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Fisheries and water productivity in tropical river basins: Enhancing food security and livelihoods by managing water for fish

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Abstract

Faced with growing pressure upon freshwater resources, increased water productivity in agriculture is essential. Efforts to do so however need to consider the wider role of water in sustaining food production. This paper considers the importance of water management in sustaining fish production in tropical river basins, and the potential for enhancing food production and income to farmers by integrating fish production into some farming systems. Specific examples from selected river systems and irrigated farming systems in Africa and Asia are provided. These highlight the benefits of integrating the water requirements for fish into water allocation decisions. In some cases, these benefits can be realised without any reduction in the water available for other purposes, while in others, a trade-off needs to be considered. The nature of these trade-offs needs to be better understood for better decision making in water management.

Keywords: Fish; Fisheries; Aquaculture; Rivers

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1. Introduction

The past decade has seen growing recognition of the crisis facing the world's water resources and the need for concerted action to use these more efficiently. In this context, the work of national and international agricultural research centres to improve water productivity in crop agriculture is of immense importance. In moving forward to develop the technological and institutional innovations required to achieve this, it is however essential to ensure that the wider role of water in supporting food production and sustaining household incomes is recognised, and the water requirements to sustain this incorporated fully into water management decisions. Foremost amongst these concerns is the role of water in sustaining fish production, the principal source of animal protein and income to large numbers of low-income families in Africa, Asia and Latin America. The present paper examines these concerns and reviews approaches to improving food production by incorporating fish into water management from basin to farm levels.

2. Freshwater fish—the protein of the poor

Over large parts of Africa, Asia and Latin America, freshwater fisheries are a crucially important resource for poor rural families. Rich in protein and minerals, fish are a high-value food. Many are also rich in healthy unsaturated fatty acids that play an important role in the development of bones, nervous system and brain in children. Most small fish are eaten whole and contribute significantly to calcium intake. Teutcher (2001) reports that small whole fish tend to contribute far more to dietary balance than do prepared portions of larger fish.

In contrast to the marine fisheries of developing countries, most of which are the focus of a technology intensive multi-million dollar international industry, the majority of inland freshwater fisheries are harvested using a range of comparatively simple, low-cost technologies ranging from traps to clasp nets and spears. In this way, these resources are widely available to millions of people, including to women and children who frequently harvest small, but nutritionally important quantities (Thilsted et al., 1997; Thilsted and Roos, 1999) in ponds, streams and marshes within easy reach of their homes (Sverdrup-Jensen, 1999).

Rivers and their associated floodplains are particularly important in sustaining those fish harvests and correspondingly play a central role in sustaining livelihoods and providing high quality nutrition. For example in Cambodia fish, harvested primarily from the Mekong river system, constitute 65–75% of total protein in the diet (Guttman, 1999) and the value of the catch is between US $150–200 million yearly (Van Zalinge et al., 2000). The total direct use value of the fishery resources of the Lower Mekong Basin has been estimated as US $1478 million (Sverdrup-Jensen, 2002). In Bangladesh, fish contribute 60% of the intake of animal protein, and inland fisheries contribute some 42% of the total fish catch. In inland rural areas about 80% of households catch some fish each year, either for their own consumption or for sale (Williams, 1999).

3. Water requirements for river fisheries

As demand for water for agricultural, industrial and domestic needs has increased, river flows have been reduced. Today a growing number of rivers run dry along part of their course for all or part of the year, including the Colorado (USA and Mexico) and the Huang Ho (China). While use of river water to meet these needs has brought enormous benefits in many cases, it has also brought costs. Looking forward to the next 25 years, it is important that the future management of water brings benefits to agriculture while sustaining food production from fisheries.

Production from river fisheries is influenced by a number of parameters of which the most important are water level, duration of the flood, timing of the flood, regulation of flooding, characteristics of the flooded zone, migration routes and dry season refuges (Welcomme, 1985; Baran and Cain, 2001). Of these, the first four are functions of the flooding regime and are therefore particularly vulnerable to changes in flow that result from water allocation decisions within the river basin. Reduced water levels also exacerbate problems of pollution and eutrophication, especially in floodplain water bodies, which rapidly become anoxic in highly eutrophic conditions.

