Low impact aquaculture

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Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Heading</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Executive summary</td>
<td>iv</td>
</tr>
<tr>
<td>1</td>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Synopsis of problems associated with aquaculture</td>
<td>2</td>
</tr>
<tr>
<td>2.1</td>
<td>Reduced functionality</td>
<td>4</td>
</tr>
<tr>
<td>2.2</td>
<td>Self-pollution</td>
<td>4</td>
</tr>
<tr>
<td>2.3</td>
<td>Social tension and conflicts</td>
<td>5</td>
</tr>
<tr>
<td>2.4</td>
<td>Impacts on option and non-use values</td>
<td>6</td>
</tr>
<tr>
<td>2.5</td>
<td>Summary</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>High potential strategies for low impact aquaculture</td>
<td>7</td>
</tr>
<tr>
<td>3.1</td>
<td>Community-based management</td>
<td>7</td>
</tr>
<tr>
<td>3.2</td>
<td>Horizontally integrated production</td>
<td>9</td>
</tr>
<tr>
<td>3.3</td>
<td>Resource efficient production</td>
<td>11</td>
</tr>
<tr>
<td>3.4</td>
<td>Sustainable feed supplies</td>
<td>12</td>
</tr>
<tr>
<td>3.5</td>
<td>Sustainable seed supplies</td>
<td>14</td>
</tr>
<tr>
<td>3.6</td>
<td>Organic and fair-trade production</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Policy initiatives to promote success</td>
<td>17</td>
</tr>
<tr>
<td>4.1</td>
<td>Environmental management</td>
<td>17</td>
</tr>
<tr>
<td>4.2</td>
<td>Low impact aquaculture systems development and uptake promotion</td>
<td>18</td>
</tr>
<tr>
<td>4.3</td>
<td>Participatory planning for enhanced natural resources management</td>
<td>21</td>
</tr>
<tr>
<td>4.4</td>
<td>Development planning and investment</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>Conclusions</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>25</td>
</tr>
</tbody>
</table>

Tables and Boxes

<table>
<thead>
<tr>
<th>Table / Box</th>
<th>Heading</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Negative impacts associated with aquaculture development</td>
<td>3</td>
</tr>
<tr>
<td>Box 1</td>
<td>Local Resource Users’ Groups</td>
<td>8</td>
</tr>
<tr>
<td>Box 2</td>
<td>Integrated shrimp, shellfish and seaweed production</td>
<td>10</td>
</tr>
<tr>
<td>Box 3</td>
<td>Periphyton-based aquaculture</td>
<td>12</td>
</tr>
<tr>
<td>Box 4</td>
<td>Sustainable feed</td>
<td>13</td>
</tr>
<tr>
<td>Box 5</td>
<td>Sustainable seed</td>
<td>15</td>
</tr>
<tr>
<td>Box 6</td>
<td>Organic shrimp farming, Bahía de Caráquez, Ecuador</td>
<td>16</td>
</tr>
</tbody>
</table>
Executive Summary

- Calls for greater emphasis on low impact aquaculture development are reviewed, notably recommendations from the United Nations Environment Programme concerning post-tsunami rehabilitation and reconstruction.

- Problems with poorly planned and inappropriate aquaculture development are discussed, including environmental impacts, reduced functionality, self-pollution, social tension and conflicts and impacts on option and non-use values.

- Promising strategies to facilitate low impact aquaculture are presented; a general introduction to each strategy is followed by practical examples, a case-study and caveats demanding attention.

- Strategies discussed include community-based management, horizontally integrated aquaculture, resource efficient production, sustainable feed and seed supplies and organic and fair-trade production.

- Reviewing international codes of conduct, best practice guidelines and the development literature, policy initiatives to support the uptake of low impact aquaculture are outlined.

- Practical steps to contribute towards low impact aquaculture are identified, including appropriate site selection, enhanced water management and conservation and adoption of integrated and resource efficient production systems.

- Low impact aquaculture should be included in integrated coastal area and watershed planning and management, and such strategies should be developed in consultation with all stakeholder groups.

- Institutions and legislation that support low impact aquaculture, including community-based and poverty focused initiatives are required.

- This paper aims to provide an overview of promising approaches to low impact aquaculture, raise awareness amongst development practitioners and promote dialogue on this issue which is critical to the future of aquaculture development.
1. Introduction

Problems associated with poorly planned and inappropriate aquaculture development, outlined in Section 2, have resulted in calls for future development initiatives to focus on low impact, ecologically sound and sustainable aquaculture. Writing in Nature, Naylor et al. (2000) note that ‘Long-term growth of the aquaculture industry requires both ecologically sound practices and sustainable resource management’. Whilst concluding an article in Science, Naylor et al. (1998) note that ‘reorienting national policies immediately towards an ecologically, socially, and economically sustainable view of aquaculture is both feasible and necessary.’ Furthermore, Principle 6 of the UNEP ‘Guiding principles for post-tsunami rehabilitation and reconstruction’ (UNEP, 2005) recommends the adoption of:

‘Ecosystem based management measures; promote sustainable fisheries management in over-fished areas, and encourage low impact aquaculture’.

Furthermore, the principles:

‘Encourage investment in community-based aquaculture and other livelihoods that bring benefits to local populations and do not degrade coastal ecosystems.’

And specify that:

‘Rehabilitated aquaculture must adopt environmentally sound management practices that do not pollute, damage habitats or cause long-term harm, including use of feed that is taken from sustainable sources and seeds that are raised in environmentally sound hatcheries or taken from sustainable fisheries’.

The guiding principles outlined above aim to address unsustainable fisheries and aquaculture activities in conjunction with post-tsunami reconstruction efforts throughout the tsunami affected area. However, similar problems exist in many other situations, both coastal and freshwater.
Consequently, an urgent need has been identified for policy guidelines that:

- provide a clear synopsis of problems associated with existing aquaculture practices;
- profile high potential strategies to realise the goal of low impact aquaculture;
- highlight opportunities for low impact aquaculture using case-studies;
- identify policy initiatives that would promote success with low impact aquaculture.

Furthermore, the guidelines presented here make frequent reference to knowledge and information resources to aid the development of low impact aquaculture programmes and strategies that are appropriate for local environmental, social, economic and institutional conditions.

