Review of environmental impact, site selection and carrying capacity estimation for small scale aquaculture in Asia

Patrick White
Michael Phillips, Malcolm Beveridge

FAO expert workshop on Site Selection and Carrying Capacity Estimates for Inland and Coastal Waterbodies

A worldwide expert consultation to be held at the Institute of Aquaculture, University of Stirling, Scotland. December 6th to 8th, 2010.

Table of Contents

Abstract

Asia is the leading aquaculture region in the world, contributing to 85% of total world aquaculture production. Of the top 10 aquaculture producing countries 9 are Asian with China accounting for more than 65% of Asian production. Aquaculture in Asia contribute more than 80% of an estimated 17-20 million aquaculture farmers in Asia providing livelihoods, food security and export earning power but at the same time there are growing problems with environmental impact from large numbers of small-scale producers and the difficulties in planning and management of further development.

Traditional integrated aquaculture systems which are sustainable environmentally continue to play an important role for many small-scale farmers and local communities, particularly at the subsistence level. However, recently more productive and profitable aquaculture practices have developed using formulated pelleted feed and allowing intensification of production. Small-scale producers are characterised small farm units and low productivity but in many cases, aquaculture develops in clusters of small-scale farms favouring sheltered bays, estuarine areas and coastal fringe, lakes and dams. Whilst individually such farms create little environmental impact, the cumulative effects of large numbers of farms in “clusters” can be significant.

Mitigation of these environmental impacts is difficult due to the number of individual small scale-farmers. However the effects of cumulative environmental impact can be reduced by the introduction of carrying capacity estimation using models before development, the implementation of Better Management Practices and control of feed quality and feeding strategy and management can reduce the cumulative impact.

1 Background

The purpose of paper is to highlight the continuing importance of aquaculture in Asia to provide livelihoods, food security and export earning power but at the same time to highlight the problems with environmental impact from large numbers of small-scale producers and the difficulties in planning and management of further development.

Aquaculture in Asia has a rich history of more than 2,500 years and is recognized as the leading aquaculture region in the world, contributing to 85% of total world aquaculture production. FAO statistics show that there are over a hundred species of finfish cultured in the region (FAO Fishstat Plus). Of the top 10 aquaculture producing countries 9 are Asian with China accounting for more than 65% of Asian production. In many Asian countries, the contribution to national GDP from aquaculture exceeds that from capture fisheries.

Asian aquaculture is characterised by a wide diversity of species. Production in Asia continues to grow at a fast pace due to both area expansion and production intensification. However recently, along side with this intensification of Asian aquaculture, there has been a deterioration in environmental and health conditions.

Aquaculture in Asia is dominated by small-scale farmers characterized by (De Silva 2009):

- Small land and water areas
- Family scale operations/businesses with few small production units. For example in China there are around 240 million agriculture farmers, with less than 0.1 ha.

- Use of family labour
- Often based on family land (which is declining in area)
- Vulnerability to many external factors (feed price, Climate Change, market price)

Small farmers:

- Contribute more than 80% of an estimated 17-20 million aquaculture farmers in Asia
- Are major contributors to food production in many countries
- Are major contributors to global farmed fish supply
- Are highly innovative sector
- Are important for rural development, communities, employment, poverty reduction and environmental sustainability

1.1 Majority small-scale producers.

Small-scale producers are characterised by a low-asset base, low technology and low productivity. However, they dominate the agriculture landscape throughout the developing world, and similarly play an important part in aquaculture in many countries, sometimes through livelihoods which integrate aquaculture, livestock, farm crops and other on- or off-farm activities, and sometimes through increasingly more specialisation in aquaculture as a household-managed enterprise.

Small farms are characterised as largely owned and operated by households with limited access to assets such as land, water, finance and material inputs (seed, feed, etc.) and consequently, farm production volumes tend to be low. Small-scale producers in Asia face varying degrees of financial, knowledge, market access and other constraints, and therefore commonly face difficulties in raising productivity and incomes. Due to their special social, economic and environmental significance as well as the cumulative effect of impacts, environmental management measures need to give special attention to this part of the sector.

Asian aquaculture is characterised by a diversity of practices, with varying degrees of interactions with the environment. The use of trash fish as feed, and fry sourced from the wild or derived from wild-caught broodstock is still practiced widely.

1.2 Traditional aquaculture

Many of the traditional production systems in Asia have been environmentally sustainable for hundreds of years with minimal impacts to the environment (Edwards 2009). Traditional extensive and semi-intensive forms of aquaculture, and integrated aquaculture, may be considered to represent an ecosystem approach as they tend to have less immediate impact on the wider environment than more intensive forms of culture.

Aquaculture is often integrated with agriculture with on-farm integration of aquaculture with crops and/or livestock and referred to as integrated agriculture – aquaculture systems (IAAS).

However, aquaculture may be linked with other human activity systems such as sanitation and agro-industry in peri-urban areas and fisheries. In such broader integrated systems the links between aquaculture and other activities may be direct and closely associated spatially. Examples of broader integrated systems are integrated fisheries-aquaculture systems (IFAS) which use small freshwater or marine trash/low-value fish as feed; integrated peri-urban-aquaculture systems (IPAS) using wastes of cities and industry such as wastewater (human sewage or agro-industrial effluents), waste vegetables from markets, waste food from canteens and restaurants, and factory processing wastes from the food industry, including offal from slaughterhouses and fish processing factories.

The principles of traditional aquaculture can also involve polyculture of fish with complementary spatial and feeding niches in the pond; waste or by-product reuse such as terrestrial or aquatic vegetation, livestock manure, nightsoil, brans and oil cakes, and food and drink manufacturing residues; nutrient and water reuse and multiple use between farm subsystems or enterprises; and pond for the production of high protein natural food in situ as well as an aquatic environment for fish.

1.3 Decline of traditional integrated aquaculture

Traditional integrated aquaculture systems continue to play an important role for many small-scale farmers and local communities, particularly at the subsistence level. However, recently more productive and profitable aquaculture practices have developed that require considerably increased nutrient flows than can be provided from other on-farm or local sources. Formulated pelleted feed is becoming the most significant source of nutrition for farmed fish, allowing intensification of production.

