Urban Aquaculture

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1. Scope and objectives

As with the other contributions in this series this introduction to urban aquaculture is aimed primarily at reviewing the most important literature and knowledge sources on this topic, providing a contemporary, up-to-date reference. In the initial sections a working definition for urban aquaculture will be discussed and a typology for urban aquaculture based on species, location and intensity of production developed. In the following section, prevailing characteristics of existing urban aquaculture systems will be described, and associated benefits discussed. Recognised constraints and emerging threats to urban aquaculture will then be presented. From this assessment, it is anticipated that it will be possible to highlight important knowledge gaps and to suggest areas demanding resources for further research and development. In contrast to other reviews dealing with aquaculture development, this work emphasises the need to consider the role of urban policy and planning, especially concerning recommendations for future developments relating to urban aquaculture. References and resources included in the annotated bibliography were selected based on the objectives of the review, the quality and scope of information presented, their appropriateness for a wide-ranging audience and their accessibility.

2. Defining urban aquaculture

Prior to discussing the current status, opportunities and constraints for urban aquaculture it would be useful to consider a general definition for this activity, or more correctly, group of activities, as urban aquaculture, as it will be presented here, is not homogeneous. Firstly, it is worthwhile considering the urban setting in which aquaculture is deemed to occur, in this review, like that presented by Iaquinta and Drescher (2000) urban environments or more properly communities, are considered to have three key characteristics. Firstly, urbanisation is associated with demographic change in a particular area, namely increasing population size and density. Secondly, the economy moves toward a workforce primarily engaged in nonagricultural activities. Thirdly, those living in urban areas have a social-psychological consciousness of what this means. 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. The social-psychological dimension of urbanisation means that through processes such as the transfer of remittances and nonincome resources from rural-urban migrants; diffusion of consumerist and urban ideas and modes of behaviour; participation of returning migrants in community decision-making, even rural communities may undergo urbanisation.
According to Iaquinta and Drescher (2000) peri-urban environments and communities share many facets with those which are regarded as urban; usually the transition from urban to periurban to rural communities is regarded as a continuum. In this review we consider that aquaculture activities undertaken in both urban and peri-urban settings share many characteristics, however, we also hope to demonstrate that as communities or environments become more urban in nature, then the management of aquaculture must become more intensive, however, exceptions and limitations exist.

At this point it is useful to consider what is meant when considering aquaculture. According to the FAO (1995) aquaculture may be defined as “the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as the regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms that are harvested by an individual or corporate body that has owned them throughout their rearing period contribute to aquaculture, whilst aquatic organisms that are exploitable by the public as common property resources, with or without appropriate licenses, are the harvest of fisheries”. Beveridge and Little (2002) in contrast suggest 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.

From the FAO definition it should be noted that aquatic macrophytes, cultivated in many Asian counties constitute an important aquaculture activity, however, this production is not recorded in the FAO statistics. Ranching, defined as "an aquaculture system in which juvenile fish are released to grow, unprotected, on natural foods in marine waters from which they are harvested at marketable size" (Thorpe, 1980) may also be considered within the FAO definition where ownership can be retained or transferred. The FAO definition appears to exclude groups other than individuals and corporate bodies from engaging in aquaculture, however, households, families, communities, co-operatives and governments 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 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. Therefore, for the purpose of this review, urban aquaculture may be defined as the practice of aquaculture occurring in urban settings, or areas subject to urbanisation, incorporating by definition, peri-urban areas. In the following section different approaches to urban aquaculture are reviewed with respect to the species cultured and intensity of cultivation.

3. Approaches to urban aquaculture

Considering the range of species produced in aquaculture systems, this review will cover the most significant and widespread groups produced in urban settings, including aquatic plants. With many urban centres located in coastal areas, it is also important to note that urban aquaculture, although probably dominated by production in freshwater, may also include aquaculture in brackishwater and marine environments. Considering briefly the distribution of aquaculture globally, the FAO's database states that in 1998, Asia accounted for 89% of aquaculture production, Europe accounted for 6.3%, North and South America, 2.1 and 1.9 percent, respectively, and Africa and Oceania less than 1% each. The distribution of case studies presented in this review largely mirrors this situation, with most accounts of urban aquaculture coming from Asia, and a substantially lesser number from other regions.

Further to characterising urban aquaculture based on location, species and environment concerned, the review presented here will attempt to demonstrate that the intensity at which urban aquaculture is managed also varies in response to external pressures and incentives for producers. Invoking aquaculture systems typology developed by Coche (1982) we can better describe the nature of aquaculture occurring in urban areas. Extensive aquaculture is characterised by the dependence of stock on natural food; semi-intensive production involves fertiliser applications to enhance natural food production and/or the provision of supplementary feed, which is usually low in protein; culture in intensive systems relies almost exclusively on an external supply of high-protein (>20%) feed. Practically, however, these distinctions can become blurred. Many peri-urban culture systems rely on seepage or the guiding of fertile run-off or 'black water' into water bodies. These inputs may be more or less unregulated although the harvest of products as fish or plants may be highly managed.