Using data from the Niger, Shire and Kafue rivers of Africa, Welcomme (1985) has examined the relationship between river flow and fish production in some detail and shown that it is possible to predict catches in river systems from regression analyses of the past performance of the fishery. This work has been further developed for the Niger by Lae (1992). More recently, Baran et al. (2001a,b) have modelled the flow-catch relationship for the Dai (large stationary trawl nets fixed in the river) fishery on the Tonle Sap lake/floodplain system of the Mekong where there is a strong correlation between water level and the annual Dai catches. As the catch estimate for the Dai fishery in Tonle Sap at a particular period of time varies considerably, relationship is established using three sets of catch estimates (Fig. 1). From the highest production of 20,000 tonnes, a drop of every 1 m in flow predicts a loss of approximately 2500 tonnes at high flood levels rising to 5000 tonnes at low water levels.

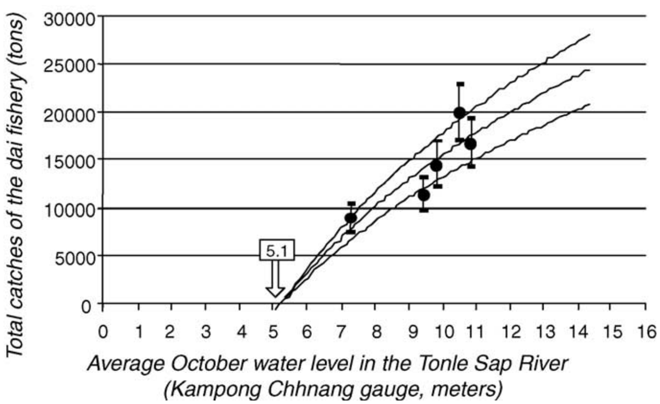

Fig. 1. Relationship between annual dai catches and average water level in October in the Tonle Sap River (logarithmic regression) (Baran et al., 2001a).

However, while these analyses from a range of river systems illustrate the importance of river flow for sustaining river fisheries, they provide only part of the information required to manage rivers for sustained fisheries production. In each case, only the portion of the fishery with the best available data has been examined. While in the case of the Niger, this focuses upon the inner delta and a substantial part of the recorded catch along the river, the analysis can only provide management guidance for the inner delta. In the case of the Mekong, the Dai fishery is only a small component of the system. The model illustrated in Fig. 1 may therefore be used to identify the specific flow requirements for that fishery, but can serve only as a very partial indicator for the larger Mekong fishery.

Even for the Niger, where Welcomme (2001) concluded that at least 14 years of data are required to accurately predict catch from flood levels, this is conditional upon there being no major changes to the resource base through overfishing, environmental change and other factors. In light of the pressures upon these river systems from a diversity of sources, and those upon the communities who use them, this condition is rarely met today.

In addition, while the biological basis of these flood-fishery relationships holds true in broad terms in different river systems (Welcomme, 1985, 2001), the detailed nature of that relationship and the consequent response of the fishery to changes in flooding and other factors varies from river to river. For this reason, detailed studies from one river system are at present of little value in providing specific guidance on how to sustain or improve productivity in other river basins.

In recognition of these constraints, increasing attention is being devoted to the development of decision-support tools that integrate recent advantages in modelling of river fisheries with contemporary methodologies for assessing environmental flows. A recent review of these environmental flow methodologies, fisheries production models and Bayesian risk assessment approaches (Arthington et al., in press) has emphasised the importance of moving towards the development of scenarios that can be used by river basin authorities, and water and fisheries managers, to predict the impact of changes in water flow upon fisheries and other in-stream resources, and the livelihoods dependent upon them.

After examining the strengths and deficiencies of a comprehensive group of holistic environmental flow methodologies, Arthington et al. (in press) identified the downstream response to imposed flow transformations (DRIFT) methodology as the most amenable to integration of specific fisheries modelling tools. Following on from this analysis, research is now needed to integrate these different modelling approaches into a single framework model for tropical river fisheries that will allow specialists to select the appropriate components, models and parameters depending on where they are situated in a river system, and on the available data. Such research is now being designed for several rivers in Africa.

As this work develops, it needs to be pursued in conjunction with efforts to strengthen and provide information in support of governance systems for these river systems. Without such engagement, including effective interaction with concerned community organisations, information on water-fish dynamics is of limited practical value for improving food security and livelihoods. Future work needs to be designed and managed in a manner that will address these concerns.