Combining intensive and semi-intensive aquaculture, some intensive pellet-fed fish farms discharge the nutrient-rich effluent into semi-intensive ponds stocked with Chinese and Indian major carps and tilapia as a fertilizer where it is treated and converted into plankton and grazed by filter-feeding fish

Wastes from pellet-fed tilapia raised in cages are also sometimes treated and recycled in a static water pond in which the cage is floated. Tilapia fingerlings are nursed in semi-intensive culture in the pond feeding solely on natural food produced by fertilization of the pond with caged-fish wastes. Fingerlings are subsequently stocked in the cages and raised on pellets until they reached a marketable size.

The Chinese 80:20 pond fish culture system combines intensive production of one high-value species such as grass carp, crucian carp or tilapia fed with pelleted feed in polyculture with a “service species” such as the filter feeding silver carp which helps to clean the water and the carnivorous mandarin fish (*Siniperca chuatsi*) which controls wild fish and other competitors. Eighty percent of the harvest weight comes from the pellet-fed target species and the other 20 percent comes from the filter feeding service species.

Such systems are widely thought to be more environmentally sustainable, however, economic incentives are driving intensification and specialisation, resulting in changes to such traditional systems, with likely loss of environmental services. Another aspect of certain systems – such as rice-fish – is the implication for release of greenhouse gases (GHG). Research on rice -fish suggests that integrated systems of fish in rice fields may lead to greater release of GHGs. Further research is warranted on environmental implications of changing aquaculture systems in Asia.

Box 2. Examples of other forms of traditional aquaculture that do not breach the carrying capacity.

- Asia (China, Vietnam, Indonesia) Rice-fish culture benefits millions of rural people; rice –fish aquaculture ecosystems have designated as a "Globally Important Agricultural Heritage System". World Fish Center (2008); FAO (2009); Lu and Li (2006); Dela Cruz et al. (1992)
- Asia (China, Thailand, Cambodia, Vietnam, Indonesia) Integrated aquaculture benefits millions of rural people. Edwards (2009)
- Asia (China) Integrated Multi-trophic Aquaculture of fish, shellfish and seaweeds bioremediates and increases total yields up to 50%. Zhou et al. (2006)
- VAC system in Vietnam (VAC in Viet Namese is vuon, ao, chuong which means garden/pond/livestock pen).

1.4 Development of new integrated systems

Fed cage within unfed cage (Indonesia)
Cage culture in three Indonesian reservoirs, Saguling, Cirata and Jatiluhur, of the greater Ciratum watershed, West Java, provide some other innovative approaches to resource use and management (Abery et al, 2005). In all three reservoirs, cage culture of common carp, *Cyprinus carpio* L., and later of common carp and Nile tilapia, *Oreochromis niloticus* (L.), were encouraged as an alternative livelihood for persons displaced by the impoundment. A two-net culture system, locally known as 'lapis dua', in which in the inner cage (7 × 7 × 3 m) is used for common carp culture and the outer cage (7 × 7 × 5/7 m) is stocked with Nile tilapia, is practised .

There is also interest in further development of integrated mariculture systems, with some research in China (ref needed) indicating multiple economic and environmental services from such systems.

2 Issue Identification

2.1 Devolution - decisions at the lowest level of Government

Decentralisation of government responsibilities, occurring widely across the region, is leading to delegation of some environmental planning and management decisions from central to local government authorities.

This approach provides opportunities for better management, but raises considerable challenges, due to limited capacity for aquaculture planning and environmental management at local levels in many countries, and sometimes unclear or overlapping legal responsibilities and procedures and is problematic particularly in the Philippines, Thailand and Indonesia because of weak local institutional capacities and sometimes unclear delegation of responsibilities. (Phillips EIA)

For example, in the Philippines the local governments are tasked to implement activities and projects related to natural resources management. However, ordinances formulated and passed by the Local Government Units (LGUs) must be in accordance with the national fishery and environmental laws. Such constraints are recognised in the Philippines where recent “better practice” guidelines have been drafted to assist local governments in environmental management of aquaculture, and provide the basis for capacity building. Such guidelines could be made more widely available and adapted/translated to local circumstances in several countries with decentralised aquaculture management responsibilities.

2.2 Small scale production

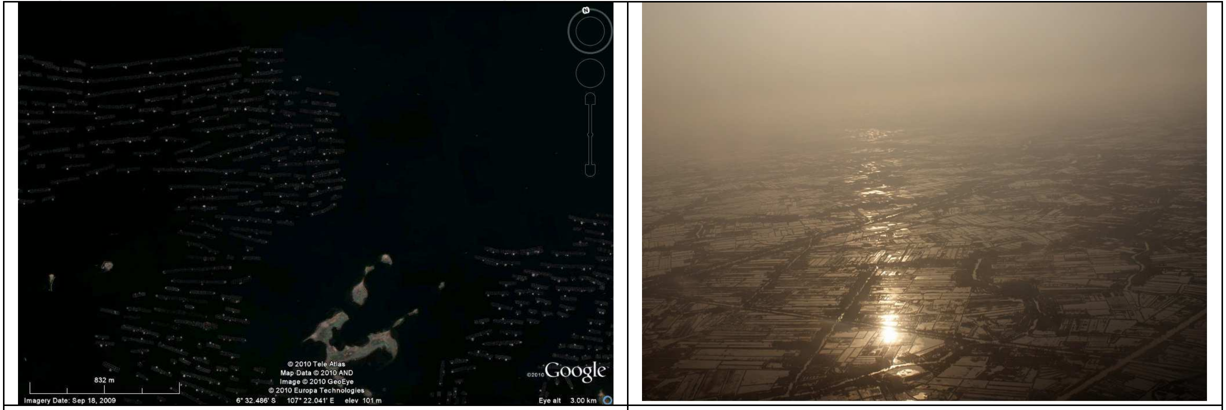
Small-scale producers are characterised by a low-asset base and low productivity and they dominate the agriculture landscape throughout Asia, and similarly play an important part in aquaculture in many countries, sometimes through livelihoods which integrate aquaculture, livestock, farm crops and other on- or off-farm activities, and sometimes through increasingly more specialisation in aquaculture as a household-managed enterprise. Small farms are characterized as largely owned and operated by households with limited access to assets – land, water, finance and material inputs (seed, feed, etc.) and consequently, farm production volumes tend to be low.

Small-scale producers face varying degrees of financial, knowledge, market access and other constraints, and therefore commonly face difficulties in raising productivity and incomes – moving up the “enterprise ladder” to become more competitive micro- and small enterprises. Whilst individually such farms create little environmental impact, the cumulative effects of large numbers of farms in “clusters” can be significant.