In many rural areas where demand and markets for aquatic products are limited, it is common for producers to adopt extensive aquaculture practices, or semi-intensive approaches, but with only selected or restricted interventions. Often aquaculture in such settings is vital to ensure household food security, but of limited potential for generating substantial off-farm income. In certain situations it may also be possible for communities to rely on wild capture fisheries, or at least enhanced fisheries, to meet both their individual needs and local demand. In some cases aquaculture can become a strategy to reduce or mitigate risks from uncertain natural fisheries; stocking fish becomes more popular in parts of Cambodia when the rains, and fish yields from the ricefields, are less abundant. However, as aquatic resources in even the remotest settings become privatised and access becomes restricted, many rural communities are forced to forgo traditional aquatic foods, or to invest in aquaculture, albeit of an extensive or limited semi-intensive level.

In peri-urban areas, access to larger markets and more consistent and reliable demand, mean 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 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 appear to offer them a significant advantage over producers with limited access to such production enhancing inputs. In selected examples access to such resources has lead to dramatic growth in peri-urban aquaculture and widespread benefits for producers. A pertinent example of this is the tilapia seed producers utilising sewage near Ho Chi Minh City that have a valuable competitive advantage over other producers on the Mekong Delta, even after transportation costs (AIT/CAF, 2000).

However, despite the benefits of being located close to urban markets and being able to access waste resources, there are potential constraints associated with undertaking aquaculture in peri-urban areas. 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 aquaculture systems also means there are risks from airborne pollution, particularly agrochemical spray drift, predators such as piscivorous birds, and theft by poachers. This latter problem is often exacerbated by the settlement patterns of poor people in periurban areas who often site their homes on the periphery of water bodies.
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. External pressures that lead farmers to adopt more intensive production strategies may be considered as ‘forcing mechanisms’; shifting to more intensive production often demands financial investment, acquisition of more responsive and skilled management techniques, and greater effort devoted to monitoring product health, systems functioning and potential external hazards. Therefore, although largely used to categorise aquaculture systems based on production intensity and management demands the classification presented by Coche (1982) is helpful in indicating the degree of control and surveillance operators are able to exercise, both practically and in terms of the assets upon which they have to draw.

The transition from extensive to semi-intensive may be attributed to various factors, however, 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 by largely 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.

4. Prevailing characteristics of urban aquaculture

This section reviews recent accounts of urban aquaculture, assesses the scale, distribution and relative importance of urban aquaculture and describes the prevailing management characteristics of extensive, semi-intensive and intensive production systems.

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). Considering Wuhan, culture-based fisheries in Donghu Lake (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 (>13 cm). The control of predatory fish is also undertaken 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 (Starling, 1998).

A serious constraint to aquaculture in urban reservoirs is the multiple-use 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 gain exclusive 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). However, the continuous cropping of tilapias and other self-sustaining fish stocks in eutrophic urban waterbodies is probably one of the most productive, and beneficial, systems accessed by the poor in Asias' cities.

Cage culture is practiced 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 t y^{-1} 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. In the case of Saguling, large-scale fish kills during the months of January and February have been reported, although the exact cause has not been identified. This *de facto* privatisation of the common pool resource, inevitably requires capital assets less available to the poor, who can therefore be quickly excluded.

Although beyond the scope of the current review it is important to note here that urban wastewater, through nutrient enrichment of receiving water-bodies, can enhance production from 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.

Semi-intensive urban aquaculture

Unlike aquaculture in reservoirs and large lakes, pond-based aquaculture offers farmers greater control over the culture system and permits better surveillance, enabling producers to better guard against hazards such as theft, predation and contamination. Accounts of semiintensive pond-based aquaculture in urban settings have been reported for several counties. Proceedings of the 1988 conference held in Kolkata, India dealing with wastewater aquaculture (Edwards and Pullin, 1990) provide a useful review of what in many cases may be considered examples of urban aquaculture. Cases studies presented at the conference came from several Indian States (Bihar, Madhya Pradesh, Maharashtra and West Bengal) and several countries including, China, Germany, Hungary, Israel, Nepal, Peru and Vietnam.

Around Kolkata (Calcutta, India) urban aquaculture is practiced in ponds covering an area of ~3,500 ha, 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, furthermore, landowners are commonly absentee landlords and management of the fisheries is largely undertaken by 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 t y^{-1} of fish for sale in urban markets, many of which serve poor communities. A detailed account regarding the management of the system and constraints facing producers has recently been produced (Bunting, Kundu and Mukherjee, 2002). Accounts concerning the history, management, constraints and opportunities associated with urban aquaculture in Kolkata constitute perhaps the most valuable resource regarding the future management and development of urban aquaculture in other towns and cities. A similar system has evolved in Thanh Tri District close to Hanoi, Vietnam an area of ~1,100 ha is managed for urban aquaculture and some 3,000 t of fish are produced annually (Hoan, 1996).

