social status and conformity demand consideration (Sen, 1995). As consumers become more aware about the origins of the food they eat and get to know that products are derived from urban farming systems, which might be subject to even low level contamination, possibly from traffic fumes or road run-off, their perceptions may be negatively influenced, possibly restricting acceptability (Little and Bunting, 2005). Alternatively, through intensification permitting greater control and consequently quality assurance, it may be that consumers would be willing to pay a premium for products from intensively managed urban systems, and the proximity of urban aquatic production would also address emerging concerns over 'food miles'.

Box 2 Integrated aquaculture and avian flu

A possible relationship between outbreaks of H5N1 avian flu with poultry waste fed integrated aquaculture systems in Southeast Asia has been suggested. This has serious implications for both small and large-scale integrated fish farming systems in urban and peri-urban areas, particularly those utilising wastes from their own chickens, ducks and geese or bringing in commercial poultry wastes from outside sources. Birdlife International, a British-based organisation with partners in over one hundred countries and territories, recently highlighted the issue on their website and urged governments and relevant agencies to ban the use of untreated poultry faeces as fertiliser and feed in fish farms.

Scholtissek and Naylor (1988) identified a similar hazard earlier in a letter entitled 'Fish farming and influenza pandemics' published in Nature and on the promotion of integrated aquaculture systems in Asia stated that 'the result may well be creation of a considerable potential human health hazard by bringing together the two reservoirs of influenza A viruses, generating risks that have not hitherto been considered in assessment of the health constraints of integrated animal-fish farming'. In integrated systems where poultry and pigs are reared in close proximity there is the possibility of mutation of the virus within pigs into a more virulent strain which can more readily be transmitted from human to human, thus leading to fears of a pandemic. However, as Edwards, Lin, Macintosh, Wee, Little and Innes-Taylor (1988) note in their reply, pigs and poultry have been raised together on farms in Asia and Europe for centuries, and they discussed why the 'co-location of pigs and poultry to supply manure for fish culture is neither prevalent nor likely to become so' noting that most integrated livestock-fish farms combine a single terrestrial species with fish.

A recent newspaper article from Ho Chi Minh City stated that considerable quantities of chicken manure were used as feed for fish in Tri An lake, Dong Nai province and that 'the practice of using chicken excrement to feed fish in southern Vietnam is threatening millions of people with bird flu in Ho Chi Minh City and should be stopped' (Than Nien News, 2005). Despite such reports, evidence concerning the transmission of the virus to humans, mediated by such integrated fish farming has not yet been produced. In this regard there is a clear need for further research that can support the much needed risk assessments concerning the possible role of integrated aquaculture systems as reservoirs for the transmission of the virus, and whether the joint rearing of poultry, pigs or other livestock could lead to the mutation of the virus into a more virulent strain.

Considering the future of urban aquaculture this issue highlights more general food safety concerns regarding how fish and aquatic plants are produced using recycled wastes e.g. wastewater, and the paucity of research that has addressed this issue. The PAPUSSA project is assessing heavy metal levels in aquatic plants and fish raised using wastewater in Phnom Penh and Ha Noi, as well as the biological and chemical water treatment capacity of peri-urban aquaculture systems in Phnom Penh, Ha Noi, Ho Chi Minh City and Bangkok. If peri-urban aquaculture is to be sustained and deliver the potential benefits attributed to it in the future, such concerns will require greater attention and targeted human health and food safety oriented research so that policy makers, city planners, potential investors, entrepreneurs and perhaps most importantly consumers, will have the necessary and pertinent information available to them to feel more reassured.

Management constraints

Constraints to urban aquaculture presented above suggest that producers face a number of problems, many of which are beyond their control, but which have a significant influence on the management strategies employed. When practising extensive aquaculture, producers are often unable to exert control over the prevailing hydrology, whilst farmers managing large water areas for semi-intensive aquaculture may find it difficult to regulate all inflows and discharges. In such circumstances, the openness of the culture system may allow contaminants, predators and diseases to enter and nutrients, food resources and stock to escape. The physical openness of many extensive and semi-intensive systems also means there are risks from airborne pollution, particularly agrochemical spray drift, predators such as fish-eating birds, and theft by poachers. Considering that many constraints to production in extensive and semi-intensive aquaculture systems are beyond the control of the farmer, one potential management strategy to limit the risks posed by such hazards is to restrict the openness of the culture system. However, as both extensive and semi-intensive production activities depend on environmental goods and services to supplement inputs from the farmer, restricting the openness of culture systems requires the farmer to either reduce production or to compensate for the loss by increasing inputs.