2.3 Clusters of small scale aquaculture

In many cases, aquaculture develops in clusters of small-scale farms favouring sheltered bays, estuarine areas and coastal fringe, lakes and dams. Success of a few farmers can often lead to rapid expansion, creating significant clusters of small farms in many areas of Asia.

Figure 1. Examples of cluster farming in Asia



Clusters of cages in Jatiluhur Dam, Indonesia

Contiguous ponds in Ca Mao, Vietnam

	
Fish pens in Dagupan, Philippines	Fish cages in Taal Lake, Philippines

Clusters of small farms often develop where there is poor control of permits, licensing or allocation of space for aquaculture development together with a lack of carrying capacity estimation. In other cases, due to fragile cage design (eg bamboo frames) cages are clustered in areas sheltered from strong winds and waves.

Individual small scale farms rarely impact the environment significantly, however, clusters of farms can cumulatively cause impact within a watershed or enclosed water body. Improvements need to be based on collaborative management practices which add to complexity and investments needed for change.

Aceh, Indonesia, provides an example of some successes

Fish and shrimp farming are important livelihood activities for many poor people living in the coastal areas of the Indonesian province of Aceh. Nearly 100 000 households, mainly along the north-east coast districts, depend on aquaculture for income, although productivity is very low and poverty remains endemic. Shrimp and milkfish are the major aquaculture products from Aceh, a mix that contributes to export earnings and provincial food security, along with growing volumes of tilapia, and minor species such as catfish, crabs, seabass and grouper.

A coalition of partners[1] has worked together in Aceh since 2005 to assist coastal fish and shrimp farmers and communities recover from the December 2004 earthquake and tsunami, and to build better livelihoods. Good progress has been made in physical rehabilitation of ponds and canals, introducing improvements in farming practices – so-called "Better management practices or BMPs" which have been well accepted by farmers – and rebuilding a traditional system of village farmer groups supported by innovative Aquaculture Livelihoods Service Centers (ALSCs). This approach - helping farmers to organize themselves and development of community services – run on business lines by local people for the local farming community – has worked well. In 2010, over 2 600 poor households from 82 villages joined a voluntary BMP program, supported by the four ALSCs, generating increased household incomes of USD 600-800/farmer – a substantial improvement in a poor province. The approach is becoming exceedingly popular, with an estimated 6 000 farmers

---

[1] Asian Development Bank/Earthquake and Tsunami Emergency Support Project, OISCA/Japanese Fund for Poverty Reduction, BRR, MMAF, FAO/American Red Cross, WorldFish Center, Network of Aquaculture Centres in Asia and the Pacific, and World Wildlife Fund, WorldFish Center, Network of Aquaculture Centres in Asia and the Pacific, and World Wildlife Fund

now showing interest and other farming communities wishing to establish ALSCs in their areas.

Environmental management improvements have been integrated into the "Better Management Practices" which are adopted at farm level, and among groups of farmers. A major driver in adoption by farmers has been the improved profitability of farming as a result, and reduced risk of disease losses. Environmental improvements are seen in reduction in chemical use, improved feed use efficiency and reduces shrimp disease occurrence. Further research is necessary on the cumulative environmental improvements in coastal areas from this cluster management approach, but they are considered to be substantial. Similar approaches are being used in India, where farmer groups have taken increase responsibility for management of common water channels, and mangrove replanting. Further research is needed on cluster management options, and then policy and investment is required to support such local management initiatives.

2.4 Boom and bust

Some aquaculture development has been characterized by boom-and-bust development resulting in adverse environmental impacts and indicating poor governance. Over-emphasis on profit, and limited market incentives for change, or knowledge, means that farmers usually give limited consideration to environmental issues even though it is undesirable for aquaculture farms to exceed the capacity of the environment in which they are located. There are numerous cases of aquaculture severely affecting its own culture environment as well as the surrounding aquatic environment through self-pollution. Promotion of aquaculture has been successful in most countries in Asia but if a certain aquaculture venture is profitable governments have often found it difficult to control "runaway development" with often catastrophic adverse environmental impact.

Governments that are encouraging aquaculture development as a means for providing livelihoods may accept a higher level of environmental impact. Such trade-offs are common, but need much more careful consideration where natural resources are in limited supply, or competition is significant, such as in crowded lake and coastal areas, or water limited regions.

2.5 Social, economic and environmental perspectives

Aquaculture's importance as a source of income, food, and employment for many poor people is widely recognized. Aquaculture will continue to grow, but faces a host of challenges in sustaining let alone increasing the provision of social and economic services to rural and urban populations worldwide. A number of over-arching external drivers influence the sector, such as increasing competition for ecosystem services, the use of available land and water resources for aquaculture expansion, pollution, climate change, natural disasters, HIV/AIDS epidemics, governance challenges, and local risks associated with increasing globalization and others. Internal sectoral dynamics, related to globalization drivers, are strongly influencing the sector's growth; with increasing integration of supply chains for many internationally-trade commodities now merging into domestic markets in Asia, ever higher market standards, and competitive forces driving buyers to most efficient and reliable producing countries.

Within this generally dynamic picture of growth and change, small-scale aquaculture farmers, in common with agriculture farmers, face significant challenges. Limitations related to infrastructure, producer capacity, access to finance, public sector servicing capacity and other factors often create a cycle in which low productivity depresses income and thus a “vicious cycle” of deepening problems. They are also among the most vulnerable to external drivers such as climate change, market demands and other factors which are largely out of their control. Coordinated engagement by private and public stakeholders, including the business sector, can help address such dynamics. Approaches to improve environmental management need to take account of these different aspects.

3 General considerations

3.1 Production aspects

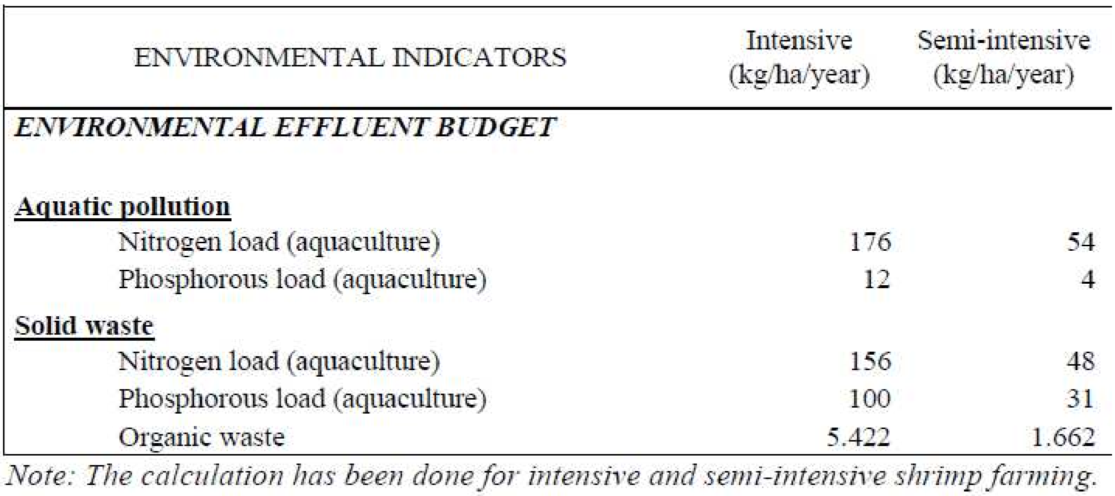
Brackishwater and marine fish and shrimp pond culture