2. Synopsis of problems associated with aquaculture

Articles in popular science journals have focused public attention on the potential negative environmental impact of aquaculture, in particular intensive production of salmon and shrimp (Naylor et al., 1998; Naylor et al., 2000; New Scientist, 1996; Nature, 1997; New Scientist, 1998). However, as Boyd (1999) noted the debate over impacts associated with aquaculture can become distorted by stakeholder groups with markedly different agendas, and consequently, he advocated impact assessment based on a rational appraisal, using the best available data.

Environmental impacts associated with aquaculture development include: habitat and ecosystem loss associated with site development; appropriation of environmental goods and services; physical and chemical degradation of water resources; nutrient enrichment in receiving waterbodies and subsequent eutrophication and altered ecological status; release of escapees, disease and parasites into the environment. Principal causes and affects associated with these environmental impacts are discussed below and summarized in Table 1; Bunting (2001) provides a more comprehensive review. Consequences of these negative environmental impacts can include reduced functionality, self-pollution, social tension and conflict and impacts on option and non-use values.
Table 1: Negative impacts associated with aquaculture development

<table>
<thead>
<tr>
<th>Impact</th>
<th>Consequence</th>
<th>Key features</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>modified hydrology</td>
<td>reduced flow rates, modified channel morphology and flow regimes and</td>
<td>Beveridge and Phillips (1993); Phillips et al. (1993); Tran et al. (1999)</td>
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<td></td>
<td>seditation</td>
<td>salinisation of surface waters in coastal areas</td>
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<tr>
<td>Chemical</td>
<td>pollutants</td>
<td>excreted ammonia toxic to invertebrates; waste nutrients lead to</td>
<td>Nature Conservancy Council (1990); Phillips et al. (1993); Weston (1996);</td>
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<td></td>
<td>reduced oxygen</td>
<td>hypernutrification; therapeutants and their residues affect non-target</td>
<td>Davies et al. (1997)</td>
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<td></td>
<td>concentrations</td>
<td>organisms leading to antibiotic resistant strains</td>
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<td>Nutrient enrichment</td>
<td>eutrophication</td>
<td>increased phytoplankton and periphyton production near cages, including</td>
<td>Nature Conservancy Council (1990); Bonsdorff et al. (1997); Selong and</td>
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<tr>
<td></td>
<td></td>
<td>possible stimulation of toxic algae blooms; increased epiphyte growth</td>
<td>Helfrich (1998); New Scientist (1999)</td>
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<td></td>
<td>modified species</td>
<td>elimination of pollution sensitive invertebrates and fish; increased</td>
<td>Oberdprff and Porcher (1994); Loch et al. (1996); Selong and Helfrich</td>
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<tr>
<td></td>
<td>assemblages</td>
<td>abundance and biomass of tolerant species and eutrophication leading to</td>
<td>(1998)</td>
</tr>
<tr>
<td>Shifting trophic</td>
<td>predation, competition and</td>
<td>ecosystem disruption through foraging and consumption of native flora and</td>
<td>Welcomme (1988); Arthington and Bluhdorn (1996); Bardach (1997)</td>
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<tr>
<td>status</td>
<td>ecological impacts</td>
<td>fauna; escapees breed with resident populations leading to genetic</td>
<td></td>
</tr>
<tr>
<td>Disease and parasites</td>
<td>loss of native species</td>
<td>viruses, bacteria and parasites infest native populations, exotic parasites</td>
<td>Arthington and Bluhdorn (1996); McAllister and Bebak (1997)</td>
</tr>
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<td></td>
<td></td>
<td>may also devastate non-resistant indigenous populations</td>
<td></td>
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<tr>
<td>Self-pollution</td>
<td>reduced production</td>
<td>upwelling of anoxic water causing fish-kills in cages; reduced water quality</td>
<td>Lumb (1989); Bluck et al. (1994); Corea et al. (1998)</td>
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<td></td>
<td>and product quality</td>
<td>leading to disease outbreaks and stimulation of toxic algae blooms</td>
<td></td>
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<tr>
<td>Restricted amenity</td>
<td>decline in capture fisheries and water quality</td>
<td>competition and disease can damage capture fisheries; sedimentation and plant growth restricts water flow in navigation and irrigation canals; reduced water quality affects access of livestock and humans to water causing social unrest</td>
<td>Nature Conservancy Council (1990); Phillips et al. (1993); Primavera (1997); Tran et al. (1999)</td>
</tr>
<tr>
<td>Reduced functionality</td>
<td>loss of ecological functions</td>
<td>discharged wastewater can degrade ecosystems leading to habitat loss,</td>
<td>Burbridge (1994); Robertson and Phillips (1995)</td>
</tr>
<tr>
<td>Impacts on option and</td>
<td>reduced perception</td>
<td>decreased diversity, restricted storage capacity for nutrients and water and</td>
<td>Turner (1991); Folke et al. (1994); Muir et al. (1999)</td>
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<td>and non-use values</td>
<td>of aquatic resources</td>
<td>disruption to flows of environmental goods and services</td>
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</tr>
</tbody>
</table>

(adapted from the review by Bunting, 2001)
2.1. Reduced functionality

Natural wetland functions support a wide array of environmental goods and services that sustain economic activities and societal systems (Burbridge, 1994). However, aquaculture development can damage the functional integrity of wetlands, disrupting the supply of environmental good and services. Considering shrimp farm wastewater, Robertson and Phillips (1995) noted that where the assimilative capacity of a mangal ecosystem was exceeded and excessive loads of ammonia and organic matter resulted in anaerobic sediments, mangrove trees might die and various functions may be lost.

Reduced biomass production and decreased nutrient assimilation and cycling could potentially lead to increased nutrient export and consequently adverse impacts on the receiving environment. Loss of the mangrove root system could decrease sediment stability, leading to erosion, which could increase saline intrusion and the risk of flooding inland. Loss of mangrove habitat also represents a loss of nursery areas for juvenile fish and shrimp, which would affect fisheries and threaten biodiversity.

