SNF Working Paper No. 42/06

AQUACULTURE DEVELOPMENT IN ASIA: CURRENT STATUS, ECONOMICS AND FUTURE OUTLOOK

by

Madan Mohan Dey, Natasja Sheriff and Trond Bjørndal

SNF project No. 5257: Marknadsforskning

The project is funded by The Research Council of Norway

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, NOVEMBER 2006
ISSN 1503-2140

Abstract

The purpose of this article is to analyse aquaculture development in selected Asian countries. The contribution of Asia to world aquaculture will be documented. In Asia, different culture systems are practised and numerous species are farmed, and these will be surveyed. Patterns of fish supply, demand and trade are described, followed by an analysis of economic conditions in aquaculture. Finally, a number of scenarios for future development are analysed.

1. INTRODUCTION

Aquaculture is the legacy of an ancient history dating back more than 2500 years. Since these early beginnings, aquaculture has developed on every continent, and the term now unifies an industry characterised by its incredible diversity. Approximately 220 aquatic plant and animal species are currently cultured worldwide, in a vast range of systems and contexts, from subsistence to commercial scale, extensive to intensive, from pond based culture on small homesteads to offshore farms.

Despite its long history, aquaculture has only recently emerged as an industry, and has experienced a dramatic growth in production during the last three decades. In 2004, global production figures indicated a total production from aquaculture (including aquatic plants) of 59 million tonnes. It is currently the fastest growing food-producing sector, with an average annual growth rate of 8.9% over the last three decades, surpassing both terrestrial livestock meat production and capture fisheries.

Historically, capture fisheries have provided the bulk of fisheries production for global consumption. However, since the 1980s fisheries production has stagnated, although demand for fish and fish products continues to increase, with the world's growing population putting increased pressure on resources. Aquaculture is viewed as a possible solution to meet growing demand. Asia, where aquaculture currently accounts for 63% of total fish production and 90% of global aquaculture output, is leading expansion. Food security issues and the challenge of meeting the Millennium Development Goals (MDGs) also place aquaculture in a central role as an important contributor to the reduction of hunger and poverty, particularly in Asia and Africa.

The purpose of this article is to analyse aquaculture development in selected Asian countries. The contribution of Asia to world aquaculture will be documented (Introduction). In Asia, different culture systems are practised and numerous species are farmed. These will be surveyed in Section 2. Patterns of fish supply, demand and trade are described in Section 3,

followed by an analysis of economic conditions in aquaculture (Section 4). In Section 5, a number of scenarios for future development are analysed.

World Aquaculture and the contribution of Asia

Of the global aquaculture production in 2004 of 59 million tonnes, marine aquaculture accounted for 51%. However, in terms of aquatic animal production, freshwater aquaculture dominates. In 2004, 25.8 million tonnes (44% of total production) of aquatic animal production took place in freshwater systems, of which 23.4 million tonnes was freshwater fish (Figure 1).

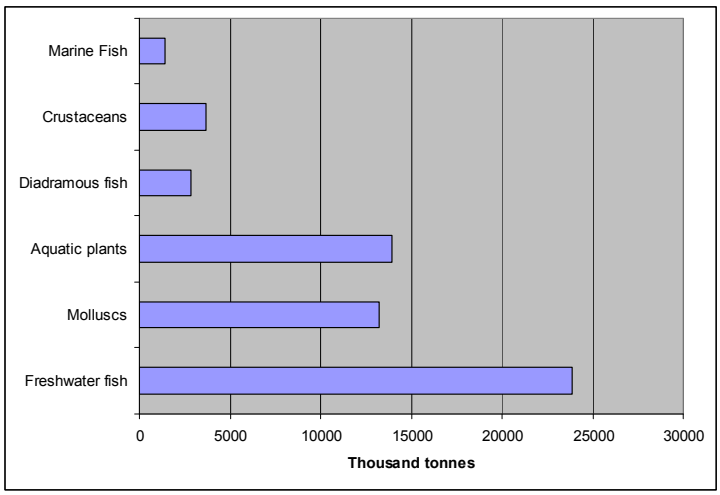

Figure 1. Production of major species in 2004 (Source: FAO FIGIS)

Production of each of the five species groups into which aquaculture is commonly grouped continues to grow, although recent figures suggest that production is beginning to slow since 2000 (Table 1).

Table 1. Average growth rate of different species groups.

Time period	Crustaceans	Molluscs	Freshwater Fish	Diadramous fish	Marine fish	Overall
1970-2002	18.1	7.8	9.6	7.4	10.5	8.9
1970-1980	23.9	5.6	6.0	6.5	14.1	6.3
1980-1990	24.1	7.0	13.1	9.4	5.3	10.8
1990-2000	9.9	5.3	7.8	7.9	12.3	10.5
2000-2002	11.0	4.6	5.8	6.7	9.5	5.9

(Source: FAO, 2004)

Asian aquaculture dominates world aquaculture production. In 2002, aquaculture production in Asia contributed 91.2% to global production. Freshwater and diadramous fish accounted for the largest proportion of this total, followed by aquatic plants and molluscs. All sectors of production continue to grow, with the most dramatic increases seen in the miscellaneous aquatic plants, showing an annual production growth rate of 39% between 1983 and 2003. Total aquatic plant production (brown seaweeds, red seaweeds, and miscellaneous aquatic plants) reached 12.4 million tonnes in 2003. Carps continue to dominate production in the region, accounting for 33% of total production (Table 2).

Table 2. Production and growth of top 10 species produced in Asia.