Small ponds managed semi-intensively for aquaculture are commonly observed in the suburbs of towns and cities throughout Asia, however, production from urban aquaculture is not usually differentiated in regional or national statistics from that originating from rural areas, and consequently it is difficult to assess the overall extent of this practice. Risks, possible costs and potential benefits associated with small-scale urban aquaculture systems are poorly defined and understood and this lack of knowledge may prohibit investment of time, money or resources in developing enhanced approaches. Risk assessment in relation to household aquaculture practices in urban settings may be critical if sustainable practices are to be identified and promoted.

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 t y^{-1}. Edwards (1998) notes that aquaculture practices that utilise food processing and agricultural by-products, such as poultry manure, are widespread and diverse, and that 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 interraction between livestock and fish production in periurban, as opposed to rural environments.

The integration of aquaculture with wastewater treatment using lagoons is also widely advocated and several operational systems have been developed; Mara, Edwards, Clark and Mills (1993) describe a rational design approach for lagoon-based wastewater treatment that optimises both wastewater treatment and fish production. Formal 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 Peru, treated wastewater from the San Juan stabilisation pond complex close to Lima has been used to produce tilapia (*O. niloticus*) and preliminary studies demonstrated that fish cultured in this way are acceptable to consumers and that the proposed approach was economically viable (Cavallini, 1996).

Intensive urban aquaculture

Although perhaps beyond the scope of this review, intensively managed aquaculture operations in urban areas are being developed by entrepreneurs in several countries, however, such enterprises are largely confined to North America and Europe. Although less land may be required per unit production for intensive as compared to semi-intensive production units (Bunting, 2002) 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, regulating better factors such as water quality, feed delivery and stock management. More intensive, less open systems also offer the producer 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 North America and Europe, intensive urban aquaculture systems have been used to produce high value fish such as tilapia, sea bass and eels. Although often this is only possible where investment costs are reduced through using redundant buildings or waste heat, for example from power stations, used to subsidise operating costs. In developing countries, intensive urban aquaculture systems do exist, for example, producing ornamental species for export, however, intensive farms producing food fish for local communities have not been reported.

5. Benefits of urban aquaculture

In the following sections the principal benefits associated with urban aquaculture are reviewed. Employment, income generation and food security constitute important and tangible benefits, 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. According to Goodland (1990) the World Bank has acknowledged the need to include a wider range of issues in economic decisions and to revise the economic appraisal of projects to include externalities and sustainability. From the review presented here it is evident that a more thorough assessment of benefits associated with urban aquaculture is needed to inform planners and policy makers as to the true value of this activity, both for poor people and society in general.

Food security and meeting market demand

The primary driving force behind the development of many urban aquaculture activities is reliable and high level demand for aquatic products in urban markets. Farmers engaged in urban aquaculture have a number of advantages over rural producers, their proximity to markets means 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, access to wastewater means 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). The contribution of urban aquaculture to food security in poor households and communities has not been widely considered, however, there is a growing recognition that in some areas it may play a significant role. Products from aquatic systems, particularly fish, are important in ensuring the health and nutrition of many poor people. Thilsted, Roos and Hassan (1997) noted that in Bangladesh, fish consumption makes a significant contribution to the nutrition of poor people.

Observations by Morrice et al. (1998) provide valuable information on changing demand for fish with respect to size, species and freshness depending on the wealth of the community served. Furthermore, the authors suggests reasons why operators of urban ponds managed for wastewater aquaculture tend to produce small fish, highlighting the diversity of motivations for producers and providing an insight to risk management in dynamic urban settings. Investigating the diversity and price of fish for sale in suburban markets serving the poor, Morrice et al. (1998) observed a dominance of small freshwater fish, harvested from local ponds. Despite the higher price per unit weight for larger fish, these pond operators continue to harvest their fish at a small size to reduce risks posed by flooding, poaching and poisoning, both intentionally and through contaminated wastewater inputs. Management strategies including multiple stocking, partial harvesting and the sale of live fish have been adopted to optimise the production of small fish and compensate for the price differential between large and small fish. In one market, the authors observed that small (<100g) live tilapia commanded a higher price than equivalently sized Indian major carp, furthermore, it was noted that wild fish (catfish, *Clarias batrachus* and *Hereoneustes fossilis*; snakehead, *Channa striata*; climbing-perch, *Anabas testudineus*) attracted the highest prices in both urban and suburban markets.

Employment and income

Depending on the scale and extent of urban aquaculture it has been noted that such activities can provide employment for large numbers of people (Kundu, 1994; CRG, 1997). Employment is created directly, with jobs including stocking, harvesting and maintenance, and indirectly in associated activities such as producing and supplying seed and feed, making nets and boats and transporting and marketing harvested products. For example, estimates suggest that as a direct result of urban aquaculture around Kolkata 8,000 people are employed (Kundu, 1994), whilst employment in associated sectors servicing the farms has been estimated at over 20,000 people. Employment of one family member, either directly of indirectly, as a result of urban aquaculture may provide a valuable source of income, however, inequity may result in benefits being divided unfairly amongst household members (Harrison Stewart, Stirrat and Muir, 1994).

Furthermore, where urban aquaculture is practiced on family farms, inequality within households may mean the distribution of tasks unfairly burdens particular individuals. Inequitable distribution of benefits derived from large-scale urban aquaculture operations has been cited as constraining investment and innovation. As noted in the previous section, many urban aquaculture operations are able to operate throughout the year due to perennial supplies of wastewater, consequently workers employed in such activities are less vulnerable to seasonal fluctuations in labour demand. However, it should be noted that 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.