Penaeid shrimps are widely cultured in coastal ponds. Other commodities that are cultured include brine shrimp, milkfish, mullets, mud crabs, and seabass. Ponds cover a wide range of coastal areas from backishwater estuarine areas to coastal mud flats. Along with this large spatial distribution, there are a variety of culture intensities of production (from extensive to super intensive) practiced. Semi-intensive and intensive shrimp culture area has developed rapidly, but faces a number of issues such as intake and effluent output to the same water source leading to self-pollution, the sharing the same water source with other farms up or down stream and lack of zoning.

Other than where large areas of coastal wetland ecosystems are removed for ponds environmental impact is low from extensive or traditional systems which operate at low stocking density and without any supplemental feed except some fertilisation. Impacts afre also lowfrom semi-intensive systems, where a small amount of supplemental feed is given for a part of the culture period.. However, higher impact is experienced from intensive systems, where the majority of the nutrient supply comes from compounded feed and there is a much greater requirement for management.

Waste water from shrimp ponds is often discharged directly to estuaries with impacts on other shrimp farms and the local environment. However much of the nutrients from feed and fertiliser remain in the pond and contribute to primary production and supplemental feed for the shrimp and fish. Nutrients are released during exchange of water in the pond and after harvest when pond sludge is removed, the latter being a significant component of waste load.

Nutrient release to the environment can be reduced by the use of sedimentation ponds for the effluent water.



ENVIRONMENTAL INDICATORS	Intensive (kg/ha/year)	Semi-intensive (kg/ha/year)
ENVIRONMENTAL EFFLUENT BUDGET		
Aquatic pollution		
Nitrogen load (aquaculture)	176	54
Phosphorous load (aquaculture)	12	4
Solid waste		
Nitrogen load (aquaculture)	156	48
Phosphorous load (aquaculture)	100	31
Organic waste	5.422	1.662

Note: The calculation has been done for intensive and semi-intensive shrimp farming.

Freshwater fish pond culture.
The majority of Asian fish production is undertaken in freshwater ponds for carp production. Similar to brackish and marine ponds, nutrients generally remain in the pond. Sediment accumulating in the fish ponds is usually used to increase the height of the pond walls or as fertilizer for orchards or agriculture.

Le (2005) calculated that nutrient released from intensive culture of *Pangasius* catfish ponds was estimated about 23.2 g of nitrogen and 8.66 g of phosphorus per kilogram catfish production. Nevertheless, research on such systems in the Mekong Delta of Vietnam suggest they make only a small contribution to net loadings of nutrients to the delta and coastal waters (DeSilva et al, 2009).

The location of freshwater farm plays an important role in fish pond management and practices. Farms are typically situated along rivers, river branches, water canal, and irrigation canals which have favourable condition with regard to available water resources. However, water quality may contain toxic residues, pesticides or organic matter which is discharged from agriculture, industry sources or residence areas without treatment. Floods may also be threat the fish ponds in the rainy or flood season.

Fish farms which originate in rice fields may share the water resource with agriculture. These farms normally locate far from residence areas thereby reducing the negative impact of human activities and conflict among communities. However, activities in the paddy fields, such as the application of pesticides, may negatively affect ponds. Water shortages in ponds may occur when paddy fields start to be irrigated. Farm located in residence areas may receive water waste from human, animal raise activities. Water source is usually from rain or groundwater. These farms are hard to manage because of limited water source and security issues.

Cage-pen aquaculture
Culture of fresh and brackishwater finfish (milkfish, tilapia, flounders, grouper, carp, Asian sea bass) is widely practiced though out Asia. A limited number of marine fish species such as, rabbit fish (*Siganus canaliculatus*), Asian sea bass (*Lates calcarifer*), red snapper

(*Lutjanus argentimaculatus*), grouper (*Epinephalus spp.*). are cultured in tropical coastal areas.

In cage and pen culture, water passes through the nets freely and the distribution of the nutrients is highly influenced by the hydrodynamics of the site location. All excess nutrients are released to the environment increasing the dissolved nutrient concentration in the water body and enriching the sediment beneath the cages. If the environment is not able to assimilate these nutrients quickly enough they will tend to accumulate causing eutrophication and changes to benthic biodiversity.

In many parts of Asia, cages are typically located in neashore more sheltered coastal areas. This is for traditional reasons of security and ownership and because most cages are small-scale locally made operations, with limited capacity to withstand more open environments. To date, there has been little use of offshore cages, although interest is increasing and the number of more offshore located farms is slowly increasing, particularly in China and recently in Indonesia and Malaysia.

Raft culture

Mussels and oysters and seaweeds are cultured using rafts or longlines. However, culture of these commodities is considered as environment friendly due to their nutrient assimilating capacity. Despite their role in assimilating nutrients, molluscs also cause localized biodeposition of pseudofaeces, which have some impacts similar to those of wastes deposited of marine cage culture.

Though mussels or oysters act as a bio-filter, organic pollution from large-scale mussel or oyster culture in form of pseudofaeces can not be neglected. For example, an individual mussel produces 5.7 mg organic matter per day (Dankers and Zuidema 1995). A typical oyster rack with 420,000 oysters can generate 16 t of faecal and pseudofaecal material during a nine month culture period. Deposited organic matter that originated from mollusk farms stimulates microbial activity, thus increase BOD, sulphate reduction and denitrification (Nunes and Parsons 1998).