	Production (million tonnes)	Annual growth rate 1983-2003	% growth 2002-2003
Carps and barbels	16.7	9	3.2
Misc. Aquatic plants	4.9	39	25.1
Brown seaweeds	4.9	0.8	-2.6
Oysters	4.2	11	3.5
Misc. Freshwater fish	3.8	12.5	17.2
Clams, cockles, ark shells	3.7	10.9	11.2
Red seaweeds	2.5	7.0	2.1
Shrimp and prawns	1.5	8.3	29.2
Tilapias and cichlids	1.3	10.6	12.0
Misc. Marine molluscs	1.2	25.6	-11.3

Source: FAO FIGIS.

Production is overwhelmingly concentrated in China, where aquaculture has surpassed fisheries production since a zero growth policy for fisheries was adopted in 1999. In 2004, China produced 70% of the world's total aquaculture production. Carp production dominates Chinese aquaculture, representing 35% of total production. Mollusc production is also important with 32 species under production. Production of clams, cockles and oysters has been particularly rapid in recent years, increasing three-fold during the last decade. The marine finfish sector has seen the most rapid growth, although tonnage remains low, growing at an average rate of 23% per year since 1993.

Per capita consumption of fish, crustaceans and molluscs worldwide was estimated at 16.2 kg in 2002, an increase of 21% since 1992, when consumption was in the region of 13.1 kg per capita (FAO, 2004). This growth can be attributed primarily to increased consumption in China which represented 33% of the world's consumption in 2002. Excluding China, per capita consumption is closer to 13.2 kg. However, across the developing world, fish consumption has almost doubled since the 1970s. This is in stark contrast to patterns of fish consumption in the developed countries, where consumption has remained stagnant at 23.5 kg. The contribution of fish to nutrition also shows a high level of variation at the national level. In 2001, for example, 100 million tonnes of fish was available worldwide, of which two-thirds was consumed in Asia, and only 6.3 million tonnes in Africa (FAO, 2004).

In selected Asian countries, an increase in per capita fish consumption has been accompanied by a substantial increase in the consumption of freshwater fish in particular (Dey *et al.,* 2005a). Significantly, there is a strong relationship between higher per capita consumption and the growth of freshwater aquaculture. Dey *et al.* (2005a) found that countries with a higher share of freshwater fish production show higher per capita consumption, with freshwater fish contributing a greater share to overall consumption.

The development of Asian aquaculture is increasingly focused on export and the production of high-value species, although trade is currently largely confined to a few developed country markets such as the EU, USA and Japan.

At the global level, world trade in fish and fish products reached US$58.2 billion in 2002, a 45% increase since 1992 (FAO 2004). In 2002, the quantity of fish traded was 50 million tonnes (live weight equivalent) representing an increase of 40.7% since 1992 (FAO 2004). However, after decades of strong growth, the quantity of fish traded has recently stabilised. China is the world's main exporter of fish and fish products, having overtaken Thailand in 2002. However, although China's exports were valued at US$4.5 billion, fishery exports still represented only 1.4% of the country's total exports and 25% of agricultural exports (FAO 2004). Fishery exports from China do continue to grow, with an average growth of 11 percent per year since 1992, despite a policy of zero growth in fisheries production. Increased

aquaculture production and processing therefore explain China's continuing export increases. Interestingly, China is also the world's eighth largest fishery importer (FAO 2004). Thailand is currently the world's second largest exporter, with exports valued at US$3.7 billion in 2002. Norway is the third largest exporter with 2002 exports valued at US$3.6 billion (FAO 2004).

Fishery imports reached a value of US$61 billion in 2002, with developed countries accounting for 82% of total import value. Japan remains the worlds largest importer of fish products, representing 22% of world share in 2002, followed by the United States and Spain (FAO 2004). In general, trade in fishery products tends to flow from the less-developed countries to the developed countries, although some two-way trade exists, primarily in demersal species, herring, mackerel and salmon, between more developed countries (FAO 2004).

Processed fish products form the bulk of traded fisheries commodities, accounting for more than 90% of traded fish. However, improvements in logistics and technology and the rise in demand for live fish has led to an increase in the trade of live, fresh or chilled fish (FAO 2004). Shrimp continues to be the main traded commodity in value terms, although exports have declined slightly in recent years, accounting for 18% of trade. Currently, products from aquaculture account for approximately 22% of exported fishery commodities (FAO 2004).

2. SYSTEMS AND SPECIES

Within Asia, much variation can be found in terms of production, consumption, technology, ecosystem type and institutional characteristics. A broad spectrum of systems, practices and species are adopted through a continuum ranging from backyard household operations to large-scale commercial systems, producing large quantities of affordable food fish for domestic markets and home consumption. The choice of system used and species grown is increasingly influenced by the emergence of a growing middle-class, urbanisation and growth of the export trade in fish and fish products.

2.1 Culture systems

The environments in which aquaculture takes place are commonly characterised as freshwater, brackish and marine. They may also be described as inland or coastal/marine systems. In Asian countries, 54% of total aquaculture production is conducted in inland, freshwater systems, followed by brackish water (24%) and marine systems (22%). Management systems include extensive to intensive systems, with high-input intensive systems commonly found in Japan, Taiwan and Malaysia, and traditional low-input systems of stocking catchments and seasonal ponds popular in Bangladesh, India and Burma.

Freshwater aquaculture

Freshwater aquaculture provides the largest source of farmed fish in Asia, with China, India, Bangladesh, Vietnam, Indonesia and Thailand being the top producers. Between 1990 and 2000 freshwater aquaculture production in the region grew by 196%, from 6.57 MT to 19.48 MT. Pond culture is the dominant form of production system, although fish culture is practised in almost every type of water body, with cages, pens and net enclosures frequently established in reservoirs, lakes, rivers, channels and paddy fields. Carp and tilapia culture form the bulk of freshwater production.