2.2. Self-pollution

Wastewater from land-based aquaculture is routinely discharged to streams and rivers supplying other aquaculture operations downstream, whilst waste discharged from pen and cage farms may be conveyed to other farms by currents and tides. Moreover, for pen and cage aquaculture and pump-ashore facilities there is a danger that discharged wastes may contaminate water intended to supply the farm. Problems of self-pollution have been associated with shrimp farming in the inter-tidal area surrounding the Mundel-Dutch Canal lagoon system in the northwestern province of Sri Lanka (Corea et al., 1998). Farms were discharging wastewater containing high concentrations of ammonia, nitrite, nitrate and metals to the same areas used to supply their own, or neighbouring culture systems. The problem was compounded as mixing in the shallow lagoon was limited and a sandbar prevented exchange between the lagoon and ocean.

Furthermore, destruction of mangroves and salt marshes to build shrimp farms resulted in a loss of flood buffering capacity and elevated sediment loads which compounded water quality problems in the lagoon. Self-pollution caused disease outbreaks, encouraged parasite infestations, increased gill fouling with suspended
solids, retarded growth and resulted in poor quality shrimp production (Corea et al., 1998). Similarly, wastewater discharged from Indonesian shrimp farms caused water quality problems in adjacent small-scale tambak shrimp farms that were unable to regulate the exchange of water between ponds (Muluk and Bailey, 1996).

Increased oxygen consumption by microbial communities in sediments below cage farms may lead to anoxic conditions and the evolution of methane and hydrogen sulphide; release of which has been implicated in causing gill disease on fish farms (Black et al., 1994). Furthermore, respiration by benthic invertebrates and microbial communities in sediments receiving organic inputs from cage farms may depress oxygen concentrations in the water column. Such depressions have been observed beneath cage farms (Gillibrand et al., 1996; Lumb, 1989) whilst upwelling of this anoxic water poses a serious threat to the health of cultured fish and has been implicated in causing fish kills (Beveridge, 1996). Nutrients from aquaculture have also been implicated in stimulating toxic algae blooms, which in certain situations have resulted in restrictions on shellfish fisheries (New Scientist, 1999).

2.3. Social tension and conflicts
Aquaculture induced environmental impacts can affect other aquatic resources users. Deteriorating water quality in the Mundel-Dutch Canal lagoon system, attributed to increased shrimp farming, was blamed for declining capture fisheries; this caused resentment in local fishing communities, which manifested itself as poaching (Corea et al., 1998). Furthermore, during a survey in the local community several people complained of skin diseases possibly associated with poor water quality and although no direct link was established, such concerns may strengthen opposition to shrimp farming.

Saline wastewater from shrimp farms in Songkhla, Thailand has been implicated in causing the death of livestock drinking from canals (Primavera, 1997). Furthermore, this author reported that following salinisation of surface water by shrimp farm discharges in Nellore district, India, women were forced to spend longer collecting drinking water from distant sources. Yields on farms cultivating rice have been affected by saline water released from neighbouring shrimp farms, however, this situation arose due to leaching during the dry season and bunds being breached during
the growing season (Tran et al., 1999). Furthermore, these authors noted that shrimp farming may increase the sediment load to local canals and rivers and Phillips et al. (1993) reported that sediment in shrimp farm wastewater in Thailand and Sri Lanka caused irrigation canals to become silted.

Aquaculture wastewater may encourage nuisance growths of macrophytes that interfere with recreational activities, for example, angling, swimming and boating. Disease transmission from cage farms to native fish stocks was blamed for declining returns to recreational fisheries (Nature Conservancy Council, 1990). Furthermore, reductions in native crayfish populations owing to diseases introduced with farmed animals resulted in a proliferation of aquatic macrophytes, eliminating habitat for game fish (Thompson, 1990). Declining recreational fisheries and habitat loss can have severe implications for rural economies that receive income from visiting anglers and tourists.

2.4. Impacts on option and non-use values
Reduced quality of the aquatic environment can influence the value an individual attributes to preserving the resource to allow the individual, other individuals and future generations the option of using the resource at a later date (Muir et al., 1999). The impact of an activity on this option value may be estimated by assessing the willingness-to-pay (WTP) of an individual to preserve the environment. Folke et al. (1994) extrapolated marginal costs of $^{1}$SEK 50-100 and SEK 20-30 kg$^{-1}$ for nitrogen and phosphorus removal, respectively, from sewage in Sweden, to represent the WTP of Swedish society to limit nutrient discharges from salmon aquaculture. Based on a comparison of waste production presented as person equivalents, it was estimated in 1994 that the cost to society of eliminating nitrogen and phosphorus discharges originating from salmon aquaculture equated to SEK 4-4.5 kg$^{-1}$ of production. These authors also calculated that internalising this cost increased production costs for salmon to SEK 31-31.5 kg$^{-1}$, and although the 1994 farm gate price for salmon was not given, such an increase would reduce profits and possibly threaten the viability of salmon farming.

$^{1}$US$ = \sim 6$ SEK. Folke et al. (1994).
Environments also have non-use values, the intrinsic or existence value of environments is unrelated to humans and their present, or potential, direct or indirect use of the resource (Turner, 1991; Muir et al, 1999). People, although unlikely ever to visit a region may attribute value to its existence and feel a sense of loss when the ecosystem is damaged or degraded through inappropriate aquaculture development. Environmental degradation would also reduce the value ascribed to passing the asset onto future generations, termed the bequest value. Therefore, although changes in non-use values of environments due to aquaculture development have not been described, they may be expected to be negative.

2.5. Summary
Environmental impacts, cases of self-pollution, restricted amenity and functionality and decreased non-use values associated with aquaculture development were reviewed above. Growing recognition that aquaculture development may be responsible for a wide range of environmental costs and stakeholder conflicts has lead to increased awareness regarding the need for more rational, low impact aquaculture development. The following sections detail some of the most promising approaches to low impact aquaculture, provide pertinent case studies and highlight possible limitations.

3. High potential strategies for low impact aquaculture
Considering aquaculture development in terms of poverty alleviation, social development, equitable use of natural resources and environmental protection several high potential strategies for low impact aquaculture are reviewed below.