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, Edwards and Muir, 1999). By distributing some fish at harvest time to community members residing closest to the ponds, the pond owner found it was possible to reduce the proportion of unaccounted for fish. This was attributed to either a reduction in poaching by the recipients or greater vigilance on behalf of his neighbours, reducing the incidence of poaching and predation.

Household and community health

In several cases urban aquaculture is helping facilitate the managed reuse of waste resources; 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. The World Bank estimated that in 1990, a total of 1.7 billion people were without access to adequate sanitation, and that by 2030 this could increase to around 3.2 billion (World Bank, 1992). Providing sanitation is an important development process, and is recognised as being of prime importance in improving the general health of the population. By providing sanitation, infant mortality caused by communicable diseases e.g. cholera, typhoid and diarrhoea is greatly reduced, as is the incidence of severely malnourished individuals with associated physical and mental health problems (Ahmed, Zeitlin, Beiser, Super and Greshoff, 1993). In more general terms, it has been suggested that life expectancy in communities generally increases as a result of providing sanitation (World Bank, 1992). Inadequate sanitation results in the degradation and contamination of groundwater and surface water, in such situations it is often recommended that contaminated water be boiled, a process that uses large amounts of fuelwood, the combustion of which results in atmospheric pollution and may lead to an increase incidence of respiratory disease (Birley and Lock, 1999). Possible nutritional and food security benefits associated with urban aquaculture were noted in the previous section.

Economic benefits to society

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. For example, in Trujillo, Peru the cost allocation formula recommended for development of a lagoon-based wastewater treatment facility was to charge construction costs to the municipality and charge local farmers, who wished to irrigate with treated wastewater, with land and operation costs (Mara and Cairncross, 1989). Responding to a survey, local farmers indicated that this was an equitable solution; in some cases the cost of treated wastewater was expected to be half that paid for groundwater. The 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 (Watson, Reed, Kadlec, Knight and Whitehouse, 1989). 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. Where wastewater is reused in urban aquaculture pre-treatment is recommended to ensure products cultured are safe to eat; Mara and Cairncross (1989) provide a review concerning appropriate treatment levels for wastewater used for aquaculture. Employing lagoon-based approaches to treat wastewater prior to reuse represents a low cost solution to ensuring water is of sufficient quality for reuse (Mara, 1997).

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 conventional approaches to disposing of wastewater and solid organic waste, productive reuse of waste resources in urban aquaculture offers a greater degree of environmental protection.
Reusing nutrients contained within waste flows from societal systems reduces the loss of non-renewable resources; this is of particular importance where nutrients such as phosphorus may become entrained in the unidirectional flow of matter in the hydrological cycle. The assimilation of nutrients through ecological systems, as opposed to the mechanical removal of nutrients from the wastewater, avoids the problem of developing hampered effluent accumulation processes (HEAP) traps, where former point source pollution is ultimately converted into non-point source pollution' (Gunther, 1997).

Urban aquaculture practices that exploit waste resources have the potential to avoid the creation of HEAP traps, nutrients discharged within waste streams, instead being assimilated into biomass that can be harvested and either recycled through the city, incorporated into agricultural systems or removed from the watershed. Furthermore, although conventional technologies may be efficient at removing certain waste fractions depending on the design and operation of the treatment plant, discharge water may still contain significant quantities of nutrients that may result in environmental degradation in the receiving environment. The productive reuse of wastewater as a resource, as opposed to indiscriminate discharge into wetland, coastal and oceanic ecosystems, reduces the risk of cultural eutrophication (Edwards, 1993). Furthermore, the assimilation of waste through urban aquaculture would contribute to reducing the ecosystem area appropriated to supply environmental goods and services, leading to a reduction in the ecological footprint of the community (Folke, Jansson, Larsson and Costanza, 1997).

Wastewater reclamation and reuse is currently practiced in a number of countries and fulfils a wide variety of functions. With adequate treatment, water can be returned to consumers; water of a lower quality used by industry or in producing various biomass products including food, fodder, fiber, fuelwood and timber. Productive wastewater reuse in irrigation schemes and macrophyte production is of particular importance in dry climates where the production of biomass via photosynthesis consumes approximately 1,000 m_3 of water per ton of biomass produced (Falkenmark, 1989). Postel, Daily and Ehrlich (1996) estimated that in 1990, approximately 2,880 km_3 of freshwater were used by agriculture to irrigate 240 million hectares of land. Depending on climatic factors, crops being cultivated and efficiency of the irrigation system, between 50% and 80% of irrigation water is consumed; assuming a value of 65% to be representative, global agriculture consumes 1,870 km_3 of water, equivalent to 82% of water consumed directly for human purposes.