Longlines

In the tropics, seaweed is a rapidly growing aquaculture industry and currently occupying a large proportion of world aquaculture production in wet weight basis. Commonly cultured species are *Eucheuma sp* (Indonesia, Philippines), *Kappaphycus sp*. (Indonesia), *Gracilaria sp* (Indonesia, Philippines, Fiji), *Porphyra sp, Nori sp* (Japan), *Enteromorpha sp* (Japan, USA), *Caulerpa sp, Codium sp, Hypnea sp, Soliera sp, and Acanthophora sp* (Fiji).

3.2 Nutrient balance

Most aquaculture production systems are based on nutrients imported from outside the system, although some are primarily dependent on relatively local sources (e.g. manure). Others use regional resources (such as food processing wastes, fresh trash fish) while yet others use global sources (commodity feedstuffs and fertilizers). Traditional integrated agriculture aquaculture involves relatively little waste discharge to the wider environment of the waterbody or watershed. Internal or relatively local recycling serves the dual purpose of enhanced production and waste assimilation. It has been suggested that such systems might offer a model for ecologically sustainable aquaculture but many depend on the import of feed for livestock, whose wastes in turn serve as the inputs to aquaculture. Furthermore there is a general tendency to intensify these systems.

Wastewater-fed aquaculture actually serves as a waste treatment system as it uses domestic wastewater as a source of fertilizer and feed. These systems act as net extractors of nutrients from the environment, so effluents are “cleaner” than the influent. However, waste-water fed systems are in decline. Although there are guidelines to safeguard public health (need reference), they are largely being replaced by modern wastewater treatment facilities. The quality and productivity of the fish is compromised by toxic industrial effluents and they are typically located in peri-urban areas where the value of land is rising rapidly due to urban development.

Most modern fish culture involves more intensive input of nutrients in the form of feed, with only a small proportion of the nutrients actually being converted into the target product. The rest accumulates in the system and is discharged in waste water or is removed as pond sludge and applied to pond dykes where it may fertilize fruit trees, or to waste ground or agricultural land. Effluent discharge to canals, rivers or lakes may cause eutrophication, an undesirable ecosystem change. In other cases, depending on dilution rates, effluents may be a beneficial addition of nutrients which boosts natural or agricultural productivity.

3.3 Environmental aspects

Not all the nutrients given as feed are assimilated by the fish and other aquatic animal products as production. A large proportion is excreted either as dissolved nutrients that increase their concentration in the water column or as faeces that settle to the sediment. The level of nutrient release is greatly influenced by feed quality, feeding strategy, over-feeding and type of feed (pellet, trash fish, home-made feeds). The exceptions are most molluscs, which are net removers of nutrients and organic matter from the environment, although even then molluscs farms can have significant influence on ecosystems through alteration of nutrient cycles.

Factors affecting release of nutrients and organic matter include poor utilisation of feed resulting in poor Food Conversion Rate (FCR), the quality of dry feed or trash fish and the feeding strategy. FCRs can vary between 1.2:1 for salmon to 2.8:1 (or higher) for milkfish (commercial pellets) depending on feed quality and feeding strategy.

Feed can contribute up to 60% of the total production outlay for commercial aquaculture. Aquacultural feed management strategies control how farmers feed their fish and have a considerable influence upon the economic and environmental sustainability of their enterprises (Cho and Bureau, 1998). Feed management regulates ration size, the spatial and temporal dispersal of feed, feed delivery rate and the frequency and duration of feeding events (e.g. Talbot et al. 1999). In addition to influencing key performance indicators such as growth rate or food conversion rate, each of these components can also have a profound effect upon environmental impact.

Feed formulation

A primary concern amongst aquaculturists is to deliver feeds that meet the nutritional requirements of the fish at ration sizes that optimise both growth and FCR. However, the exact energy and nutritional requirements are often not fully known leading to nutritional imbalances and causing reduced fish performance.

Fish feed producers have responded to the need for simplicity in daily farm operations by producing generic formulations for species such as milkfish but that are grown in very different culture conditions (ponds and cages) by offering feed products recommended for culture systems. However, fishes grown in cages and ponds have different nutritional requirements. It is therefore important to understand the impacts on cost efficiency, animal welfare and environmental impacts of using species-specific feeds and feeding protocols and to use this ionformation to design better, more system-specific feeds.

Feed quality

The quality of dry compounded feeds is influenced by the digestibility of the ingredients, the suitability of the formulation to individual cultured species and season, the stability of the pellets in water, the storage and handling of the feed and whether the feed is extruded or pelleted.

Feed type

There is generally a lack of feeds formulated for specific species, for specific culture systems and for different seasons. In addition many small scale farmers produce farm-made feeds. Farm-made feed are generally less stable in water and have poorer FCRs than manufactured feed, leading to increased pollution. There are particular concerns about pollution from cage effluents, deterioration of water quality and fish disease outbreaks. Ammonia, nitrates, and organic matter released in fecal wastes can be assimilated rapidly where high water temperatures prevail..

Feeding trash or low value fish also results in environmental impacts. The quality of wet feed (Low-value/Trash-fish) is influenced by quality and storage, whether the trash fish is fed whole or chopped or minced, as this influences the leaching of nutrients into the environment before being eaten. The age (days after capture) and storage conditions of the trash fish influences bacterial levels in the material and the addition of bacteria to the culture water.

Food conversion Rate

Feed Conversion Rates (FCR) are determined by many factors including appetite and palatability (and thus how much food is ingested), by digestibility, nutritional needs and fish metabolism. . Dietary ingredients, feed manufacture feeding regime, species, fish size, water temperatures and oxygen levels also influence FCR. The recorded feed conversion rates for farmed fish may vary widely from farm to farm and with production cycle. Farmers can improve FCR by feeding the appropriate quantity of feed amount, and by considering when, for how long and how often to feed.

Feeding strategy and management

The greatest influence on the amount of excess nutrients entering the environment is through poor feeding strategy by the farmer, resulting in under- or over-feeding.
Under-feeding has detrimental effects on production efficiency (Bureau et al., 2006) while over-feeding typically increases feed wastage (Thorpe and Cho, 1995), leading to poor feed conversion ratios (Talbot et al., 1999) and excess feed wastes that contribute to environmental degradation in cage culture (Cho and Bureau, 1998). Commercial fish farmers

must address each of these factors when designing economically and environmentally sustainable feed management strategies.

Appetite and feed consumption rates of fish vary within and between days and also between seasons (Noble et al., 2007).