3.1. Community-based management
Community-based management usually centres on common pool resources which in the context of India, for example, have been defined as ‘non-exclusive resources to which the rights of use are distributed among a number of co-owners, generally identified by their membership of some group such as a village or community’ (Chopra and Dasgupta, 2002), and thus include: community pastures, grazing lands and forests, wastelands, dumping grounds and threshing areas, watershed drainage schemes, village ponds, rivers and other common pool wetlands. Definition and characterisation are likely to vary between countries and regions, as will associated
use rights and management arrangements. Some examples of community-based management follow, however, a number of limitations have been linked to prevailing management approaches and these are discussed below.

**Examples**

- Peri-Urban Participatory Action Planning and Implementation (PU-PAPi) an output from DFID NRSP Project R8365 in Kolkata (Bunting and Lewins, 2006)
- Participatory Action Plan Development (PAPD) as a tool to planning the management of wetland and common pool resources
- Integrated Floodplain Management in Bangladesh
- Local Resource User Groups formed for community-based management of farmer managed aquatic systems under DFID AFGRP (STREAM, 2006; Box 1)

**Box 1 - Local Resource Users’ Groups**

Aquatic animals collected from often interconnected rice plots, trenches, canals, ponds and open water bodies can contribute to household incomes and food security in poor rural communities in countries such as Vietnam and Bangladesh. As such it was recognised that community-based management was required to improve and sustain the exploited aquatic animal populations; the management approach developed was based on forming Local Resource Users’ Groups (LRUGs) from households to ‘work together in managing a specific area in the community to enhance productivity and yield of aquatic animals’. LRUGs help members identify interconnections and explore joint management options; facilitate listening and knowledge sharing; enhance participation in decision-making for improved aquatic resource management; promote accountability within the group and the broader community. Four steps to group formation were identified: discuss the situation and management practices that might be applied with the community; identify the area to be managed during transect walks and discussions and households with land in the area as potential members; present management options identified in step one to the group and agree on most appropriate one to implement; members of the LRUG implement management of the area. Management activities identified in trials included deepening water bodies, habitat creation, maintaining broodstock and nursing juveniles in haps and household ponds.

**Caveats**

Changing patterns of access to natural resources associated with aquaculture development, even where these changes are based on models of community-based management can have negative social impacts. Ellis and Allison (2004) note that current approaches to community-based natural resource management are flawed as they are often based on a particular sector e.g. fisheries, forestry and wildlife and often act to exclude new or different users from accessing the resource. It should also
be acknowledged that it is difficult to ensure effective participation and inclusion of the most marginalised men and women in communities. As Chambers (2005) says:

‘The challenge is how to give voice to those who are left out and to make their reality count’

Furthermore, Chambers (2005) notes:

‘The tendency for local elites to capture projects and programmes and use them for their own benefit should indeed by recognized as a fact of life.’

However, dealing with such realities and understanding the roles of leadership, patronage, unions, political parities and frequently coercion and extortion, may present opportunities to achieve more effective implementation and sustainable livelihoods enhancements for poor people; discussing the probability that local elites will monopolise initiatives, Chambers (2005) comments:

‘there are benefits as well as costs in this. Leaders are often leaders because they have ability, and projects may be better managed through their participation. Leaders, especially where there is an active political party, may seek support and legitimacy and so have an incentive to spread the benefits of projects to more rather than fewer people.’

3.2. Horizontally integrated production

Horizontally integrated production has been defined as ‘the use of unexploited resources derived from primary aquaculture activities to facilitate the integration of secondary aquaculture practices’ (Bunting, 2001). Horizontal integration has the potential to perform several important functions, the most valuable being the assimilation of wastes, reducing discharges to the receiving environment, whilst at the same time producing aquatic species that can be marketed. Reducing waste discharges through horizontal integration will contribute to environmental protection and reduce the risk of negative feedback mechanisms, limiting the possibility of self-pollution. Practical experiences with this approach are summarized below and possible limitations discussed.
Examples

- culturing green mussels (*Perna viridis*) on bamboo sticks in wastewater draining from a commercial shrimp farm in the Upper Gulf of Thailand (Lin et al., 1993),

- culturing cockle and seaweed in shrimp farm wastewater in Malaysia (Enander and Hasselstrom, 1994) (Box 2),

- exploring prospects for integrating the culture of macroalgae in shrimp farm effluent under the DFID AFGRP programme (Briggs and Funge-Smith, 1996).

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**Box 2 - Integrated shrimp, shellfish and seaweed production**

Cultivating hairy cockle (*Scapharca inaequivalvis*) and seaweed (*Gracilaria* spp.) in wastewater from a commercial shrimp farm in Kota Bharu, Malaysia reduced the concentration of ammonium, TN and TP by 61, 72 and 61 per cent, respectively (Enander and Hasselstrom, 1994). Wastewater was passed through two ponds in series, one with a surface area of 30 m² and 0.3 m deep stocked with 60 kg of cockles and one with a surface area of 18 m² and 0.7 m deep containing 5 kg of seaweed. Two sets of ponds were operated in parallel and each received 5.5 m³ d⁻¹ of wastewater. Mean TN and TP concentrations in shellfish ponds were reduced by 55% and 67%, respectively, whilst seaweed ponds reduced mean TN and TP concentrations by 36% and 10%, respectively. A mass balance model predicted that during one month, bivalve production (30 kg) would sequester 260 g of nitrogen and 9 g of phosphorus, whilst seaweed production (60 kg) would assimilate 5 g of nitrogen and 7 g of phosphorus. Enander and Hasselstrom (1994) noted that bivalves and seaweed are both potentially useful products for shrimp farmers, as they may either be recycled for shrimp feed or sold for supplementary income. Another suggested advantage is that diversifying species may disperse financial risks associated with farming shrimp.