Although there is uncertainty regarding the extent of the world's freshwater resources (Rodda, 1995), evidence provided by Postel et al. (1996), supports the hypothesis that human appropriation of accessible runoff is approaching an upper limit. Alternatives to using accessible runoff include the expensive option of desalination or constructing new dams with their associated economic, social and environmental costs (Postel et al., 1996). In several arid and semi-arid regions, the freshwater resource is indeed being depleted from surface and groundwater sources at a rate exceeding replenishment; in this situation, wastewater reclamation is the most economically viable source of water (Okun, 1991).

Functional and non-functional values
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 suggest that a similar range of benefits to those suggested by this author may be attributed to agro-ecosystems supporting urban aquaculture close to cities such as Calcutta, Hanoi, Ho Chi Minh and Phnom Penh. As discussed in the previous

section, urban aquaculture systems receiving solid waste, agricultural by-products and wastewater assimilate nutrients contained in such resources reducing environmental degradation. Agro-ecosystems supporting urban aquaculture also represent a valuable habitat for wildlife, both aquatic and terrestrial. The ecological value of wetlands supporting urban aquaculture in Kolkata has been recognised by the International Union for Conservation of Nature and Natural Resources (IUCN), leading to the designation of such systems as a special category of man-made wetlands due to their contribution to preserving nature (Edwards, 1996). On a cautionary note, converting natural wetlands to urban aquaculture could reduce their value as wildlife habitats.

6. Constraints to urban aquaculture

Furedy (1990) reported that wastewater aquaculture, much of which occurs in urban settings, was declining in countries such as Japan, Malaysia and Taiwan, and that in China, aquaculture using human excreta was due to be phased out. Furthermore, indicators, including the area managed for aquaculture, number of people employed and financial viability, suggest urban aquaculture in Kolkata is in decline (Kundu, 1994; Muir, Goodwin and Walker, 1994; Mukherjee, 1996). Considering traditional 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.

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 demand for new settlements, temporary housing and slums may encroach on agricultural land, but more often become established on embankments, roadsides and derelict land. Conversion of land managed for urban aquaculture is often related to higher-value residential and industrial developments; costs associated with building on low-lying land (draining, filling and flood-proofing) are often higher than for agricultural land. Roads constructed to service new developments often greatly improve access to peri-urban areas further increasing pressure to convert agricultural land to meet the demands of an expanding urban population; the construction of by-passes and improved public transport also stimulate urbanisation.

Urban development encroaching into peri-urban areas affects the physical environment, but also leads to more subtle changes in society; noted by Iaquinta and Drescher (2000) as the third characteristic of urban communities. In the recent past the Indian government imposed compulsory acquisition on peri-urban areas used for aquaculture; this had both a direct impact on those people displaced and generated feelings of insecurity within the more general community. The largely unregulated sprawl of the urban fringe is seen as an irresistible force, once again generating feelings of insecurity; feeling which manifest themselves in what have been termed ‘law and order’ problems (Kundu, 1994). Disgruntled labourers, confused as to the legal basis of ownership, dewater the ponds and poach the fish prior to the seemingly inevitable cessation in operations. Producers in the region consider poaching a key constraint to the sustained operation of ponds managed for aquaculture. Harrison et al. (1994) considered poaching of fish from ponds in Africa in a different light, suggesting it may constitute a mechanism for redistributing benefits derived from aquaculture to the poorer sectors of the community. However, in Kolkata poaching is often an orchestrated and frequently violent affair (Kundu, 1994), and it is doubtful that the poorest community members benefit; anti-social behaviours such as poaching, theft and vandalism can represent a serious constraint to investment in infrastructure and improved management strategies in urban settings. Feelings of insecurity engendered through the common practice of issuing short-term leases have been cited as stifling innovation and constraining investment in maintaining infrastructure that supports urban farming around Kolkata.

Labour migration

Many studies suggest that people migrate from rural to urban areas in response to a number of ‘push’ and ‘pull’ factors e.g. limited livelihood options in rural areas or opportunities for livelihoods enhancement in urban areas, respectively. However, in many cases rural-urban migration reflects traditional patterns of labour movement determined by social and cultural institutions, and societal strategies to obtain livelihoods (de Haan, 1999). Describing the status of those families involved in urban aquaculture around Kolkata, Kundu (1989) noted

that a significant number of those employed were migrants from other States.
Migration within rural areas and from rural to urban areas has been documented in a number of settings. In contrast, studies focusing on micro-scale migration of individuals from periurban to urban livelihoods appear largely absent from the literature. The reasons for this are not clear, and it may be that this type of migration is not considered significant, or that difficulty in assessing if and where it is occurring has constrained detailed assessment. However, following an investigation of problems affecting the operators of farming systems in peri-urban Kolkata, Kundu (1994) noted that the loss of labour to more highly paid employment represented a constraint to continued operation. Experiences from other regions also demonstrate that the opportunity cost of labour is important in determining the livelihoods adopted by household members. Edwards, Demaine, Innes-Taylor and Turongruang (1996) report that low-input aquaculture is declining, as it contributes <10% to the income of smallscale farmer households in northeast Thailand, with much of the household income being derived from off-farm employment.