Aquacultural feed management strategies determine how a farmer feeds their fish. In addition to influencing key performance indicators such as weight gain or feeding efficiency, each of these components can also have a profound effect upon fish behaviour and welfare. A primary concern amongst aquaculturists is to deliver a ration size that optimises both growth and feeding efficiency, and many aquaculturists still rely upon experience or feed tables to establish the daily ration sizes for fish. Although these recommended rations are based upon extensive research into fish nutrition, they assume fish will consume food whenever it is offered, irrespective of time of day or feed regime or health status.

An important opportunity to improve governance and management of the aquaculture sector and thus increase the social and economic benefits to small-scale producers lies in promoting and developing collective action in the form of farmer organizations or “clusters”. Clustering of smaller producers can create economies of scale and volumes that attract business, sellers of fish feed and fry, and buyers of aquaculture products.

Farmer cooperatives have been widely promoted in agriculture but there is little well documented information on cluster farming by commercially-oriented small-scale aquaculture producers. Recent experiences in the field show that promotion of cluster farming in aquaculture and managing these clusters with technical improvement, such as through application of better management practices (BMPs), can yield benefits. Such approaches can be successful tools for improving aquaculture governance and management of small-scale producers to work together, improve production, develop sufficient economies of scale and enhance knowledge that allows participation in modern market chains and thus reduce vulnerability. Such governance and management approaches can lead to improved economic performance of the aquaculture sector, better farm incomes and improve resilience of farm production systems and households.

4 Planning

Strategic planning

Strategic planning is widely recommended as a way to address the cumulative environmental effects of large numbers of small-scale aquaculture developments which characterize the bulk of aquaculture worldwide (e.g. GESAMP, 2001). However very few countries require or have implemented Strategic Environmental Assessment for aquaculture development.

Strategic Environmental Assessment (SEA)

Strategic Environmental Assessment offers a comprehensive approach to identifying likely sectoral impacts, and establishing environmental objectives, standards, limits and so on for the industry. It is also a good basis for developing aquaculture development and management plans or integrated coastal zone management plans (ICZM).

Strategic environmental assessment (World Bank, 2008) is a new concept to the region. As of 2005, only China, Hong Kong SAR, Japan, the Republic of Korea and Viet Nam have legal requirements, to a certain extent, for SEA at national or local levels, or for aquaculture plans. SEA is being implemented in South Australia, and New Zealand.

Australia provides one example where environmental assessment is conducted on proposed aquaculture zones in coastal areas, which can be considered a form of SEA. India has also conducted an environmental assessment of the shrimp-farming sector. China is increasing attention on environmental assessment of "special programmes" that can include aquaculture development plans. While many countries are enshrining the possibility of applying SEA to the aquaculture sector there has been limited application to date.

It is important to encourage and apply strategic assessment for large numbers of small projects. Government investment will likely be necessary for the conduct of such area based SEA initiatives, as is common in Australia, for example.

Zoning

Many countries in Asia do not have formal planning relating specifically to aquaculture, but do have land and water use zones which may restrict aquaculture activity. Zones may be either positive (i.e. aquaculture development zones or parks) or negative (i.e. aquaculture is excluded or highly restricted). Positive zoning is relatively unusual, though well established in some countries such as China, Japan, Republic of Korea.

Aquaculture "Master Plans" have been developed in Viet Nam and include some provisions for zoning. In Malaysia informal assessments have been undertaken for zoning initiatives, such as the Sabah Master Plan for aquaculture development. In the Philippines the new National Code of Practice serves as the basis for local framework. Planning for aquaculture is also relatively highly developed in China and Japan.

Aquaculture parks

Aquaculture "parks" have been promoted in some Asian countries. This represents a very positive approach to aquaculture development planning and management but needs to be handled carefully with carrying capacity estimation and restriction of licenses otherwise the cumulative impact could severe in enclosed and semi-enclose water bodies.

Environmental Impact Assessment (EIA)

EIA legal requirements are commonly focussed on high value, intensive farming, and particularly shrimp and marine cage farming Asia. Most legislation is oriented towards farms that cover larger areas, and that have a high potential environmental impact. Small-scale and inland aquaculture systems are less subject to EIA legislation/regulations. Seaweed and mollusc culture is rarely mentioned in EIA legislation or guidelines.

To date EIA has only been applied consistently to some large scale shrimp farming projects in South East Asia and to marine finfish farming in Australia. It is difficult to apply it to large numbers of small-scale fish farm developments.

In Asia, the requirements for EIA and monitoring are ambitious relative to the capacity to deliver. Capacity is weak in several dimensions: general skills (although country papers do not generally identify this as a key constraint); access to essential assessment and monitoring techniques; financial and institutional support; and enforcement.

Carrying capacity estimation
A key issue for sustainability of aquaculture is extent of nutrient discharge or other wastes to the receiving water body, which may lead to a deterioration in ecosystem structure (biodiversity) and the supply of ecosystem services (food, clean water, waste assimilation, etc.). To address this requires an understanding and assessment of assimilative (environmental) capacity. Environmental capacity is dependent on society's wishes and needs. If it can be estimated, then strategic precautionary limits might be placed on aquaculture and other activities to ensure that standards are not breached.

Carrying capacity in Asia is often seasonal (PHILMINAQ 2004). The nutrient release from watershed after the first heavy rains of the rainy season release high levels of nutrients into the water body that are in addition to the input from fed aquaculture and other inputs. This can lead to lowering of the aquaculture production carrying capacity and if this is not taken into consideration greatly increases the risk of algal bloom and low oxygen levels that can result in fish kills.

Many countries, including Indonesia, Japan, the Philippines and Viet Nam, are now developing environmental capacity models for a range of water bodies. In Japan these assessments are used to inform “Aquaculture Ground Improvement Plans”.

Box 2. Carrying capacity estimation in Japan.

Japan, with its long established intensive marine farming industry, has studied environmental capacity issues for some time. The approach has been to define environmental capacity in terms of the *maximum rate of assimilation*. Benthic oxygen uptake is taken as an indicator of the rate of mineralization and benthic ecosystem activity. This peaks at a certain organic matter loading, beyond which function is clearly impaired. This is taken to correspond to environmental capacity − and the total organic matter loading from farms must not be allowed to exceed this amount.

This is an example of managing the environment to maximize an environmental service (i.e. organic matter mineralization) − in this case a service to the aquaculture industry itself. This contrasts with the approach in many other countries, where environmental capacity is usually defined in terms of the organic matter or nutrient loading which can be accommodated without breaching the particular water quality standard agreed for that water body − usually through reference to historic water quality, national standards, or as agreed with other users. In other words the focus is not just on ensuring sustainable aquaculture, but on maintaining water quality for a variety of reasons. Japan has also developed indices of site suitability based on “embayment degree” and specific characteristics (water/sediment/fauna) which to some degree serve as indicators of environmental capacity.