Carp production is concentrated in China, India, Bangladesh and Indonesia, accounting for 95% of world carp production. Four carp species contribute approximately half of total finfish production globally: silver carp (*Hypophthalmichthys molitrix* Valenciennes), grass carp (*Ctenopharyngodon idellus* Steindachner), common carp (*Cyprinus carpio* L.) and bighead carp (*Aristichthys nobilis* Valenciennes), although 20 native carp species are raised. Carp production is growing rapidly, with an annual growth rate of 12% during the last decade. Relying primarily on low trophic level fish, and often cultured in polyculture or integrated farming systems, carp farming meets many of the criteria deemed to be important to the efficiency and sustainability of aquaculture systems (Naylor *et al.,* 2000). However, as Michielsens *et al.* (2002) have shown, generalisations about carp culture are problematic as

carp culture takes place in a wide variety of systems. By far the most common system is the pond-based, semi-intensive system, using mainly inorganic fertilisers and feeds of farm origin, accounting for approximately 59% of carp production (Michielsens *et al.,* 2002), while integrated semi-intensive systems (using feeds and fertilisers of both on and off-farm origin) accounted for 27%. Compared to other systems, these systems showed the highest levels of protein and nutrient efficiencies.

In Asia, carp farms are usually operated by private owners, with the exception of China and northern Vietnam, where many farms are operated by collectives or by the state (Dey *et al.,* 2005b). The size of culture ponds varies with the average area cultivated as high as 4.24 ha in India or as low as 1.04 ha in Vietnam. In Bangladesh, the average pond size is only 0.20 ha, where ponds are used for a variety of purposes in addition to fish culture. Most carp production takes place in pond polyculture systems, except in Indonesia where monoculture in running water systems and cages is common (Dey *et al.,* 2005b).

Tilapia are a freshwater fish species, native to Africa. They demonstrate numerous favourable characteristics which have led to their widespread dispersal in tropical and temperate regions as ideal candidates for aquaculture including a fast growth rate, tolerance to a wide range of environmental conditions, resistance to stress and disease, ability to reproduce in captivity, feed at low trophic levels and acceptance of artificial feeds at an early stage of development (El-Sayed, 2006).

Tilapia are farmed in more than 100 countries worldwide, although five countries dominate production: China, Egypt, Philippines, Indonesia and Thailand, together accounting for approximately 87% of the global total. Production expanded gradually between 1970 and 1990, until massive expansion in the last decade saw production increase by more than 390% to 1.5 Million MT in 2002, showing an annual growth rate of 12.2% (El-Sayed, 2006).

Tilapia production ranges from rural subsistence farming to large-scale commercial systems. Earthen ponds are the most common type of culture system, with concrete tanks and raceways used in seasonal climates for intensive and super-intensive production (Gupta and

Acosta, 2004). Cage culture, pioneered in Asia by the Philippines, is practised in lakes, reservoirs, rivers and estuaries. Pond culture in Bangladesh, China, Taiwan, Thailand and Vietnam is generally practised as a polyculture, and may be integrated with agriculture and animal farming. In the Philippines, pond monoculture is more common. Intensive culture of tilapias in concrete tanks is practised in Taiwan, Malaysia and the Philippines (Gupta and Acosta, 2004).

Economically, tilapia is profitable although variations in profitability exist between countries. Dey and Paraguas (2001) report that cage culture of tilapia in Indonesia cost on average US$0.43/kg, while the average cost in China is US$1.30/kg. The average cost of pond culture in the Philippines is US$0.99/kg, whilst in Bangladesh only US$0.16/kg. Feed accounts for up to 87% of total costs in cage systems or 34% in pond systems. In general, cage culture requires lower capital and operating costs than ponds (Gupta and Acosta, 2004).

Brackish water and marine aquaculture in Asia

The boundaries between marine and brackish water aquaculture are often blurred, with some species, particularly the groupers, raised in both environments. Brackish water aquaculture generally refers primarily to the culture of shrimp in coastal ponds, produced mainly for the export market. Thailand, Indonesia, India, Malaysia, the Philippines and Vietnam are currently the principal shrimp exporting countries. In contrast, China produces shrimp for domestic consumption.

Traditionally, marine aquaculture concentrated on the production of molluscs and seaweeds; however, increasing demand for high-value fish and fish products has fuelled regional growth in the marine aquaculture sector leading to recent rapid growth in the market for high-value marine finfish such as groupers, snappers and wrasse. The main markets for these products are Hong Kong, Taiwan and mainland China, where the fish are preferred live until minutes before serving.

The marine sector is, however, still reliant to a large extent on wild fry and trash fish feed, which has raised concerns for the environment. Efforts are underway to find hatchery reared alternatives, and numerous successes have been reported. Backyard hatcheries in Indonesia are now providing substantial quantities of grouper seed to local farmers. Culture takes place primarily in floating cages, although marine fish are also raised in net pens and ponds in some areas.

Mariculture in Asia is far more diverse than the European industry, with changes occurring rapidly in terms of species and commodity groups. At present, the culture of marine finfish is dominated by the production of Japanese Amberjack (*Seriola quinqueradiata*) in Japan, which makes up 17% (160,000 mt in 2003) of marine finfish production in Asia (Rimmer, 2006). Production of seabreams, including the Barramundi or Asian Seabass (*Lates calcarifer*), is widespread and has remained relatively constant over the last decade, although production is decreasing in Asia and increasing in Australia (Rimmer, 2006). The culture of various species of grouper has been expanding in Asia for a number of years. Milkfish (*Chanos chanos*) production is particularly important in the Philippines, where it is an important contributor to overall fish consumption. Traditionally carried out in brackish water ponds, milkfish production is increasingly seen in intensive mariculture cages (Rimmer, 2006).