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 underemployed community members and recent migrants. Permitting them to consolidate their asset base and in turn gain access to better employment opportunities in urban activities. However, de Hann (1999) suggests migration is linked to a range of factor, including access to information regarding opportunities, transaction costs, labour-intensity in rural areas, remittances and expectation of returns through inheritance or continued access to rural income generating activities. These in turn will strongly influence the potential benefit derived by the individual, household and community, and ultimately will influence the decision of whether or not an individual should migrate.

Competition for markets
When threatened by development during the 1950s, a key argument for retaining the 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 large Indian major carp had mostly been imported from other Sates, from Uttar Pradesh by truck and from Madras, Orissa, Gudjarat and Punjab by train.

Changing access patterns for inputs
The inadequate supply of wastewater has been identified as a major constraint threatening the continued operation of traditional urban aquaculture practices around Kolkata. Consequently it appears that producers are increasingly employing more manageable inorganic fertlisers to sustain production and limit their dependence on the unpredictable supply of free wastewater from the city. Individual farmers have no control over water levels in the canal network whilst the priority of the urban authorities is to ensure that wastewater is drained effectively and safely from the city. Local authorities responsible for urban drainage are under no obligation to supply the needs of the urban fish farmers, it has been suggested that the farmers find themselves in this position as no payment is made for the waste resource (Muir et al., 1994).
Other factors can also constrain the equitable distribution of wastewater resources amongst users, siltation has been implicated in limiting the degree of control urban authorities have over wastewater levels in canals supplying the fishponds; Kundu (1994) cites problems of maintaining pumping stations and regulating sluice gates in hampering the delivery of wastewater. This author also suggests competition between farmers exploiting the wastewater resource may be preventing effective distribution. Introducing a pricing system may be one approach to optimising waste resource use, although such a strategy would probably disadvantage the poor. The potential of developing markets for waste resources in stimulating improved supply channels has been further highlighted by Furedy, Maclaren and Whitney (1997); these authors 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. The use of livestock waste in fish culture and horticulture dominant areas to the south and east of Bangkok are examples of the networks that develop between producers

and users of waste where communications and infrrastructure is well developed (Little and Edwards, 2003)

Contamination

Contamination of surface water resources with pollution from domestic and industrial sources constitutes a widespread threat to urban aquaculture. According to Biswas and Santra (1998) the heavy metal content of fish purchased from urban and suburban markets in Kolkata was higher than similar products from rural markets. Studying bioaccumulation of metals in fishponds receiving a high proportion of industrial effluents, Deb and Santra (1997) demonstrated that fish in these ponds accumulated higher levels of copper, lead, zinc and chromium than fish from neighbouring ponds; accumulation was found to vary between fish species and between tissue types. Focusing on mercury dynamics in fishponds receiving Kolkata wastewater, Sadhukhan, Ghosh, Ghosh, Chaudhuri and Mandal (1996) found that levels in fish were not above the permissible level; highest mercury levels were recorded in sediment dwelling fish species and this may have implications for stocking and management practices. Cage culture has been undertaken successfully in ponds receiving wastewater in South Africa (Gaigher and Krause, 1983; Gaigher and Toerien, 1985) and represents a management practice to reduce the risk of fish being exposed to contaminated sediments.

Referring to urban aquaculture in Hanoi, Vietnam, Edwards (1997) noted that water from the Set River is now 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 is apparently in decline, the canal network has fallen into disrepair and rubbish dumped in the canals is compounding the problem. Inadequacies in wastewater supply have resulted in fish producers purchasing fertiliser inputs and by-products from local breweries. Reduced wastewater use in urban aquaculture has resulted in increased discharge of untreated wastewater to local rivers. Problems of contamination are also reported for the Chinese wastewater aquaculture systems in Han Kou region, accounts suggested 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 risks posed by contaminants demand careful assessment, and in some cases a monitoring programme may be required to ensure the use of contaminated resources is restricted. For small-scale systems it may be sufficient to conduct a general survey of the catchment or surrounding area; local knowledge may be invaluable in this situation, permitting the identification of industries and activities that could pollute. Bartone and Benavides (1997) identified a range of small-scale and cottage industries associated with hazardous waste problems in developing countries; these include tanneries, textile dyeing plants, dye producers, metal working and electroplating shops, foundries, automobile repair shops and petrol stations. However, as urban aquaculture in a region increases, or residential or industrial development occurs in the catchment or surrounding area, it may become increasingly difficult to monitor potential pollution sources.

Pollution sources other than contaminated waste inputs require consideration; indiscriminant dumping of solid waste and refuse may cause serious problems. Physical filling of waterways with rubbish interferes with local drainage patterns and dumping of toxic or hazardous chemicals may contaminate urban ponds. Agrochemical drift or leaching represents a further hazard to urban aquaculture; pesticides and herbicides applied in terrestrial farming may impact severely on aquatic environments and harm plants and animals being cultured.

Practical steps to safeguard against contamination with agrochemicals may include establishing buffer zones between aquatic and terrestrial farming systems, or the development of guidelines for those engaged in applying these chemicals. Buffer zones between landfill sites would also help prevent contamination, however, leachate management may require prior planning to facilitate effective collection and treatment.