Although farmers may wish to enhance or intensify production, insecurity of tenure often constrains innovation and investment, with farmers unwilling to invest in new technologies and management techniques, instead wishing to limit their exposure to financial risks. Limited access to finance can also constrain innovation by those willing to invest; Kundu (1994) noted that farmers around Kolkata were unable to access bank loans as they lacked documentary evidence of ownership and cultivation rights. Furthermore, urban aquaculture producers often have limited access to information, even on fundamental aspects such as disease and pest management and seed quality, therefore, development of enhanced dissemination pathways may be an important component in ensuring that farmers information needs are met.

Challenges for planners, policy-makers and natural resource managers

The nature, extent and management of urban aquaculture in various settings have been discussed above, and the most significant benefits and constraints associated with this farming activity have been described. However, from this assessment it is apparent that various gaps exist in the knowledge base relating to urban aquaculture and important areas requiring further consideration are discussed below.

Future direction – diversity in adversity?

Many traditional urban aquaculture systems, in particular extensive and semi-intensive systems, are undergoing rapid change in response to burgeoning urbanisation and industrialisation. Assessing the findings of recent research focused on peri-urban communities in Bangkok, Hanoi, Ho Chi Minh City and Phnom Penh, it is possible to identify some common trends and promising future scenarios which may be relevant outside Asia. Of the sixteen communities studied under PAPUSSA it seems likely that eleven would stop growing fish and aquatic plants within five years (Leschen, Little, Bunting and van Veenhuizen, 2005). The reasons behind this can be summarised as increasing pressure on land for residential and industrial construction and increasing environmental problems caused by industrial and chemical discharges in wastewater leading to declining production. The remaining communities are all located on the periphery of the cities, and some have been included within designated ‘agricultural production areas’ on official urban development plans, which may provide some security and explain their continued interest and involvement in urban aquaculture.

Within all of the communities studied a number of aquatic producers exhibited risk averse management strategies in response to the dynamic and changing environments in which they live. In Bangkok and Ho Chi Minh City certain fish farmers have gone into the production of ornamental fish species, often developing their systems into more intensive lower land use facilities and frequently utilising treated wastewater. In Ho Chi Minh City some hatchery producers have also started cultivating and selling ornamental house plants. Similar livelihoods diversification strategies were observed in Hanoi where adopting a rotation of aquatic plant species, i.e. morning glory, mimosa, watercress and water dropwort, provided farmers with significantly overall higher incomes and some protection from seasonal price fluctuations. Successful aquatic plant producers in Hanoi have also used their profits, and drawn on other human and social assets, to set up small-scale electro-plating workshops producing kitchen and bathroom utensils, whilst in Phnom Penh many of the women working in the cultivation of morning glory in the wastewater-fed Beung Cheung Ek lake have developed other small businesses, including shops and stalls selling food and household items.

Following a considered assessment of findings from Bangkok, Hanoi, Ho Chi Minh City and Phnom Penh, Leschen et al. (2005) concluded that the disappearance of aquaculture from the livelihood strategies of some urban communities is inevitable due to intensifying urbanisation, a process which also involves the gradual shift of urban aquatic production to more peripheral peri-urban areas. This mirrors experiences from other cities around the world where agricultural production has similarly been displaced. However, displacement should not be equated with absolute loss as many of the communities and locations to where aquaculture is relocated are still considered urban or at least peri-urban in nature.