The productivity of many coastal fisheries is also dependent upon freshwater inputs in a number of ways (Bunn et al., 1998). Water, nutrient and sediment inputs from rivers play an essential role in sustaining the productivity and dynamics of a wide range of coastal ecosystems. For example, subsidence and erosion as a result of reduced riverine input have been demonstrated for the Po delta and Venice lagoon in Italy, the Rhone delta in France (Hensel et al., 1999), and the Mississippi delta in the United States. The impact of such modifications in the case of tropical countries whose deltas support many millions of people such as Bangladesh, Vietnam, Mozambique or Nigeria is the subject of international concern, but has yet to be adequately quantified. Similarly, the risk of salinization in the lower reaches of river systems as well as of reduced flows at the mouth of big rivers (e.g. Vietnam, Australia) is of concern but poorly documented and assessed. In addition to effects on agriculture, this salinization drives a change in the natural vegetation structure, whose diversity is reduced, impacting subsequently the livelihood of local populations. Turbid water and low salinity in estuaries act as barriers to many marine predators and so help provide safe nursery conditions. In addition, river borne nutrients fertilize inshore coastal habitats and ‘‘flood’’ regimes trigger the seaward migration of shrimp and the spawning of catadromous species. Some river floods open the temporarily closed estuaries (e.g. South and East Africa), allowing estuarine-dependant species to fulfill their biological cycle.

However, while the importance of these relationships is well understood by scientists working in the coastal zone, few of the studies carried out so far in tropical and sub-topical regions of Africa, Asia and Latin America allow quantitative analysis and clear prediction of the impacts of reduced water flow in coastal ecosystems. More such analyses are therefore required and more widely applicable predictive tools need to be developed.

4. Potential for improving water productivity by incorporating fish into water management

Water productivity and the techniques used to measure it vary depending on the spatial scale being addressed—from pond/field to basin. The most widely used definition is expressed in terms of weight or value derived per unit of water used/consumed (Molden and Saktivadivel, 1999). However, this is only a partial concept of water productivity. At the ecosystem or basin level, water provides a wide range of goods and services, all of which need to be considered in broader analyses of the value obtained from water. Most of the previous studies of water productivity (with the notable exception of Renwick, 2001) have concentrated on measuring the value of crop production only and excluded the existing and potential contributions by living aquatic resources.

Water productivity can be increased by producing more output per unit of water used or by reducing water losses, or by a combination of both. Various hydrological/engineering approaches have been developed to improve water productivity by reducing water losses (Molden and Saktivadivel, 1999; Molden et al., 2001; Droogers and Kite, 2001). Over the last several years, the International Water Management Institute (IWMI) has been leading a number of research initiatives that focus on increasing water productivity for food production and rural livelihoods (Kijne et al., 2003; Rijsberman, in press). However, in view of the analytical focus on crop productivity, it is not surprising that strategies for increasing output have so far been limited mostly to crop cultivation only. Water productivity at several organisational levels can be increased further by integrating fish and other living aquatic resources into the existing water use systems.

4.1. Integrating fish into irrigation systems

Irrigated agriculture is the largest user of the world's fresh water (Seckler et al., 1998), producing one-third of the world's food from 240 million ha, 17% of the world's cropland (Oi, 1997). As efforts to enhance water productivity in agriculture increase, one option is to enhance the production and harvest of fish from irrigation systems, so increasing the overall food production without increasing water use.

At present, no comprehensive assessment of the value of fisheries in irrigation systems exists. However, fish have been harvested in irrigation systems for at least two millennia (Fernando and Halwart, 2000) and a variety of studies show that these continue to yield substantial fish harvests (Ruddle and Zhong, 1988; Haylor, 1994). Yet, as argued by Fernando and Halwart (2000), the current use of irrigation systems for fish production falls far short of potential.

The canals and channels associated with irrigation systems are a particularly promising option for further development. Redding and Midlen (1991) calculate that 2.5 km of larger canals and 10 km of smaller channels are created for every 1000 ha irrigated. Using the figure of 240 million ha, this gives an estimate of 600,000 km of larger channels and 2.4 million km of small channels. While there are no systematic data on the proportion of these irrigation systems that are used for fish production, nor for current or potential harvests, studies reviewed by Redding and Midlen provide an indication of the range of yields from capture fisheries and cage and pen culture (Table 1). On the basis of this review, Redding and Midlen conclude that while there is potential for the management of irrigation canals as capture fisheries, the greatest potential lies with cage and pen culture. They argue that use of pens and cages for fish culture could substantially increase the efficiency of water use in irrigation systems.