Shrimp production in coastal ponds, and to a lesser extent crab culture, dominates coastal aquaculture production. However, the culture of other crustaceans including the tropical spiny rock lobsters (family Panuliridae) takes place in cages, primarily in Vietnam and the Philippines (Rimmer, 2006). In Vietnam, fixed, floating and submerged cages are used. As with many of the marine finfish species produced, the culture of spiny rock lobsters is also dependent upon wild inputs of seed and feed, limiting production and jeopardising environmental sustainability.

In addition to finfish and crustaceans, bivalves are an important component of Asian aquaculture. Mussel culture dominates, but pearl farming is also substantial. The production of scallop, particularly the yesso scallop (*Pecten yessoensis*), is greatest in Japan and China.

Sea cucumbers, sponges and seaweeds are also contributors to aquaculture production in Asia. The production of aquatic plants is, in fact, a major production component in Asia (Rimmer, 2006), with approximately 13.5 million tonnes produced in 2003.

3. PATTERNS OF FISH DEMAND, SUPPLY AND TRADE

In order to place aquaculture development in Asia in context, it is important to understand the nature of supply and demand which drives the industry. Here we look at the current demand for fish and fish products, based on recent work by the WorldFish Centre to understand the demand for fish at the household level in selected Asian countries. The findings of the study provide a detailed analysis of the patterns of fish demand, supply and trade in Asia as well as the structure of supply and demand behaviour.

Demand

Consumption of fish in Asia shows large variations across, and within, countries on a per capita basis. Survey data gathered during the WorldFish study showed that annual per capita consumption ranged from 43.64 kg/yr in the Philippines, to almost a third of this figure in India (15kg/yr). However, it must be noted that only a third of India's population are fish eaters – adjusting for this provides a per capita consumption that is roughly comparable to other countries. In Vietnam, it was found that annual per capita consumption in the south of the country was more than double that of northern Vietnam (Table 3). At the regional level, consumption of fish in Southeast Asia is generally higher than that in South Asia (The WorldFish Center 2005).

The analysis of the WorldFish Center study, presented in Dey *et al*. (2005a), emphasises the importance of disaggregation when considering the demand for fish. Traditionally, the literature on fish and food security aggregates fish into broad categories, or as a single commodity (Williams 1996). However, this obscures the heterogeneity which exists within the fishery sector, in terms of types of fish, sources of production and behavioural response to market changes. This is a particularly pertinent consideration for the development of

poverty targeting programs. As a result, the WorldFish analysis estimates demand responses to changes in fish price and income based on the adoption of seven broad categories, namely: low-value freshwater fish, high-value freshwater fish, low-value marine fish, high-value marine fish, shrimp/prawn, other crustaceans/mollusc, and processed fish.

The significance of these groupings becomes apparent when per capita fish consumption among various income groups is analysed. Dey *et al*. (2005a) found that fish consumption varies widely between economic groups. With the exception of the Philippines, the per capita annual fish consumption increases consistently with increase in income. The average price paid for fish also increases as income increases. Not surprisingly, poorer households consume lower value fish than the rich. However, despite the lower cost of the fish they purchase, the share of fish expenditure of total animal protein expenditure is still higher for poorer households, indicating the importance of fish in the diets of poor people, primarily due to the higher cost of other sources of protein (Dey *et al*. 2005a) (Table 3).

Table 3. Annual per capita expenditure on fish and its share of total expenditure on food and animal protein.(Adapted from Dey *et al*., 2005a)

Income Quartile	Country							
	Bangladesh	China	India	Indonesia	Philippines	Thailand	Northern Vietnam	Southern Vietnam
	Annual per capita fish consumption (kg)							
I	13.05	13.08	10.1	na	52.84 [b]	22.08 [a]	6.86	23.88 [a]
II	19.2 [a]	23.4	11.5 [a]	na	32.82 [a]	27.96 [ab]	11.71 [a]	25.56 [a]
III	22.92 [ab]	33.72	13.8 [a]	na	34.42 [a]	32.40 [a]	13.68 [a]	39.24
IV	33.64 [b]	54.12	24.5	na	54.07 [b]	32.52 [a]	19.32	62.52
All	22.2	31.08	15	na	43.64	28.8	12.86	37.8
	Expenditure on fish as a share of total food expenditure (%)							
I	26.1	31.2	13.7	9.2	53.6	14.1	12.5	74.0
II	26.8	43.1	10.3	8.6	41.3	14.9	10.6	25.4
III	25.4	52.4	10	8.2	38.5	15.9	9.5	27.2
IV	23.9	63.4	12.6	7.4	34.8	16.5	8.2	27.6
All	25.2	51.8	11.8	8.1	42.1	15.6	9.4	29.8
	Expenditure on fish as a share of total animal protein expenditure (%)							
I	77.77	58.8	63.00	na	78.05	76.94	17.20	92.00
II	73.91	70.8	35.50	na	73.05	79.38	16.90	55.40
III	71.92	77.7	29.50	na	68.87	82.29	15.80	53.50
IV	68.94	85	30.70	na	48.12	72.72	15.50	51.10
All	71.89	77.6	33.50	na	68.15	77.5	16.00	56.10

Source: Field surveys conducted by the WorldFish Center and its partners. For the Philippines: DEGITA field survey 1995-1996. For other countries: Surveys of fish consumers in inland areas, 1998-1999.

Note: i) Duncan's Multiple Range Test (DMRT), a mean separation test, was conducted to examine pair wise differences between average per capita consumption of different quartile groups. Figures with the same letters in the uperscripts are not pair wise statistically significant at 5% level of significance.
ii) na: refers to "not available".

Fish consumption also shows variation in terms of type and price according to a rural/urban divide. Data from Bangladesh, India, the Philippines and Thailand indicate that annual per capita fish consumption is generally higher in rural than in urban areas (Dey *et al*., 2005a). Amongst rural consumers, fish producers consume more than non-producers. In urban areas, consumers tend to consume higher amounts of marine fish than in rural areas.