New and innovative examples of urban aquaculture are emerging, as exemplified by intensive production of catfish in small areas around Lagos, Nigeria, and examples of family aquaculture from Cuba (Coto, 2005; Rana et al., 2005). And it has been proposed here that other intensively managed farms producing high-value food fish and high-quality seed are destined to emerge in other urban and peri-urban settings in response to market demand, rising land prices and concerns over environmental, animal and public health. Unlike many traditional systems in developing countries, these new urban aqua-farming activities will only require a relatively small area and production will be more intensive, based on supplementary feeding as opposed to waste inputs, thereby avoiding problems related to health risks and consumer acceptance. Innovative urban aquaculture operations being developed in North America and elsewhere are also increasingly regarded as multifunctional, producing food, whilst also contributing to social development, education and environmental protection.

For cities being considered as part of the PAPUSSA study the linkages upon which urban aquaculture depends - access to low-cost by-product and waste inputs and marketing opportunities associated with proximity to the city - remain and continually evolve. Notably, however, in the case of Hanoi the municipal authorities have retained large wetlands and lakes within the city boundaries for aesthetic and flood control reasons, and these remain accessible for aquatic food producers and indeed this is encouraged by the authorities as they believe the residents of Hanoi will equate food production with good environmental health, thus providing reassurance to consumers (Leschen et al., 2005).

The future for growing both aquatic plants and fish using urban wastewater will depend on planners being able to coordinate and develop strategies for the effective separation of industrial waste effluents from domestic sewage. This is desirable from other perspectives too, including other farming groups, such as lower income households who may rely on the cultivation of land vegetables and crops using wastewater as their main, and often only, source of water and nutrients, and in terms of more general environmental protection. However, implementing separation or on-site treatment by industries could prove impractical in larger cities where space may be limited and the costs of modifying existing infrastructure may be prohibitive. However, there are examples from Hanoi, Ho Chi Minh City and Kolkata where the relocation of industries from urban areas to industrial parks and zones should allow the more effective treatment and monitoring of effluents. Smaller provincial cities and towns may be better placed to incorporate aquatic food production in their development plans, but further work would be required to confirm this. There are opportunities for producers to diversify into producing high-value food fish, high-quality seed and ornamental species in intensively managed systems with more controlled environments, but there are financial and technical risks associated with such a strategy.

Stakeholder roles and priorities

Awareness and understanding concerning the roles and priorities of stakeholders, their relationships and associated strengths and weaknesses is an important step when developing planning and management strategies that take into account the demands and expectations of producers, consumers and other community members. The findings from a stakeholder analysis summarised below demonstrate that producers, planners and policymakers have different priorities and agendas.

Results from the PAPUSSA project demonstrated that fish farmers benefited from training and extension more than aquatic plant growers, but both government and non-government organisations remain focused on more commercially oriented aquaculture development in provincial areas. As with plant growers, there was little evidence, except in the case of Bangkok, of group formation or trade associations that might help protect their interests or help in marketing. Fish producers were better represented in urban planning through Fisheries Departments, but still had little influence. Considering local planners and district and commune officials, most local officials had a limited role in providing information and statistics for higher centralised urban policy makers. Overall there is little planned integration of aquaculture with other uses of urban water resources. Centralised planners and policy makers generally lack information about the relative importance and benefits that can be associated with producing fish and aquatic plants in urban environments, or indeed the possible hazards associated with such practices. There has been limited provision for future development or even maintenance of urban fish and aquatic plant cultivation in previous city development plans, but a policy of zoning being implemented in peri-urban Ho Chi Minh City and to a lesser extent around Hanoi does make provision for urban food production, including aquaculture. Priority setting by key stakeholders was largely governed by the most influential government ministries and political and commercial lobbyists.

An interdisciplinary and multi-stakeholder approach is critical in the identification and involvement of the principal stakeholders needed to formulate and implement development plans that can accommodate the continued cultivation of fish and plants in cities (Kundu, Halder, Pal, Saha and Bunting, 2005). Hung and Huy (2005) summarise the findings of a detailed analysis of the institutional linkages and hierarchy within the urban planning and policy process relating to aquatic production systems in Ho Chi Minh City. They note that though the urban authorities have designated some areas for agriculture and aquaculture, areas used for aquaculture outside these zones are undergoing rapid conversion for residential and public construction. Aquaculture rarely has priority in land use planning and often doesn't feature on the agenda. With limited information on city development plans and the future prospects for urban aquaculture, farmers are reluctant to take risks or invest in aquatic production activities.