Reservoirs are an essential component of most irrigation systems and, together with those built for flood control and power generation purposes cover a vast area worldwide. The 60,000 largest reservoirs – those with a volume of 10 million m^3 – are estimated to cover a surface of about 400,000 km^3 and together hold some 6500 km^2 (Miranda, 1999),

Table 1
Annual yields from capture fisheries and from cage and pen culture in irrigation canals (after review by Redding and Midlen, 1991)

Location	Yield	Source
Capture fisheries		
Gezira, Sudan	50–2786 kg/ha (mean 660 kg/ha)	Coates (1984)
Bangladesh	500 kg/ha	Marr (1985)
Thailand	350 kg/ha	Swingle (1972)
Cages and Pens		
Indonesia	50 tonnes/ha	Costa-Pierce and Effendi (1988)
Egypt	100 tonnes/ha	Ishak (1982, 1986)
China	300–1350 kg/ha	

while there are many hundreds of thousands of small ones. In eastern and southern Africa alone there are estimated to be between 50 and 100,000 small water bodies (Haight, 1994).

This large area and volume of reservoirs plays an important role in global fisheries (Moreau and DeSilva, 1991; Petrere, 1996; Fernando et al., 1998; Miranda, 1999), and there is considerable potential remaining. Culture-based fisheries of small reservoirs can augment fish yield in a substantial way as they did in China (743 kg/ha, De Silva, 2001), and contribute to almost the entire inland fish production in small island developing nations like Sri Lanka (300 kg/ha; Pet, 1995) and Cuba (125 kg/ha). In Cuba, fish produced from small reservoirs is the main source of freshwater fish supply and provides an essential source of animal protein (Sugunan, 1997). However, in many countries, this resource remains under-utilized as in India where the average yield from more than 19,000 small reservoirs (1.5 million ha) is less than 50 kg/ha and the all reservoirs (3 million ha) produce less than 20 kg/ha (Sugunan, 2001). In Asia, potential yields from reservoir fisheries are estimated to be 500–2000 kg/ha/year (De Silva and Amarasinghe, 1996), while the use of ‘‘cove culture’’ in the water inlets to reservoirs in China brings productivity in these areas up to the level of pond aquaculture, approximately 4500–5000 kg/ha. Advances of this sort coupled with enhanced stocking regimes are expected to enhance productivity from these systems and a range of small water bodies in the future.

In addition to stock enhancement and other measures to enhance capture fisheries, cage culture is also used to increase production in reservoirs. First developed in China, cage culture is now used in an increasing number of countries where it is seen as a means of increasing aquaculture potential without using scarce land resources, and as a means of compensating for loss of agricultural land under hydro dams. For example in the Saguling and Cirata hydropower reservoirs in West Java cage aquaculture activities employed some 7000 people, produced 25,000 metric tonnes, and generated a gross revenue of US $24 million, over twice the estimated annual revenue from the rice fields lost to the reservoirs (Costa-Pierce, 1998). The extent to which these results can be replicated in other areas is not known. In addition, serious problems were encountered with eutrophication from the cages and this will be a concern in other areas. For long-term sustainability of these systems strict adherence to guidelines regulating culture densities and water quality is required (Welcomme, 2001).

4.2. Rice-fish culture

There is an estimated 81 million ha of irrigated rice worldwide, with an additional 11 million ha of flood-prone land under rice cultivation (Halwart, 1998). Rice-fish production is possible in both of these systems under either capture systems where wild fish enter, reproduce and are harvested from the flooded fields, or culture systems where the rice fields are stocked with fish either simultaneously or alternately with the rice crop. One and sometimes both of these systems are practised in many countries (Table 2). While Asian countries like China, Bangladesh, India, Malaysia, Indonesia, Thailand and Vietnam have a long history of integrated agri-aquaculture systems, the concept is relatively new to Africa. But, today, this farming system is fast becoming a favourite option among the resource-poor fish farmers in the developing world, mainly because of its ability to remove many

Table 2
Leading countries in rice-fish production (derived from Halwart, 1998 and GAFRD, 2000)

Country (year)	Area of rice-fish (ha)	Yield (kg/ha/year)	Total production (tonnes)
China (1996)	1.2 million	3183	377000
Egypt (1995)	172600	115	19863
Indonesia (1985)	94309	670	63187
Thailand	3.1 million	25	77500
Vietnam	40000	na	na

risks associated with the stand-alone pond aquaculture of both intensive or extensive scale (Prein, 2002).