Fish price is the major influencing factor in consumer choice of a particular species. In general, freshwater fish are lower in price than marine fish. Decreasing fish prices as a result of increased production of farmed fish taking place in all the countries studied, with the

exception of the Philippines, therefore has particular significance for food security and increased access to fish by the poor.

Demand elasticities

Fish can be considered a necessary item in the diets of many consumers in Asia. In the countries selected for analysis as part of the WorldFish study (2005), own-price elasticity of fish demand was found to be less than one, with the exception of the Philippines and Vietnam. Freshwater fish were found to have slightly higher average price elasticity compared to marine fish, especially for the high-value species.

Average price elasticity for shrimp was found to be more elastic (-1.28) compared to the demand for other crustaceans and molluscs (-0.96), attributable to the relatively higher prices of shrimp and prawn compared to other non-fish marine products. The demand for dried fish is, however, highly inelastic suggesting it is a necessity, particularly in areas where fresh fish is in scarce supply.

Importantly, demand elasticities for fish vary with household income. In low-income households, low-value fish and dried fish were inelastic, ranging from -0.85 to -0.78 respectively. Poorer households appear to respond more to price changes of more expensive fish, whilst amongst higher income groups, only high value fish showed elastic demand, whilst demand for other fish types was inelastic.

Analysis of average income elasticities suggest that fish is considered a luxury item in Bangladesh, China, India, Indonesia and the Philippines, where values were greater than one. Ín Malaysia, Sri Lanka, Thailand and Vietnam, values were less than one, indicating that fish is a necessity in these countries.

Evidence from the analysis suggests that per capita fish consumption will increase with growing wealth in the region. Higher income households appear to consider fish to be a normal food item, with relatively low values found for income elasticities for all fish types in

higher income groups. These groups respond less to changes in fish price than poorer households.

Supply

Understanding fish supply is critical for the evaluation of market outlook, to understand how supply will meet demand and food security requirements, and the long-term prospects of fish producers. In recent years, production from marine capture fisheries has stagnated, reaching a plateau at around 70 million t/yr. A similar stabilisation trend has also been seen in Asia, at around 30 million t/yr. Marine capture fisheries are therefore no longer expected to meet the demand for fish from a growing global population. Instead, it is anticipated that production from other sources, particularly aquaculture, must increase to meet the gap in supply. Inland capture and aquaculture have increased in recent years, with much of the expansion taking place in Asia, which accounts for 80% of total global aquaculture and inland capture production. In 2001, total inland fisheries and aquaculture production in Asia reached 47.9 million t. With the exception of Thailand and the Philippines, growth in fish production in the Asian countries studied by the WorldFish Center (average of 7.8%/yr) has taken place at more than twice the rate of world fish production (2.9%/yr). Analysis of the shares of fish types and country distribution of fish production in Asia shows that inland aquatic systems are dominated by carp production in India, Bangladesh and China. In other southeast Asian countries (Indonesia, Philippines, Malaysia, Thailand and Vietnam) other freshwater species such as tilapia and catfish are more important. Shrimp production dominates brackishwater production. Marine production from capture fisheries is multi-species, but low-value fish form the bulk of production (WorldFish Center 2005).

Supply elasticities

A prominent feature of fish production in Asia is its multi-product, joint input technology, particularly apparent in marine capture and polyculture aquaculture systems. The supply estimation adopted for the WorldFish study incorporates this feature. The results revealed important differences between own-price supply elasticities for the supply of fish from capture fisheries and for aquaculture. It was found that fish types were generally inelastic to

changes in own-price, except for shrimp, snakehead and other high-value finfish. Fish supply from capture fisheries is therefore generally unresponsive to changes in price. However, in contrast, own-price elasticities of cultured species from both inland culture and marine/brackish culture were found to be elastic. This suggests that price plays an important role in determining the supply of fish from aquaculture. This can be attributed to the relatively controllable and managed supply of fish from aquaculture, making fish supply from aquaculture more flexible in adjusting to price changes (The WorldFish Centre, 2005). An important implication of this finding is the potential responsiveness of aquaculture supply, unlike capture fisheries, to price incentives and the altering of shifter variables such as increase in production area, farmer education and knowledge and investment in research and development.

Trade

Exports of fish and fish products from Asian countries have increased dramatically during the last three decades, fuelled by increased demand for high value products in the developed country markets such as Japan, the EU and the USA. The top exporters, China and Thailand, have shown the highest rates of growth, although growth rates in Vietnam and Sri Lanka are the fastest in the region. The top export commodity in each country is shrimp, with the exception of China, where exports are more diversified. The reliance of most countries in the region on a small number of export products, particularly shrimp, raises concerns that these countries will be vulnerable to fluctuations in the export markets. Similarly, the reliance of many countries on imports of low-value fish is of concern to producers and processors of low-value fish in the region.

Marine finfish are also a major export item, although molluscs and cephalopods are more important to India and Thailand respectively. Low-value fish are an important import commodity, usually marine fresh or processed fish. Sri Lanka's fish imports are comprised almost entirely of processed fish. The reliance of many countries on imports of low-value fish is of concern to producers and processors of low-value fish in the region. In most countries, lower income groups are creating demand for cheap foreign fish. However, despite

high levels of domestic production, Thailand imports mostly cultured shrimp. India's middle to upper classes are creating a demand for high-value fish, which dominate India's imports.