Public, animal and environmental health

Public, animal and environmental health hazards constitute some of the most significant challenges to urban aquaculture, though the risks from such hazards are likely to vary depending on site specific variables. Consequently, where urban aquaculture is practised or proposed, work should be undertaken to identify potential problems and to develop management strategies that minimise risks. The question however of who should be responsible for ensuring such a strategy is implemented may be difficult to answer. Although producers may be well placed to identify possible hazards, in the absence of clear incentives, they are unlikely to take responsibility. Instead local institutions may need to facilitate and support the identification and management of hazards; yet, institutions in many developing countries are unlikely to have the capacity or resources to undertake such a programme. Where public perceptions of products cultured in urban environments are of concern, such measures may be instrumental in ensuring continued consumer acceptance.

Where generic guidelines have been developed for managing hazards in aquaculture, such as those for Hazard Analysis and Critical Control Point (HACCP) proposed by FAO (1997), it would be desirable to first test their appropriateness for urban aquaculture at the regional or local level. Strategies for managing hazards should also be appropriate for producers, specifically taking into account their access to resources, including finance, labour and knowledge. The development and implementation of a HACCP framework for urban aquaculture could make a significant contribution to improving both the health of workers and food safety. HACCP appears preferable to product monitoring. Although desirable, several limitations have been suggested, constraining development of HACCP for small-scale farmers, therefore, only by working together may producers be able to formulate management plans that minimise risks to the environment, workers, local communities and consumers. Furthermore, given the need to base HACCP on sound scientific principles, it is evident that local government and non-government agencies would have important roles in monitoring, identifying critical control points and assessing the magnitude of the risks posed. Research is currently underway to assess the risks to both consumers and those who work with wastewater and the initial findings have been presented by van der Hoek, Anh, Cam, Vicheth and Dalsgaard (2005). A water sampling programme has also been established for inlets and outlets of different peri-urban wastewater-fed fish and aquatic plant systems in Hanoi and the results will provide indications of the potential of these systems for facilitating the cost-effective treatment of wastewater.

Knowledge gaps and critical issues

Problems in accessing information, new knowledge and credit suggest that local government institutions, community-based organisations and non-government organisations have roles to play in providing such services. However, the selection and development of appropriate extension materials and pathways and the formulation of suitable credit arrangements is likely to demand resources and require a participatory working style. This in turn may first demand capacity development within local institutions. However, there is often the question of who is responsible for urban aquaculture, for providing support and technical advice, ensuring product safety and informing consumers and others about such activities. Furthermore, in many cases, the question also is whether urban aquaculture is an activity meriting support from local, national and international organisations.

Despite the apparent importance of this activity in certain situations, in providing employment, producing food or contributing to environmental protection and resource recovery, there is no clear picture of the overall extent of the activity or contribution of products from urban aquaculture to regional or national food supplies. To understand the situation better it would be necessary for institutions that collect and collate aquaculture production data to delineate between production in urban settings and that in rural areas. However, such a distinction may be difficult to make, especially where urban aquaculture is not defined in solely geographical terms.

Ellis and Sumberg (1998) noted that ‘the significance of food production in and around towns for the overall quality of life in developing counties should not be exaggerated’. Although urban aquaculture may be important to local communities, contributing to employment and food security, it may only play a minor role at a regional scale. Therefore, institutions, especially urban authorities with limited resources subject to varied demands, need to assess rationally the net benefit for poor communities from helping sustain or supporting the development of urban aquaculture. Such an assessment should involve a broad-based socio-economic analysis, however, some factors may be difficult to quantify, whilst others may receive a disproportionate weighting depending on the agenda and priorities of those involved; relative merits of competing activities will also require assessment. Clearly the multipurpose roles of urban water bodies, for flood control, amenity uses, wildlife, and broader environmental benefits must be considered in any holistic plan that includes the promotion of aquatic food production.

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