These fish harvests add significantly to the return obtained by farmers. For example in Cambodia, Guttman (1999) reports that the value of fish caught in rice fields reaches 37–42% of that of rice production. In addition, however, the culture of fish within rice fields can increase rice yields, especially on poorer soils and in unfertilized crops where the fertilizing effect of fish is greatest. Improvement in income level attributable to rice-fish interaction in seven countries has been summarized by Demaine and Halwart (2001) in Table 3. Brummett (2002) reports six times as much cash as typically generated by Malawian small farmers resulting in three times higher net income than staple maize crop and homestead combined. In his review of trends in rice-fish farming, Halwart (1998) reports that together with savings of pesticides and earnings from fish sales, these increased yields result in net incomes that are 7–65% higher than for rice monoculture. However, the future outlook of fish culture in irrigated rice paddies is not very bright. There has been a gradual reduction in water subsidy and therefore irrigation is getting expensive over time. As a result, farmers are in general using less water for rice cultivation.

A different situation exists in flood-prone ecosystems which can be used for additional fish production and thereby make use of this unutilized and free water resource. Generally, three rice-fish culture systems can be established in floodprone areas: (1) alternating culture of dry season rice followed by stocked fish only during the flood season (i.e. without rice) in the enclosed area (e.g. as in a fishpen); (2) concurrent culture of deepwater rice (with submergence tolerance) with stocked fish during the flood season followed by dry season rice in shallow flooded areas; (3) concurrent culture of deepwater rice (with elongation ability) with stocked fish during the dry flood season, followed by dry season non-rice crops. In these ecosystems, the opportunity exists to fence-in large areas (up to several hectares) by creating enclosed water bodies and stocking these with fish. In this case, the communities who usually access and utilize these lands and waters can form community management groups that jointly decide on management and share of benefits, based on agreed rules. A recent work in Bangladesh and Vietnam has shown that community-based fish culture (CBFC) in flood-prone rice fields is technically feasible, economically profitable, environmentally non-destructive and socially acceptable (Dey and Prein, 2003, 2004a,b). The results show that the adoption of CBFC in flooded rice fields can increase water productivity per ha per year substantially; it can increase fish production by about 600 kg/ha/year in shallow flooded areas and up to 1.5 tonnes/ha/year in deep-flooded areas, without reduction in rice yield and wild fish catch. For the overall system, an additional income ranging from US $135 per hectare in southern Vietnam to US

Table 3
Selected economic indicators of rice and rice-fish farming

Indicator	Country	Change (%)	Comments
Increase in rice yield equivalent	Indonesia	+20	Research Station results, fish yield expressed in rice equivalent
Income from fish as per cent of total farm income	Malaysia	+7 and +9	Figures for owners and tenants, respectively, in double rice cropping area
Net return	Philippines	+40	Summary of results from nation-wide field trials during the late 1970s to 1987 in irrigated rice areas
Net return	China	+45	Results from four farm households in Hubei Province
Net farm income	Thailand	+18 and +35	Figures for research station and farmer fields, respectively
Cases with net return higher than rice monoculture	Thailand	+65	Difference in rice yield equivalents
Net benefit	Thailand	+80	20 out of 25 farms had higher net returns from rice-fish farming than from rice monoculture
Net profit	Bangladesh	+64 and +95	Net benefits are higher in the aman or wet season and lower in boro or dry season
Total farm cash return	Vietnam	+69	20% of the trench construction costs considered in capital costs. Operating costs increased by 83% for labor and 100% for irrigation, but had savings in the use of pesticides
	Vietnam	0	Mekong delta, beneficial and net effects thought to be related to environmental sustainability, system biodiversity farm diversification and household nutrition

Source: Demaine and Halwart (2001).

$437 per hectare in Bangladesh was achieved, which is an increase of 20–85% over the previous profitability. The arrangements involved landholders and landless, who received shares of the returns based on their contributions to management and upkeep. The landless, which were seasonal fishers in the area, had income gains from their labor and additionally were able to conduct fishing for indigenous non-stocked fish and thereby meet their family nutritional and income requirements during this period.

4.3. Integrated aquaculture–agriculture

Superficial consideration of the water requirements for aquaculture suggests that it is a water intensive means of food production. However, even when the water requirements for feed production and pond maintenance are included, Brummett (1997) has calculated that culture of channel catfish (*Ictalurus punctatus*), and tilapias (family Cichlidae) requires less water than that required to produce broiler chickens (Pimentel et al., 1997). The figures provided by Brummett of 3350 l of water required for each kilogram of catfish produced, and 2800 l for each kilogram of tilapia are based on well-managed ponds, and water requirements will clearly be greater in many instances. However, this initial analysis suggests that much more rigorous analysis of the water economics of pond aquaculture is merited.