Horizontally integrated systems have mostly been developed at the pilot-scale and been assessed based on technical issues such as nutrient retention, wastewater treatment capacity and production; few have attempted to evaluate physical parameters in association with managerial and financial indicators (Bunting, 2001; Bunting et al., 2003). Management of horizontally integrated systems may represent an increase in workload as compared with traditional practices and where this was justifiable through increased revenue it could constitute an important source of employment. Diversification through horizontal integration may help spread financial, environmental and disease risks associated with intensive production, but demands refined management approaches, planning and marketing. Lack of vision, limited access to venture capital, inappropriate policy, stakeholder pressure and poorly defined benefits for the operator all constrain innovation and diversification in aquatic farming systems.
3.3. Resource efficient production

The poor resource-base of small-scale farms in developing countries means that unexploited nutrient sources e.g. crop by-products, terrestrial weeds, aquatic plants and manure represent important production enhancing inputs to fishponds (Edwards et al., 1996). Little and Edwards (1999) reviewed the alternative strategies that have evolved to integrate the production of livestock and aquaculture; manure from cattle, buffalo, sheep, pigs and poultry has been employed to enhance production in aquaculture systems. Where access to on-farm nutrient resources is limited and the cost of inorganic fertilisers and supplementary feed prohibitive, food processing by-products, brewery waste, offal and human waste have been used to stimulate production in fishponds. Employing unexploited resources derived from within farming systems or from the immediate area to intensify production in fishponds has been termed integrated aquaculture (Little and Muir, 1987). By-products of aquaculture, notably nutrient rich water and sediments, may also be exploited to enhance production, either in agriculture or other aquatic farming systems. Examples given below highlight two promising approaches to low-impact aquaculture.

Examples

- integrated livestock-agriculture-aquaculture production systems such as the VAC in Vietnam make efficient use of resources, enhance production and spread risks

- periphyton-based aquaculture was introduced to farmers participating in the CARE-LIFE project (see Box 3); livelihoods impacts were subsequently assessed as part of a DFID AFGRP funded study (Bunting et al., 2005).

Caveats

Within the CARE-LIFE project a suite of interventions were introduced to farmers to help them improve fish production, including stocking polycultures, regular feeding and fertiliser application, dike-cropping and introducing branches as a substrate for periphyton. Combined, these interventions resulted in higher production, however, the relative contribution of periphyton to increased production was unclear. Findings from controlled trials, such as those on periphyton-based culture conducted at BAU, represent a valuable benchmark in this respect, demonstrating the principle and potential of the strategy. However, what was evident from the CARE LIFE participants was that they had adapted and refined the approach developed by
researchers to their specific situation. This indicates that guidelines prepared to promote new approaches with poor farmers should acknowledge and account for the logistical and resource limitations they face. Due consideration should also be given to prevailing and indigenous knowledge, guidelines should not be too prescriptive and highlight where alternative or more modest inputs could be applied; although potential gains may be reduced so might the associated degree of risk. There may also be unforeseen environmental and public or animal health impacts associated with adoption of modified management regimes. Widespread deployment of brushparks in Benin, West Africa to enhance periphyton-based fisheries resulted in local forests being overexploited. Concern has also been raised over the possible role of integrated fish-livestock production systems in mediating the spread of avian flu.

Box 3 - Periphyton-based aquaculture

Trials with periphyton-based aquaculture in freshwater ponds in Benin, West Africa gave significantly higher annual fish yields, as compared with production from other rural ponds managed for aquaculture (Hem et al., 1995).

Consequently, this innovative pond management strategy was proposed as a suitable technique to increase fish production in rural ponds in south Asia, in particular in Bangladesh and India. Experiments at the Bangladesh Agricultural University (BAU) conducted as part of the EU funded PAISA (Periphyton-based Aquaculture with Indigenous Species in Asia) project, demonstrated significantly higher fish production over controls with the addition of various substrates (Azim, 2001; Azim et al., 2002). Trials in freshwater ponds stocked with 6000 rohu (Labeo rohita), 4000 catla (Catla catla) and 1500 kalbaush (Labeo calbasu) per hectare, and containing substrate with a surface area roughly equal to the pond area, resulted in an extrapolated annual production of 7000 kg ha⁻¹, almost a threefold increase on average pond production in Bangladesh (Azim, 2001). In addition to enhanced production, farmers trialling the approach noted other benefits, they reported seeing fish rub against the branches in their pond to dislodge parasites and poaching, a serious concern for many, was also believed to have decreased significantly.

3.4. Sustainable feed supplies

Widespread concern has been expressed regarding the large volumes of fishmeal that are used to formulate feeds for commercial shrimp and salmon farming (Naylor et al., 1998; Naylor et al., 2000). Although, as Naylor et al. (2000) conceded ‘on balance, global aquaculture production still adds to world fish supplies’ and they noted that ‘if the growing aquaculture industry is to sustain its contribution to world fish supplies, it must reduce wild fish inputs in feed and adopt more ecologically sound management practices’. Fishmeal is not the only issue, however, rapid expansion of the prawn farming industry in Bangladesh resulted in the over-exploitation of freshwater snail
populations for feed, thus demonstrating that sustainable feed supplies are a must, even for smaller components of the aquaculture sector.

**Examples**

- research is underway to replace fishmeal in commercial feeds with meat by-products, microbial proteins and oilseeds enriched with n-3 fatty acids
- replacement of fish meal in shrimp feeds with protein rich seed pods harvested from leguminous trees cultivated on pond embankments (see Box 4)

**Box 4 - Sustainable feed**

Striving for organic production managers at Bahía de Caráquez shrimp farm, Ecuador noted that it was necessary to find a substitute for the high proportion of fish meal used in commercial feeds. Experiments conducted to develop an alternative feed formulation indicated that vegetable protein could be used to replace fish meal. However, it was necessary to source this vegetable protein from organic sources; the Encarnacion Organic Farm was established to supply feed ingredients. Furthermore, seed pods from leguminous tree species (*Prosopis* sp. and *Leucaena* sp.) planted on the embankments of the ponds provided a further source of high protein feed ingredients; owing to the harsh environment of the Caráquez estuary and saline growing conditions it was necessary to plant a combination of native and exotic tree species.

Other species planted on the embankments produce aloe vera, almonds, fruit and flowers; generating additional income, supporting organic honey production and providing habitat for wildlife. Harvesting seed pods from the trees also provides employment for local community members, an important development as disease outbreaks and the abandonment of many conventional shrimp farms resulted in widespread unemployment.