5 Models

A variety of models are used in Asia for aquaculture planning and predicting impact.

- Modelling environmental impact
- Modelling carrying capacity

5.1 Carrying capacity models

Carrying capacity models need to be more widely available, tested and suitable models promoted. Calculations in the EIA to assess carrying capacity of the waterbody and the farms should take into account the other farms in the waterbody and not only individual farm projects. A useful summary of existing carrying capacity models for aquaculture is provided in McKinnon (2007).

A number of models to calculate carrying capacity are currently in use (Table 1). Two of these are of particular relevance to the Asia Pacific region.

- CADS_TOOL (Cage Aquaculture Decision Support Tool), developed under ACIAR project FIS/2003/027, currently includes 5 modules.
- The MOM (Modelling, On-growing & Monitoring) model developed by Stigebrandt et al (2004) for salmon has been modified to apply to grouper, barramundi and rabbitfish.
- The model of Hanafi (2006), based on an oxygen budget for Pegametan Bay, Bali, and applied to grouper aquaculture
- The model of Tookwinas (2004), another oxygen-based model developed in Thailand
- The model of Pulatsu (2003) for freshwaters, based on a phosphorus budget.
- The box model of Legovic et al (2006) for fresh, brackish and marine waters based on nutrient levels that trigger algal blooms

5.2 Models to predict aquaculture impact

TROPOMOD, developed under PHILMINAQ, is an extension of DEPOMOD and MERAMOD, originally applied to cage finfish mariculture in Scotland and in the Mediterranean respectively, has been developed to apply specifically to milkfish farming in the Philippines, but has application to other tropical species. In freshwaters, it has been successfully applied to tilapia. This model is a sediment deposition model and has the goal of minimising deterioration of sediment quality.

Table 1: Summary of status of carrying capacity models used in modeling aquaculture in the Tropics

Model	Country	Environment	Species	Culture system	Basis
MOM/simplified model	Norway Indonesia Vietnam	Marine	Salmon, now simplified being tested on tropical systems (seabass, grouper, rabbit fish)	cages	Carrying Capacity Multifactorial Water quality
TROPOMOD	Philippines	Marine and Freshwater	Validated for milkfish – marine and Tilapia -	Cages and pens	Deposition of organic material

			freshwater		
Siri Tookwinas (DOF/SEAFDEC)	Thailand	Marine	Shrimp Grouper	Ponds	Carrying capacity NH3-N
Hanafi	Indonesia	Marine	Grouper		Carrying capacity O2 budget
Pulatsu	Turkey	Freshwater			Phosphorus
Cirata Dam. Dr Sonny Koeshendrajana, Centre for Marine and Fisheries Socio-Economic Research Agency for Marine and Fisheries Research and Development	Indonesia,	Freshwater	Common carp and tilapia	cage culture	Phosphorus
Linear regression model (Philippines)	Philippines	Marine and Brackish	Milkfish	Ponds and cages	Carrying Capacity based on water quality
GESAMP model					Consolidation of Models based on phytoplankton and feed
Legovic model	Philippines	Fresh, brackish and Marine	Milkfish and Tilapia	Cages and pens	

6 Management

Environmental Management Plans
EIA legislation for aquaculture widely includes reference to Environmental Management Programs (EMPs) that include environmental monitoring. Monitoring is of fundamental importance to effective environmental management of aquaculture and is strongly linked with EIA as a process to monitor and evaluate the impact. Often there is limited implementation of monitoring requirements as developed in EIA environmental management plans, and limited analysis, reporting and feedback of farm level. In addition, it rarely addresses the wider environmental monitoring of a number of farms located in the same water body. However, examples can be found in the extensive environmental monitoring networks for fisheries in China and the developing systems in Viet Nam, both of which involve substantial investment.

Monitoring
Environmental monitoring is a significant activity in most countries, typically undertaken by government authorities. Where fish farming is larger scale, companies usually undertake their own monitoring – either as required by government (sometimes directly arising from EIA and associated EMP), or for their own management information. Most countries also have national water quality monitoring systems which are not specifically related to aquaculture but serve to alert public authorities of any problems which may arise.

In some countries third parties may be involved – or partnerships of interest (e.g. Philippines) to ensure neutrality and representation of stakeholder interests.

In Japan, fishery cooperative associations are required to undertake monitoring and reporting for the farms in their area, assisted in some cases by prefectural fishery stations. In New Zealand and Australia monitoring programmes may relate directly to marine plans or aquaculture development plans, and be tailored to particular issues and zones as required. In China there is now a major sector related monitoring programme – the Fishery Environmental Monitoring network – covering 21 million hectares, with a major centre in Beijing. This covers inland and nearshore coastal waters with both disease and environmental components. A similar system is being developed in Viet Nam.

Programmatic Monitoring
In the Philippines there is provision for Programmatic Environmental Performance Report and Management Plan – but this has not yet been implemented in coastal and lake based aquaculture.

7 Indicators and standards

Environmental Quality Standards
The existence and use of standards as part of the environmental management of aquaculture, and to inform permitting procedures, enforcement, EIA and other procedures is highly variable. In many countries water quality standards are well developed, and in Europe these are now being applied in relation to particular waterbodies. In developing countries water quality standards have sometimes been copied from developed countries and may not reflect local conditions or needs.

Water quality standards
The Association of South East Asian
standardizing water quality standard
standards are applied in relation to th
example there are now national stand
types – for discharge to coastal mari
these serve as a starting point for lim
or characteristics of a particular wate

Acceptable water quality standard
The water used for aquaculture shou
human consumption. Farms should n
water in which animals are reared by
WHO guidelines for the use of waste
Farms should maintain water quality

Standards for freshwater are commo
agencies throughout the world. In m
precautionary levels. Some of these
implementation remains limited.