Intensive aquaculture systems also provide the possibility of using the nutrient rich pond water for irrigation, and a growing number of studies have demonstrated that substantial benefits can be obtained by combining intensive aquaculture with irrigated crop production in this way (Bondari et al., 1983; D'Silva and Maughan, 1994, 1996; McMurty et al., 1997). While the full operational viability of such schemes needs to be tested in an appropriate range of on-farm conditions, a growing number of systems are now being developed in West Asia and North Africa, notably in Kuwait (Cruz et al., 2000), Saudi Arabia and Egypt where water for pond aquaculture is used to irrigate crops, including alfalfa which is in turn used as fodder for sheep and buffalo. The detailed water budgets of these schemes have not been elaborated, nor are there rigorous economic analyses. These need to be studied. At the watershed level, pond aquaculture can also play a significant role in reducing erosion and helping to regulate surface water run-off (Pullin and Prein, 1995). This wider role of pond aquaculture as an integral part of resilient and productive small farming systems is increasingly recognised, especially in parts of Africa where adoption of aquaculture has only recently begun to expand as the social and economic factors governing farmers decisions have been better understood and addressed. However, more quantitative data on the soil and water implications of expanded aquaculture are needed.

Water productivity can be improved further by integrating aquaculture with other farm enterprises. Small-scale integrated farming systems are more efficient at converting feeds into fish and these produce fewer negative impacts than purely commercial fish farms. Brummett (2002) illustrates that culturing tilapia in 1 m^2 cage system involved 21,700 m^2 ecological footprint (6 g of fish produced per m^2 of footprint) while the corresponding figures for supporting a 1 m^2 water fed integrated fish pond for raising tilapia was 1.8 m^2 (264 g of fish produced per m^2 of footprint).

A recent study conducted by the WorldFish Center (Dey et al., 2004) indicates the adoption of IAA technology in Malawi has increased water productivity substantially; improved total farm productivity by 10% and increased farm income by 28% without any additional consumptive use of water. The study also shows that the adoption of IAA has improved the sustainability and environment of the adopters' farm; reduced nitrogen loss from about 10 to 5 mg of N per m^2 per day and improved nitrogen (N) use efficiency defined as N yield per kg of N applied.

5. Conclusion

Freshwater fisheries provide an essential supply of animal protein to large parts of the developing world. At national, community and family levels, these systems are critically important in sustaining food security. As demand for freshwater increases, and as further investments are made to exploit the hydro-power potential of many of the large rivers, the economic and social importance of these resources needs to be recognised and water management policies and practices designed in consequence. To achieve this, however, a much stronger understanding of the relationship between water levels and flow and the productivity and value of these fisheries is required. In recent years, there has been remarkably little detailed study of such systems and a number of methodological challenges need to be overcome if robust methodologies that can be applied in a range of river systems are to be developed. Efforts to address these need to be intensified.

It is clear from the analysis that there are many options for enhancing food production from fish in managed aquatic systems. However, the most appropriate technology will vary from country to country and site to site. In addition, the social and economic conditions under which these technologies can be pursued needs to be understood. Recent studies in Vietnam and Bangladesh show that socially viable approaches for integrating fish into rice culture systems are possible, but much more work is needed to understand the wider application of these approaches and to understand the social and economic viability of much of the intensive culture options such as cage culture in irrigation canals and reservoirs.

Similarly, the governance arrangements for capture fisheries in irrigation canals also require detailed analysis if the full social value of these resources is to be harnessed. The yields reported from irrigation systems, and the sizeable net benefits obtained by farmers integrating fish culture with rice are of great potential importance. However, this needs to be examined in more countries and communities, and the dissemination of positive results strengthened. As for river fisheries, great care is needed to ensure that work on these systems is socially relevant and that a sustainable management regime is identified.

Faced with a continuing large gap between global supply and demand for fish protein, and especially critical shortages in some regions, notably Sub-Saharan Africa (Delgado et al., 2003), aquaculture is widely regarded as having a critical role in meeting global and regional food requirements over the next 20 years. As discussed here, available evidence indicates that aquaculture can be a water efficient means of food production, while also bringing wider resource management benefits. However, more rigorous analysis of the water requirements of different forms of aquaculture need to be pursued and ways to reduce water demand further identified. Work to achieve this should be undertaken in a range of environmental and climatic conditions.

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