**Caveats**

Concern over fishmeal use in aquaculture must be balanced against the benefits it conveys as compared with other major users, namely pig and poultry production. Static fishmeal production globally and rising demand from aquaculture and livestock farming will probably mean an increase in the relative cost of fishmeal. Kristofersson and Anderson (2006) predicted that higher fishmeal prices are likely to result in innovation within the farming sector, including greater substitution with new soyabean meal products, enhanced diet formulation, increased production efficiency, a shift in cultivation to species less reliant on fishmeal, and breeding programmes and genetic engineering for novel plant-based products to substitute for fishmeal. These authors also noted that sustainable management of the pelagic fisheries from which fishmeal is derived would mean that coastal communities could benefit from the rising relative cost of fishmeal, whilst more efficient processing of the catch, with less
waste and discarded bycatch, would improve fishmeal supplies without adding to fishing pressure. Fish oil has been used as a substitute for fishmeal in aquaculture feeds, however, as with fishmeal, supplies are finite, whilst complete substitution of vegetable oil for fish oil is impossible as the digestibility, amino acid profile and micronutrient composition differ.

3.5. Sustainable seed supplies
Sustainable access to fry and fingerlings can constitute a significant constraint to aquaculture development. Several traditional aquaculture practices evolved based on the collection of gravid females or seed from the wild, however, harvest of wild seed was often unsustainable and unable to support higher production. Collection of seed, in particular, shrimp seed also involved a significant by-catch of larval fish and crustaceans that was discarded, further damaging wild stocks; Larsson et al. (1994) estimated that 872-2,300 km² of mangrove was required to supply post-larvae to Colombia shrimp farms in 1990, equating to 20-50% of the countries mangrove forest. In response state run hatcheries, often supported with external assistance, were established to supply seed to emerging aquaculture sectors, however, in many cases these hatcheries were often poorly managed, producing low numbers of poor quality seed, furthermore, production cycles were often poorly matched to farmers needs and the timely distribution of seed problematic. Considering these problems recent initiatives, outlined below and in Box 5, have aimed to enhance seed supplies, matching supply with demand, and ensuring quality and timely availability.

Examples
- government support to private hatchery development in Thailand including training, extension and marketing assistance helped ensure fish seed was readily available in northeast Thailand (Ingthamjitr et al., 1997),
- seed for prawn farming under the Greater Noakhali Aquaculture Extension Project come from disease-free broodstock maintained in hatcheries and consequently no antibiotics are required (Lecouffe, 2005), post-larvae are sold to farmers with an identity card to permit traceability, opening up the opportunity for environmental certification
Limited or unreliable supply of seed to rural and upland areas can constrain the development of aquaculture. However, in the Lao PDR promotion and support of fish seed supply networks meant that upland rice farmers in Dong Village, Sepone district were able to obtain fish seed to stock into the numerous bomb craters on the hillsides and raise fingerlings to sell on locally or to farmers travelling from more remote villages (Lithdamlong et al., 2002).

AIT Aqua Outreach, working in collaboration with the Savannakhet Livestock and Fisheries Section, Department of Livestock and Fisheries established the ‘nursing network’ to facilitate the distribution and decentralised nursing of fish seed supplied by the provincial level government. Fry from a central hatchery were supplied to nodal farmers who then distributed it to their neighbours or nursed it in net enclosures or hapas thus increasing its size and value, and making it available for longer to prospective buyers in often remote areas where communications are difficult. The potential impact of this initiative was limited by the capacity of the central hatchery and subsidised nature of fry distribution to nodal farmers. In response a ‘spawning network’ was established to promote decentralised hatchery production, although, this too required significant institutional support, training and the supply of premixed hormones to induce spawning, a step which was only possible owing to the ‘cold chain’ for animal vaccines developed previously.

**Caveats**

Even where fry-trader networks are well established there can be problems, traders have a vested interest in the stocking densities adopted by farmers, and in some cases it has been suggested that farmers have been persuaded to buy excessive numbers of fish (Bunting et al., 2005). Furthermore, traders without access to certain species may be tempted to encourage farmers to stock an inappropriate combination of fish; practical difficulties in identifying juvenile fish also constrain farmers from achieving preferred stocking rates. The quality of fish available to farmers may also represent a constraint; during a meeting with fish farmers in Kotiadi, Bangladesh participants mentioned that having to stock small fingerlings resulted in poor growth and production (Bunting et al., 2005). Furthermore, where failings in the distribution of seed are addressed by the development of hatcheries in remote and inaccessible areas there is a risk, as with poorly managed hatcheries and local programmes elsewhere that limited stock numbers will result in inbreeding (Muir, 2005).

3.6. Organic and fair-trade production

Intensive production in aquaculture can result in negative environmental and social consequences such as those outlined in Table 1. In response, organic and fair-trade production have emerged as widely advocated mechanisms to redress the balance, promoting environmental protection, animal welfare, public health, ethical trading and
corporate social responsibility. There are various interpretations of what constitutes organic or fair-trade production and only a limited number of certified producers, but growing markets demonstrate that people are willing to pay a premium for such products, and for some this may represent a pathway out of poverty.

**Examples**

- organic shrimp production in Ecuador (see Box 6)
- development of fair-trade standards for prawns, such as those produced as part of the Greater Noakhali Aquaculture Extension Project, Government of Bangladesh, supported by DANIDA

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**Box 6 - Organic shrimp farming, Bahía de Caráquez, Ecuador**

Shrimp farming in Ecuador, once the world’s largest producer, has been affected by a number of problems, self-pollution, shrimp disease outbreaks, contamination with chemicals and social injustice, as traditional resource users were excluded and land ownership was transferred to a few powerful families. In response to these problems and protests and boycotts in Europe the owners of EcoCamaronera Bahia sought advice to address the situation, and began by planning mangrove trees on the embankments and in ponds; other vegetation in the ponds was also allowed to develop as a wildlife habitat. In the late 1990s the initiative was taken to convert the farm to organic production, multi-cropping of embankments was established, organic feeds were formulated and effluent monitoring initiated. A notable problem in converting to organic production was identifying a suitable replacement source of protein for feed formulation, the solution found to use the protein rich seed pods of leguminous trees planted on embankments. Following these developments the farm was inspected and certified by Naturland, Germany as organic; subsequently two neighbouring farms adopted similar management approaches, were inspected and certified. Adopting organic practices also lead to wider benefits, modified management approaches, such as collecting seed pods, resulted in increased employment for local community members and the diverse bird fauna resident at the farm attracts birdwatchers and tourists that contribute to the local economy.