4. ECONOMICS OF AQUACULTURE

Developing appropriate policies for aquaculture development requires a detailed understanding of the variation between systems and the most viable options for farmers. An economic analysis of alternative aquaculture technologies in Asia, focusing on nine countries as in the above discussion, found that freshwater fish farming is generally profitable, although costs and returns vary substantially by production environments, type of technology and species cultured, and across countries (Dey *et al.,* 2005b). The analysis, based on survey data collected between 1998 and 1999, classifies farms according to technology, including for example, monoculture, polyculture, cage systems, running water and intensity of input use, drawing on the classification presented by Edwards (1993). As Table 4 shows, monoculture of high-value species such as prawn, snakehead and catfish are generally the most profitable of the systems analysed, however, the high cost of these systems puts them out of the reach of poorer farmers, for whom the polyculture and monoculture of omnivorous and herbivorous species such as carps and tilapias are more suitable.

Pond culture of carps and tilapias are the most productive and cost effective in Bangladesh and India. In Indonesia, tilapia culture in cages and the culture of common carp in running water and cages are the most important technologies. Here, double-floating cages show high productivity, but the rate of return is less than half of that for floating cages. Similarly, in Thailand, walking catfish and snakehead show extraordinary productivity, but rates of return are higher for monoculture of tilapia in ponds.

A comparison of the costs and returns of production intensity shows that extensive systems are highly inefficient, with some countries experiencing negative rates of return. The rate of return on semi-intensive systems is the highest in all the countries considered (Dey *et al.,* 2005b) (Table 5).

Table 4. Costs and returns per unit area[1] by key freshwater aquaculture technologies by country (US$ in 1999 prices). (Adapted from Dey *et al*., 2005b)

Technology	Yield (kg/ unit area)	Price (US$/kg)	Gross return	Total variable cost	Total fixed cost	Total cost	Gross margin[2]	Net return[3]	Return on VC[4]	Return on TC[5]
Bangladesh										
Carp polyculture in pond[6]	3 262	0.53	1 729	612	na	612	1 117	1 117	1.83	1.83
Tilapia monoculture in pond[7]	4 050	0.46	1 863	453	na	453	1 410	1 410	3.11	3.11
Tilapia monoculture in cage[8]	383	0.82	314	122	25	147	192	167	1.57	1.14
China										
Carp polyculture in pond[6]	12 085	0.89	10 756	7 349	1 195	8 544	3 407	2 212	0.46	0.26
Tilapia monoculture in pond[9]	5 860	1.35	7 911	4 013	1 230	5 243	3 898	2 668	0.97	0.51
Tilapia monoculture in cage[9]	5 613	1.91	10 721	6 182	1 132	7 314	4 539	3 407	0.73	0.47
India										
Carp polyculture in pond[6] (extensive/semi-intensive)	3 214	1.00	2 125	1 535	60	1 595	590	530	0.38	0.33
Carp-prawn culture (pond)[10]	4 000	1.09	4 360	1 870	448	2 318	2 490	2 042	1.33	0.88
Prawn monoculture (pond)[10]	1 500	5.43	8 145	3 283	589	3 872	4 862	4 273	1.48	1.10
Sewage fed polyculture without feed[10]	5 000	0.54	2 700	761	341	1 102	1 939	1 598	2.55	1.45
Sewage fed polyculture with feed[10]	7 000	0.54	3 780	1 196	391	1 587	2 584	2 193	2.16	1.38
Weed based [6]	4 000	0.43	1 720	418	122	540	1 302	1 180	3.11	2.19
Indonesia										
Common carp monoculture[6]										
Running water system	482	2.28	1 098	618	11	629	480	469	0.78	0.75
Floating cage system	574	1.64	942	225	7	232	717	710	3.19	3.06
Double floating cage	395	2.33	920	809	22	831	111	89	0.14	0.11
Tilapia monoculture[11]										

Floating cage system	789	0.96	757	280	57	337	477	420	1.70	1.25
Double floating cage	1 525	1.54	2 349	1 468	389	1 857	881	492	0.60	0.26

Table 4 Continued…

Technology	Yield (kg/ unit area)	Price (US$/kg)	Gross return	Total variable cost	Total fixed cost	Total cost	Gross margin[2]	Net return[3]	Return on VC[4]	Return on TC[5]
Philippines										
Tilapia monoculture in pond[9]	2 959	1.19	3 521	1 879	1 047	2 926	1 642	595	0.87	0.20
Tilapia monoculture in cage[9]	540	1.20	648	297	165	462	351	186	1.18	0.40
Thailand										
Carp polyculture in pond[6]	3 290	0.62	2 040	1 497	37	1 534	543	506	0.36	0.33
Tilapia monoculture in pond[12]	5 560	0.42	2 335	1 001	99	1 100	1 334	1 235	1.33	1.12
Tilapia monoculture in cage[12]	780	0.55	429	365	10	375	64	54	0.18	0.14
Stripped Catfish monoculture in pond[12]	6 925	0.34	2 337	1 965	226	2 191	372	146	0.19	0.07
Walking catfish monoculture in pond[12]	20 543	0.55	11 312	8 477	280	8 757	2 835	2 555	0.33	0.29
Big-sized snakehead monoculture in pond[12]	60 450	1.41	85 097	78 127	2 416	80 543	6 970	4 553	0.09	0.06
Small-sized snakehead monoculture in pond[12]	70 830	1.16	82 456	73 592	2 590	76 182	8 864	6 274	0.12	0.08
Freshwater prawn monoculture[12]	4 000	3.46	13 822	9 855	232	10 087	3 967	3 735	0.40	0.37
Vietnam										
Carp polyculture in pond[6]	3 654	0.65	2 375	822	198	1 020	1 553	1 355	1.89	1.33

[1] unit area is ha for pond and 100 m^2 for cage
[2] Gross margin= gross return - total variable cost
[3] Net return = gross return – total cost
[4] Return on variable cost is equal to the return over variable cost divided by the total variable cost
[5] Return on total cost is equal to the net return divided by the total cost of production

na: Data on fixed costs are not available. However, given the fact that the fixed cost of fish farming is low in Bangladesh (see for example, data on cage culture), this omission is not likely to affect the rigor of our analysis.