Indiscriminant defecation by local residents and operators constitutes a further hazard to production through urban aquaculture, possibly resulting in pathogen loads in inappropriate places. Mara and Cairncross (1989) noted that where water supply and sanitation are not adequate, local residents are likely to use ponds for bathing and defecation, consequently, water supply and sanitation for local communities is important for human exposure control.

Public health concerns

Birley and Lock (1999) describe in more general terms health hazards associated with periurban natural resource development whilst Howgate, Bunting, Beveridge and Reilly (2001) review the public, animal and environmental health hazards associated with aquaculture in developing countries. A number of authors have also described potential health hazards associated with urban aquaculture systems, and in particular those activities where wastewater reuse is practised (Mara and Cairncross, 1989; Strauss, 1991; Edwards, 1992; Edwards, 2001). Although several of these reviews make hazards associated with aquaculture explicit, it is much harder to quantify the associated level of risk. For example, risks associated with products grown using waste resources vary, depending on characteristics of the waste resource, degree of treatment prior to use, design and operation of the culture system, husbandry and processing practices, subsequent handling and preparation and susceptibility of the consumer.

Reviewing the 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. The following sections discuss the hazards faced by these different groups, describe factors that influence the degree of risk and outline potential strategies for mitigation.
Ensuring the health and safety of employees engaged in urban aquaculture is an essential component in managing risks associated with such practices. Providing protective clothing and, where appropriate, regular treatment of the workers for intestinal helminths will limit the transmission and negative health impacts of parasites and bacteria (Mara and Cairncross, 1989). However, the authors note that persuading employees to follow health and safety guidelines may be difficult. The key to implementing such safeguards may be to encourage behavioural change through the education of employees. Furthermore, the need for education regarding the health risks posed by products from urban aquaculture extends to those involved with handling and processing. Although risks to these individuals may be less than those posed to farm workers, precautions such as wearing gloves and close attention to personal hygiene may be desirable. Prophylactic use of chemical control agents and the provision of adequate facilities to treat diarrhoeal disease are also recommended for highly exposed groups (Mara and Cairncross, 1989). Providing local residents with information about urban aquaculture activities, for example, the location of ponds, particularly where wastewater is reused may help them avoid these farms and prevent their children from entering these areas. Warning signs might also be considered necessary, especially where fences are absent (Mara and Cairncross, 1989).

To assess the risk of water borne diseases transfer mediated through urban aquaculture, it is important to assess the prevalence of these diseases in local population (Mara and Cairncross, 1989). Ascertaining possible pathogen levels in the waste resource will assist in deciding what level of treatment is required to safeguard health. Buras (1993) proposed that pathogen numbers should remain under a ‘threshold concentration’ i.e. the level above which the immune system of the culture organism is overwhelmed, leading to infection. Based on a review of epidemiological data, guidelines for the acceptable level of pathogens in water for use in aquaculture have been developed (Mara and Cairncross, 1989). Furthermore, following a review of prevailing practices, these authors propose that only systems incorporating pretreatment should be employed as they represent the most appropriate methodologies for safeguarding products from contamination.

Where products from urban aquaculture are not prepared and stored in an appropriate manner the risk to consumers may be increased. Failing to prepare aquaculture products in clean water may allow pathogenic microbes to colonise the final product, while storing produce incorrectly, or display on unhygienic market stalls, may permit poisonous bacteria to proliferate (Hatha, Paul and Rao, 1998). The level of risk also varies depending on the mode and degree of exposure of the consumer and the resistance of the individual to infection. Considering urban aquaculture close to Kolkata, traditional food preparation methods, in particular cooking food for long periods or at high temperatures, has provide a safeguard against the transfer of pathogens. However, responsibility for safeguarding the quality of aquaculture products must lie primarily with the producer, although the consumer and others involved in processing and marketing have a role to play in ensuring that produce is handled and prepared so as to minimise public health problems.

Where contamination is a potential hazard, depuration can be employed to minimise health risks for consumers, the depuration period should be sufficient to allow gut contents to be expelled, and in an ideal situation, a longer depuration period should be provided to reduce the population of bacteria and

parasites present in both external and internal structures of the culture organism. Studies have shown that concentrations of persistent chemicals and heavy metals found in tissues of catfish cultured in wastewater were lower following depuration (James, Sampath and Devakiamma, 1993). The production of intermediary products such as duckweed or tilapia for use in feeds for fish and livestock production has been suggested for aquaculture systems liable to contamination (Edwards, Polprasert and Wee, 1987). Farming intermediary products not only helps reduce both real and perceived health risks but may also help mitigate against social restrictions and aversions to reusing waste resources. Alaerts, Rahman Mahbubar and Kelderman (1996) described a farming system in Mirzapur, Bangladesh where wastewater from a hospital is used to grow duckweed, which is subsequently fed to fish grown in adjacent ponds; the local community readily accepts fish cultured in this manner.
A recent innovation for improving food safety that is preventative in nature and focused on the consumer is the Hazard Analysis Critical Control Point (HACCP) framework (Ehiri, 1995; Lima dos Santos, 1995; Thompson, 1996; Reilly and Kaferstein, 1997). The FAO Fish Utilization and Marketing Service outline a code of hygienic practice for aquaculture products, including recommendations for products cultured using wastewater (FAO, 1997). In summary, these recommendations state that only treated wastewater should be used and that the microbiological and chemical quality of products should be monitored and conform to WHO guidelines (see Mara and Cairncross, 1989).