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**Caveats**

Despite recent demand growth, organic and fair-trade goods only supply niche markets and as such only a relatively small number of farmers stand to benefit (Siriwardena, 2005). With a diverse sector such as aquaculture, the transaction costs of converting to organic production can be significant; the onus rests with the producer to formulate a strategy to convert to organic production, demanding considerable investment in researching organic standards and approaches, sourcing or formulating organic inputs, modifying management practices and commissioning the
certification process. Poor small-scale farmers, by definition, will not have the resources to convert to organic production. Fair-trade agreements, such as that advocated by the Fairtrade Foundation require small farmers to organise themselves into groups, and group formation may be one way that producers could share the transaction costs of converting to organic production.

4. Policy initiatives to promote success

Drawing on a wide array of literature and sources, including best practice guides and codes of conduct, policy initiatives to promote the successful adoption and operation of low impact aquaculture systems are outlined below.

4.1. Environmental management

Phillips et al. (1993) noted that appropriate site selection, improved management, wastewater treatment and adopting effective planning and monitoring would reduce the environmental impact associated with farming shrimp; broader consideration of such aspects would undoubtedly reduce the environmental impact associated with other forms of aquaculture. Jones (1990) noted that water abstracted for fish farming reduced river flows in stretches between the farm intake and outflow to such an extent that the movement of migratory fish could be hampered. Such situations should be avoided through improved site selection and restricting abstraction to safeguard ecological flows. Water conservation measures such as those outlined by Boyd and Gross (2000) would help limit abstraction from both surface and groundwater sources:

- seepage control through employing good construction practices,
- limiting water exchange,
- providing storage for rain and runoff water.

Supplementary aeration and water reuse also have potential for improving water use efficiency in aquaculture. Measures to protect culture water quality would further reduce the need for water exchange; promoting vegetated pond margins would facilitate nutrient uptake and stabilise embankments, reducing erosion and eliminating scour which can be an important source of suspended solids in pond-based aquaculture (Funge-Smith and Briggs, 1998). In general, the use of chemicals in temperate aquaculture is closely regulated to ensure operator safety, protect the environment and safeguard product quality. In tropical developing countries where
aquaculture production has increased dramatically, the rate of expansion in the industry has frequently overwhelmed attempts to regulate and monitor the industry. Consequently, problems associated with chemical use in aquaculture may be more acute in developing countries with limited resources and poorly defined regulatory frameworks. However, as institutional arrangements evolve operators of aquaculture facilities will require appropriate management strategies and treatment technologies to limit or avoid the release of chemicals in wastewater.

Where water quality does decline during the culture process a range of strategies for reducing pollutant concentrations in discharges have been proposed, ranging from ecologically-based lagoon and wetland systems to technologically advanced filters and sterilization units (Nature Conservancy Council, 1990; Cripps and Kelly, 1995; Bunting, 2001). However, strategies developed by researchers and commercial enterprises with a vested interest in uptake are sometimes constrained by concerns regarding reliability, practical limitations, possible risks and financial demands (Bunting, 2001). Awareness of available strategies should be enhanced and operators of aquaculture facilities supported in selecting the most appropriate and effective option.

4.2. Low impact aquaculture systems development and uptake promotion

Building on recommendations presented by Siriwardena (2005) for shrimp farming, policy initiatives to support low-impact aquaculture should:

- include low impact aquaculture in integrated coastal area or watershed planning and management,

- enhance and secure access to resources for poor farmers and support community-based planning and management initiatives,

- strengthen existing institutions, to provide technical support and better manage the aquatic environment,

- implement or enhance monitoring and evaluation, strengthen legislation and law-enforcement and eliminate corruption.
**Resource efficient production**

Promotion of resource efficient production, notably integrated farming systems, will require government assistance, training, sustainable seed supplies, and management advice (New Agriculturalist, 1998); although it is also noted that ‘much has still to be learned about the factors that influence the success or failure of efforts to establish integrated agriculture-aquaculture systems’. Bioeconomic modelling offers a promising approach to exploring the performance of integrated farming systems under different management scenarios (Bunting, 2001; Bunting et al., 2003; Bunting, in press), however, as Prein noted ‘If they [farmers] are not able to observe the benefits, to understand how their farming system can be realistically enhanced and to participate in discussing how that process should happen, then the successful integration of aquaculture into existing agricultural systems, however beneficial, will not occur’ (New Agriculturalist, 1998). Invoking the DFID Sustainable Livelihoods Framework in structuring the analysis of periphyton-based aquaculture in Bangladesh enabled environmental, institutional and social constraints to adoption by poor farming households to be realistically identified, and enabled optimal system-wide opportunities for improved management practices to be elicited during discussions with farmers (Bunting et al., 2005).

**Organic production**

Conversion to organic production requires financial investment and administration, both of which may be beyond poor small-scale farmers; policies are required that support smaller farmers in adopting organic production. Furthermore, even some of the largest certifiers of organic food, such as the Soil Association, have to date only produced interim standards for organic aquaculture (Soil Association, 2005). Fundamental concerns regarding the use of fishmeal and oil from fisheries that have not been certified as sustainable constitute a significant barrier to the development of organic aquaculture; other contentious issues include the interaction of farmed and wild stocks, nutrient recycling and animal welfare. Naturland, another body that presides over standards for organic aquaculture was criticised for certifying a shrimp farm in Ecuador as organic when the legacy of unsustainable development of the industry was still in evidence, and the farm continued to use land previously covered by mangroves (Swedish Society for Nature Conservation, 2006). Prospects for the organic aquaculture of carnivorous species such as salmon where production depends
largely on fishmeal and oil from uncertified fisheries appear poor, although those producers that can meet the required standards stand to gain a worthwhile premium. However, for species such as omnivorous carp and tilapia, shellfish and seaweed, with appropriate institutional support and raised awareness amongst consumers, prospects for more widespread organic production seem promising. However, there is a recognizable need for consistency amongst standards and an internationally recognised certification scheme (The Economist, 2003).