Sources:

[6] from producer survey, Carp project ICLARM (2001)
[7] from Dey and Bimbao (1998)
[8] from Hossain and Humayon (2001)
[9] from producers' survey, DEGITA project ICLARM (1998)
[10] from Katiha (2001; 2005)
[11] from Krismono et al. (1998)
[12] from Office of Agricultural Economics, Thailand, DOF (2000)

Table 5. Cost and returns of carp polyculture in ponds by level of intensity (US$/ha), in 1999 prices (Adapted from Dey *et al.*, 2005b)

Country/Technology	Yield (kg/ unit area)	Protein (kg/ha)	Energy (000kcal/ha)	Price (US$/kg)	Gross return	Total variable cost	Total fixed cost	Total cost	Gross margin[1]	Net return[2]	Return on VC[3]	Return on TC[4]
Bangladesh												
Extensive	800	0	1 579	0.64	512	381	na	381	131	131	0.34	0.34
Semi-intensive	3 280	0	6 511	0.67	2 184	1 019	na	1 019	1 165	1 165	1.14	1.14
China												
Semi-intensive	9 191	*	*	1.10	10 110	5 838	885	6 723	4 272	3 387	0.58	0.50
Intensive	20 711	*	*	0.90	18 640	12 490	1 004	13 494	6 150	5 146	0.41	0.38
India												
Extensive	562	0	6 353	0.60	339	557	77	634	-218	-295	-0.53	-0.47
Semi-intensive	3 448	0	11 068	0.67	2 325	998	40	1 038	1 327	1 287	1.29	1.24
Intensive	19 451	0	75 093	0.59	11 553	4 709	17	4 726	6 844	6 827	1.45	1.44
Thailand												
Extensive	652	238	1 694	0.62	404	1 112	7	1 119	-708	-715	-0.64	-0.64
Semi-intensive	4 112	330	3 727	0.62	2 549	1 904	47	1 951	645	598	0.31	0.31
Viet Nam												
Extensive	801	1	560	0.65	521	503	6	509	18	12	0.02	0.02
Semi-intensive	4 062	52	2 243	0.65	2 640	1 046	11	1 057	1 594	1 583	1.51	1.50

Source: Original data are from Producers' Survey, Carp Project, ICLARM (2001)

na = data not available.
* Data on physical quantity of inputs are not available for China

[1] Gross margin= gross return - total variable cost
[2] Net return = gross return – total cost
[3] Return on variable cost is equal to the return over variable cost divided by the total variable cost
[4] Return on total cost is equal to the net return divided by the total cost of production

Shrimp culture has shown high levels of instability in many Asian countries, with variation as high as 20% in some countries (measured by the Cuddy and Della Valle index, see Dey *et al.,* 2006). In countries such as China, Indonesia, the Philippines and Thailand, which have traditionally dominated shrimp production, growth has been negative over the last decade. An inability to sustain productivity at current levels is a cause for concern for the Asian shrimp industry, which accounts for approximately 80% of global shrimp production. Competition between shrimp-producing countries has also increased, with competition heightened in world shrimp markets. Declining real prices will make competition more intense (Dey *et al.,* 2006).

In light of these developments, work by Dey *et al*. (2006) assesses farm level profitability and the relative competitiveness in the production and trade of shrimp in selected Asian countries. The results indicate that intensive culture does not guarantee a high net return, although intensive production in Malaysia had the highest rates of return by far. Semi-intensive systems were more profitable in Thailand and the Philippines. In India, extensive systems proved to be the most profitable (Table 6).

Limited data exist regarding the economics of marine fish cage culture in Asia. However, investment costs for marine fish culture are generally lower than those for pond culture. A recent study to analyse the feasibility of small-scale grouper culture in the Philippines found that capital investments for small-scale grow-out production were financially feasible for many small producers (Pomeroy *et al*., 2004). Capital costs for grow-out were approximately US$1,470.00 in the Philippines, although the cost of transport boxes are not included within this figure and could introduce high additional costs (Pomeroy *et al*., 2004). Capital investment costs for hatchery/nursery systems were found to be in the region of US$68,400.00 and therefore beyond the means of most small producers.

Table 6. Costs and returns of shrimp farming in selected Asian countries (US$/ha), 2001 (adapted from Dey *et al.,* 2006)