The standards used by government u
cause algal blooms and de-oxygenat
however need to be examined in rela
aspirations of people who depend on

8 Governance measur

8.1 Codes of Conduct (C (GAP)

Codes of Conduct (CoC) or Good A
government, private sector and NGO
certification schemes and market acc
BMPs and certification schemes app
with exported products, and food saf
cost to comply with these schemes c

regulatory procedures, as well as far
amounts to a complete management
requirement for local government an
requirement for an environmental im
provisions for the spacing of cages a
these planning related provisions, th
relating for example to organic wast

Much stronger emphasis is also need
small-scale farming sector, through s
that support improved environmenta
and technical services that will supp
with such management also need to
costs can and should be absorbed by

Cluster management[2]

Cluster management in simple terms
and implementation of crop activitie
area for example sharing common w
address the common risk factors and
reduce disease risks, increase marke
adoption through a cluster managem

Cluster management brings several a
otherwise is not possible. Because o
forward and backward integration of
respectively, is possible. A cluster ap
farmers to source quality inputs.

Certification, which is cost prohibiti
cluster certification. A cluster appro
compared to an individual farmer. T
ensures that common facilities such
developed and maintained properly.
irresponsible culture practices such a
disease affected ponds.

The key to cluster management is c

8.2 Better Management

BMP projects, in India, Indonesia, T
translating the principles of responsi
farming conditions and ensuring the
consequent gains in production, qual
They also show evidence of the adva
groups/societies), sharing resources,
adopting BMPs. The implementation
benefits to the farmers, environment

BMPs need to be grounded in valid
superficial experiences. Thus there i
quantitatively assess their impact on
to develop implementation mechanis
impacts among large numbers of sm
also, far as possible, be supported by
country i.e. the cultural contexts pre

8.3 Ways forward

How can small-scale farmers best be
sector, and demand being created fo
production stagnates?

What synergies between small-scale
rural and urban households in terms
How can the required technical and
improve and remain competitive in

Some new approaches are emerging
and improved technical and financia
services are emerging in several rura
profitability of small aquaculture ent
governance and management of the
economic benefits to small-scale

of small-scale producers to work tog
of scale and enhance knowledge that
reduce vulnerability. Such governan
economic performance of the aquacu
of farm production systems and hous

Whilst more studies are needed, eco
can yield substantial social and econ
project in India for the period of 200
the technical assistance program, a p
shrimp farmers (Umesh et al., 2009)

At the same time, the establishment,
regulatory and administrative frame
aquaculture products) are key requir
sector. These frameworks should co
provide economic incentives that en
farmers to elaborate, support and en
sustainability-conducive production

In an increasingly globalised and ma
which the larger private sector playe
that work for small-scale farmers, or
Commonly, small projects investing
work well, but sustaining these beyo
oriented approaches and solutions. T
smallholders and their organizations
turn encourage businesses to adapt t
producers (Vorley et al., 2008).

It also means bringing together diffe
sustainable enterprise development.

Within the context of better manage
integrate environmental managemen
farmers and farmer groups, .

When planning and siting of large cl
Programmatic EIAs or Environment
capacity modelling for the cluster so
sustainable.

There should be systematic and regu
large clusters of small-scale farms. T
organisation or by the local governm

There should be promotion of open s
have high production farms located i

Polyculture of appropriate species (e
waste loadings. Incentives for integr
is also necessary on the social, econo
systems, the influence of change on
optimised

Research on clusters approaches, an
to support a more organised and bett
appropriate

There should be further developmen
emphasis on reducing environmenta

The co-management of clusters shou
defined border with the cluster of fa
purchasing), use of the area (carryin
marketing) with joint environmental
management.

The clusters should be encouraged t
clusters in a given water body into a
makers, cage makers, harvesters) fo
organised into associations. Local o
basic infrastructure (improved roads
machine, etc).

References

Abery, N.W., Sukadi, F., Budhiman,
Buddhiman, De Silva, S. S. 2005. Fi
Indonesia; a case study of ambitious
Management and Ecology, 12: 315-3

Bureau, D.P., Hua, K., Cho, C.Y., 20
deposition in rainbow trout (*Oncorhy*
Aquac. Res. 37, 1090– 1098.

Cho, C. Y. and Bureau DP. 1998. De
software to estimate production, feed
Living Resources 11, 199-210

Chopin, T. et al. 2008. Multitrophic
2475.

Dankers, N. and Zuidema, D.R. (199
culture in the Dutch Wadden Sea. *Es*

dela Cruz, Cet al., (Eds), 1992. Rice-f
for Living Aquatic Resources Manage

De Silva, S. S. and Davy, F. B., 200
De Silva and F. Brian Davy, Springe
ISBN 978-1-55250-461-1, 230 pp,

Edwards, P. 2009. Traditional Asian
In: G.Burnell and G. Allan (eds.), Ne
Efficiency, Quality and Environmen
UK.

FAO Fishstat Plus. http://www.fao.

FAO/NACA/UNEP/WB/WWF. 200
Farming. Network of Aquaculture C
Network of Aquaculture Centres in
Bangkok, Thailand. 20 pp.

Indonesian). Kajian Keragaan dan Pe
Syah, R., Mustafa, A.): 83-95.

Nhan, D. K. et al., 2007. Integrated f
the Mekong delta, Vietnam: Determi
Volume 94, Issue 2, May 2007, Page

Legovic T., Janekovic I. and Gecek
Environmental impact assesment of
pp

Lu, J. and X. Li. 2006. Review of rice
Important Ingenious Agricultural Heri

McKinnon (2007) Modeling carryin
consensus view. Workshop Report L
Institute for Marine Science. (availa

Muñoz, J. C., M Shared responsibili
www.capri.cgiar.org/pdf/devolution

Noble, et al., 2007. The impact of en
feed intake of cage held 1+ Atlantic
Nunes and Parsons 1998 Mollusc or

Phillips, et al., 2004. Review of env
aquaculture in Asia-Pacific. In FAO
aquaculture. *FAO Fisheries and Aqu*
153−283.

PHILMINAQ 2004 PHILMINAQ o
www.philminaq.eu)

Pulatsü, S. 2003. The application of
capacity of Kesikköprü dam. Turkis

Stigebrandt, et al., 2004. Regulating
farming III. A model for estimation

Umesh, N.R et al., 2009. In S.S. De
Aquaculture, Springer Science+Busi

Vorley, B., Lundy, M. & MacGrego
farmers. Paper prepared for FAO an
Forum, New Delhi, 8 - 11 April 200

WHO, 2006 WHO guidelines for th
Health Organization. whqlibdoc.wh

World Bank, 2008. Strategic Enviro
(available at http://go.worldbank.org

World Fish Center (2008) Rice-Fish
http://www.worldfishcenter.org/wfc

Zhou, Y., et al.,. (2006). Bioremedia
(Rhodophyta) integrated into fed fis
252: 264–276.