**Fair-trade production**

Taking the Fairtrade Foundation as an example there are two sets of generic producer standards, one for smallholders organised in co-operatives or other organisations with a democratic, participative structure and one for workers on plantations and in factories. These generic standards specify the minimum requirements which producers must meet to be certified Fairtrade. Principles of the Fairtrade Foundation aim to encourage producer organisations to continuously improve working conditions and product quality, increase their environmental stability of their activities and invest in the development of their organisations and the welfare of their producers or workers. For organised workers, employers should pay decent wages, guarantee the right to join trade unions and provide good housing when relevant. On plantations and in factories, compliance with minimum health and safety and environmental standards is expected and no child or forced labour can occur. Furthermore, traders dealing in Fairtrade goods must: pay a price to producers that covers the costs of sustainable production and living; pay a 'premium' that producers can invest in development; make partial advance payments when requested by producers; sign contracts that allow for long-term planning and sustainable production practices. However, there are significant barriers to the expansion and diversification of the fair-trade movement, notably subsidies to domestic producers and on exports and tariffs on imports (Fairtrade Foundation, 2006). The Trade Justice Movement constitutes a coalition of more than 70 organisations working towards reform of the rules and institutions governing international trade (Trade Justice Movement, 2006) and further support to such movements would enhance prospects for fairly-traded goods.
4.3. Participatory planning for enhanced natural resources management

Discussion concerning aquaculture development has the potential to become distorted by individuals or groups with different agendas, as Boyd (1999) noted:

“there is a great diversity in the way different people perceive the proper use of natural ecosystems and resources, and their deep-seated feeling (sic) often overrule objectivity … Thus, environmental issues are volatile because they are tempered by both strong feelings and opinions.”

Only by understanding the reasons for such differences and recognising them as legitimate will it be possible to formulate management approaches that are acceptable and feasible. As Adams et al. (2002) noted:

‘Different stakeholders in a common pool resource bring to their decision-making different assumptions, knowledges and goals for that resource which are not always explicit’.

Consequently, engagement with the full range of stakeholders is critical (Bunting, 2001) as often the perspectives of poorer groups are missed, and even within these poorer groups the voices of women, children and the powerless often remain unheard. The degree of representation or engagement achieved is critical. According to DFID (2001) “Involving those who stand to win or lose from policy or institutional reform, or who may influence the reform process, helps to make the interests of key stakeholders transparent and to build ownership of the reform process”. If the process is not fully representative it is flawed from the outset, only by ensuring the interactive participation of all groups and ensuring their voices are heard will shared learning and understanding be achievable; participation in planning and decision-making should be regarded as a right (Pretty, 1995).

Furthermore, considering culture-based fisheries and stock enhancement programmes, it was noted in the Bangkok Declaration resulting from the Conference on Aquaculture in the Third Millennium that the potential of such strategies would only be realised by ‘creating conducive institutional arrangements to enable and sustain investment in common pool resources’ (NACA/FAO, 2000). In this regard approaches for the decentralised governance and management of natural resources are
required, however, as Chopra and Dasgupta (2002) noted regional variations in prevailing institutional arrangements must be considered, and ‘centralised’ drafting of ‘decentralised participatory governance’ avoided. These authors also noted that steps to enhance access and facilitate change should be transparent and first take into account pre-existing institutions of natural resources management; policy, institutional structures and legislation should complement interventions and foster and support wider uptake of equitable co-management arrangements.

4.4. Development planning and investment

Article 9 of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) proclaims that ‘States should promote active participation of fishfarmers and their communities in the development of responsible aquaculture management practices’. Furthermore, inclusion of all resource users in the development process is necessary to ‘ensure that the livelihoods of local communities, and their access to fishing grounds, are not negatively affected by aquaculture development’. Dialogue between key stakeholders and policy formers is necessary for State level agencies to ‘establish, maintain and develop an appropriate legal and administrative framework which facilitates the development of responsible aquaculture’. Research investment to support the development of methods and protocols for the participatory monitoring and evaluation of environmental health and livelihoods impacts is also needed to ‘promote responsible development and management of aquaculture, including an advanced evaluation of the effects of aquaculture development of genetic diversity and ecosystem integrity, based on the best available scientific information’ and to ‘establish effective procedures specific to aquaculture to undertake appropriate environmental assessment and monitoring with the aim of minimizing adverse ecological changes and related economic and social consequences’. The Code of Conduct also notes that policy formulation should promote ‘responsible aquaculture practices in support of rural communities, producer organizations and fish farmers’.

The Bangkok Declaration (NACA/FAO, 2000) called for collaborative multidisciplinary research; stakeholder participation in research; improved linkages between researchers, extension and producers; efficient communication networks; regional and inter-regional co-operation; and a continued effort to build the skills of
researchers involved in aquaculture development. Furthermore, it was proposed that food security and poverty alleviation could be improved through ‘promoting poor-people-centred development focus in aquaculture sector policies’; using participatory approaches to identify and assess the needs of the poor; developing and extending appropriate aquaculture strategies; promoting sustainable small-scale household production in rural areas where it may be the only source of fish for vulnerable groups such as pregnant and lactating women and families with infants and pre-school children.

The Bangkok Declaration also calls for greater investment in people, research and aquaculture development; improved environmental sustainability, notably through integration of aquaculture into coastal area and inland watershed management plan; integration of aquaculture into rural development and poverty alleviation programmes; strengthening of institutional support to implement transparent and enforceable policy and regulatory frameworks; application of innovations in aquaculture, including sustainable stock enhancement; improving culture-based fisheries and enhancements; better management of aquatic animal health; improved nutrition in aquaculture; application of genetics and biotechnology; improved food quality and safety; promotion of market development and trade. The need for enhanced information flows at the national, regional and inter-regional levels to encourage policy-making, planning and the application of rules and procedures was also highlighted; initiatives such as the FMSP Key Programme Lessons and STREAM Better Practice guides constitute important developments in this regard (FMSP, 2006; STREAM, 2006) as does this publication.

5. Conclusions

Based on the above discussion it may be concluded that a number of promising technical, social and institutional approaches with potential to contribute to low impact aquaculture have been identified and to some degree tested, however, strategies are required that promote and support their uptake and where necessary adaptation. Awareness of promising approaches to low impact aquaculture should be promoted amongst target institutions including national and local government authorities, extension agents, development practitioners, educational establishments
and communities that stand to benefits. Furthermore, policy, institutions and processes should support low impact aquaculture and where appropriate, incentives and disincentives implemented to help change perspectives and behaviour.
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