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 water samples and organs from fish cultured in ponds 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; schema 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 for operators and local authorities may assist in implementing such measures.

Changing social expectations and perceptions
Changing expectations and perceptions of operators, consumers and society may be responsible for the decline observed in once productive urban aquaculture systems (see Furedy, 1990). As mentioned previously, migration of skilled and experienced employees represents a possible constraint to the continued operation of the traditional systems. However, it is important to acknowledge that the expectations of managers and employees are not limited to financial considerations; socio-cultural factors e.g. social status and conformity also demand consideration. In Zambia, Tanzania and Zimbabwe, levelling mechanisms, such as social pressure and obligation, have been identified as constraints to adopting aquaculture, an activity that reportedly has the potential to elevate individuals above their defined social role in a community (Sen, 1995). As consumers become more aware concerning the origins of food they eat, knowledge 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, may negatively influence consumer perceptions, possibly restricting acceptability.

Management constraints
Constraints to urban aquaculture presented above suggest that managers face a number of hazards that are largely beyond their control, but which have a significant influence on the type of management strategies employed. Insecurity of tenure has been cited as a key factor in constraining innovation and investment, with farmers unwilling to invest in new technologies and management strategies, instead wishing to limit their exposure to financial. Limited information and 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. 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 farmers information needs are met.

Institutional considerations
This section presents some potential strategies for developing the capacity of local institutions to address constraints associated with urban aquaculture. Problems in accessing loans and information suggest local government institutions, CBOs and NGOs may have roles to play in providing such services. However, selection and development of appropriate extension materials and pathways and the formulation of suitable credit arrangements is likely to demand resources and require participatory approaches to working, this in turn may first demand the capacity development within local institutions. 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? In urban settings aquaculture may not be recognised as a legitimate activity by planners and may not fit easily with zoning and land use plans set out by urban authorities. A primary responsibility for institutions dealing with urban aquaculture would be to protect the health of consumers, and this may involve the implementation of standards, guidelines and regulatory safeguards. Where public perceptions of products cultured in urban environments are of concern, such measures may be instrumental in ensuring continued consumer acceptance. However, implementing such a programme, and the framework of legislation required for its support, may represent a significant cost to regional authorities, and in many situations more pressing issues may hold priority. Farming activities, including aquaculture, may also come into conflict with local and regional planning initiatives, for example the need to construct infrastructure and services to support urban growth and industrial development.

Summary
The reviewed presented above demonstrates that several constraints threaten urban aquaculture. Urbanisation leads to the physical loss of land and causes disruption in local communities, possibly engendering feelings of insecurity. Uncertainty concerning the future of urban farming activities and prospects of more rewarding employment result in the loss of experienced workers. Improved access to urban markets for rural producers diminishes the competitive advantages of urban farmers, the risk of contamination, leading to public health threats and changing consumer perceptions may further reduce demand. Operators of urban farms often have to depend on uncertain and variable waste resources and contend with limited access to finance and information. In combination these factors often result in a reluctance or inability to invest in enhanced management approaches, further decreasing competitiveness as compared with other producers, and importantly with other activities demanding space and resources in urban areas.

7. Urban aquaculture: critical gaps in the knowledge base

Building on key accounts concerning the nature, extent and management of urban aquaculture in various settings, the most significant benefits and constraints associated with this farming activity have been described. However, from the review it is also apparent that various gaps exist in the knowledge base relating to urban aquaculture; important areas requiring further consideration are discussed below.
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 occurring specifically 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.

Although various benefits are associated with urban aquaculture several factors appear to constrain and threaten the viability of existing systems. Potential public, animal and environmental health hazards constitute some of the most significant threats, however, the risk from such hazards is likely to vary depending on site specific variables. Consequently where urban aquaculture is practiced or proposed, work should be undertaken to identify potential problems and to develop management strategies that minimise risks, however, the question of who should take responsibility 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, farmers are unlikely to take responsibility. Instead local institutions may need to facilitate and support the identification and management of possible hazards, however, institutions in many developing countries are unlikely to have the capacity or resources to undertake such a programme.

Where generic guidelines have been developed for managing hazards in aquaculture, such as those for 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, in particular taking into account their access to resources, including finance, labour and knowledge. 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 due to the logistics of sampling and testing produce from individual farms and the often complex and disparate distribution networks that service many small-scale producers in urban settings, the limited capacity of institutions with facilities to implement such programmes also constitutes a further constraint. 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 agencies and NGOs would have important roles in monitoring the system, identifying critical control points and assessing the magnitude of risks posed.

There also remains the fundamental question, in many cases, as to whether urban aquaculture is an activity meriting support from local, national and international organisations. 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, and nor, too, should its claims for scarce development resources.' Although urban aquaculture may be important to local communities, it may only play a minor role in regional food production or employment, 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 cost-benefit 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 waterbodies, 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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