Cost and Return items	Bangladesh		China	India		Malaysia		Philippines			Thailand			Vietnam		
	Extensive	Semi-intensive	Semi-intensive	Extensive	Semi-Intensive	Semi-Intensive	Intensive	Extensive	Semi-intensive	Intensive	Extensive	Semi-intensive	Intensive	Extensive	Semi-intensive	Intensive
Yield (kg/ha)	**143**	**169**	**2097**	**1016**	**1927**	**3758**	**6843**	**260**	**2701**	**3057**	**104**	**356**	**2116**	**600**	**2000**	**3000**
Shrimp price (US$/Kg)	6.54	5.92	2.92	6.77	5.28	5.26	6.45	7.28	6.55	7.1	4.67	5.88	3.15	2.32	4.67	6.04
Revenue (US$/ha)	**935**	**1002**	**6119**	**6874**	**10182**	**19767**	**44137**	**1893**	**17 692**	**21705**	**485**	**2092**	**6674**	**1392**	**9340**	**18120**
Total variable cost (US$/ha)	**1103**	**1823**	**4168**	**993**	**4917**	**11058**	**23677**	**419**	**9913**	**14276**	**103**	**255**	**8449**	**755**	**6039**	**5906**
Seed	348	548	785	83	1826	1184	2358	138	1891	3882		56	1321	213	667	489
Feed	57	73	2164	40	1689	3553	11049	127	5969	7979			3115	99	2310	3771
Fertilizer	8	94	60			70	69							150		
Lime	10	162			262									53	64	
Chemical			193	701	909	531	539								2061	604
Labor	261	404	596	169	225	793	2864	96	1161	1315	42	64	1674	133	364	400
Power/ fuel			102			3730	3247	8	756	856	37	89	766	67	533	248
Management	85	113				533	1601									
Maintenance						495	1184									
Others	332	429	267		6	167	765	49	135	245	24	47	1573	40	40	394
Total fixed cost (US$/ha)			**882**	**98**	**280**	**853**	**3294**	**263**	**918**	**6511**	**80**	**144**	**1633**	**135**	**712**	**354**
Pond preparation				10	20											
Pond rent			882					47	108		47	77	978			
Interest				70	116									48	312	
Discount										6511				87	400	354
Other											33	67	655			
Annual depreciation				18	145	853	3294	216	810							
Total cost of production (US$/ha)	**1103**	**1823**	**5050**	**1090**	**5197**	**11,912**	**26971**	**681**	**10831**	**20788**	**183**	**399**	**10082**	**890**	**6751**	**6260**
Net income (US$/ha)	**(168)**	**(821)**	**1069**	**5784**	**4985**	**7855**	**17166**	**1212**	**6861**	**917**	**302**	**1693**	**(3408)**	**502**	**2589**	**11860**
Cost per kg production (US$/kg)	**7.71**	**10.76**	**2.41**	**1.07**	**2.70**	**3.17**	**3.94**	**2.62**	**4.01**	**6.80**	**1.76**	**1.12**	**4.76**	**1.48**	**3.38**	**2.09**

Sources: Bangladesh – Hossain and Humayun (2001); China – Weimin et al. (2001); India – Pillai (2001); Indonesia – Directorate General of Aquaculture (2001); Malaysia – Department of Fisheries (2001a); Philippines – Lopez et al. (2001); Sri Lanka – Siriwardane and Jayakody (2001); Thailand – Department of Fisheries (2001b); Vietnam – Hao et al. (2001).

5. FUTURE OUTLOOK

The continuing rise in the global population coupled with a stagnation of production in global capture fisheries has given rise to the concern that fish production will be unable to meet future global demands. A number of studies have addressed this issue, attempting to identify where supply and demand is likely to be greatest and what measures will be required to meet future demand. One such model is the AsiaFish model, developed by the WorldFish Centre, which addresses the need for a detailed projection on the outlook for fish production and consumption under various scenarios. Using a set of multimarket, country-specific fisheries models, AsiaFish evaluates the effects of, amongst others, technology and policy changes on prices, demand, supply and trade. Importantly, the model uses a highly disaggregated approach.

The simulations generated by the model are based on a number of assumptions that form the baseline scenario, drawn from historical trends in exogenous variables such as income, input prices, nonfish commodity prices and regional populations.

Aggregate trends under the baseline scenario indicate that total fisheries output is expected to increase between 0.21%/yr in the Philippines and 3.57%/yr in Sri Lanka. These results are relatively conservative in light of recent growth rates, however the implied changes over 15 years are dramatic. In India and Sri Lanka, for example, the results suggest that production will double in comparison to the base year.

The sources of the projected growth in output indicate that aquaculture is expected to expand for all countries, especially China (4.69%/yr), Malaysia (4.45%/yr) and Thailand (4.01%/yr). Capture fisheries production is expected to increase in all countries except Bangladesh (-2.02%/yr) and the Philippines (-0.17%/yr). Aquaculture will also increase its relative share of total output, which will be particularly pronounced in China, Bangladesh and Thailand. In the former two countries, the share may account for up to three-quarters of their total fresh fish output for 2020 (Table 7).

Table 7. Projections for growth of fish output and aquaculture share (%), 2005-2020. (adapted from WorldFish Center 2005)

	Total Output	Aquaculture	Capture	Aquaculture Share, Baseline	Aquaculture Share, 2020
Bangladesh	1.36	2.77	(2.02)	60.18	78.10
China	3.29	4.69	-	54.26	73.19
India	3.10	3.99	1.99	51.98	61.44
Indonesia	0.88	1.80	0.83	12.50	14.74
Malaysia	1.49	4.45	1.12	9.55	16.67
Philippines	0.10	2.17	(0.17)	17.23	24.85
Sri Lanka	3.57	3.60	3.33	2.00	5.63
Thailand	1.75	4.01	0.46	25.96	41.25
Viet Nam	2.03	2.01	2.01	36.66	36.67

Projected patterns for fish consumption anticipate a rise in all countries. However, growth rates range from 0.22%/year in Bangladesh to a high of 9.95%/year in Malaysia. In the case of Malaysia, aggregate fish consumption in 2020 is expected to be more than six times higher than in 2000. In Sri Lanka, per capita consumption is expected to double (Table 8).

Table 8. Projections (%) for Consumption, 2005-2020 (adapted from WorldFish Center 2005)

	Share of Urban Region, Baseline	Share of Urban Region, 2020	Growth Rate in Total Consumption	Growth Rate in Rural Consumption	Growth Rate in Urban Consumption	Projected Population Growth, Rural	Projected Population Growth, Urban
Bangladesh	20.00	20.49	0.22	0.06	0.82	1.80	1.80
China	70.53	87.19	2.53	(2.00)	3.62	-2.30	2.64
India	na	na	2.47	na	na	1.50	1.50
Indonesia	46.08	55.55	1.05	0.12	1.92	1.66	1.82
Malaysia	59.38	5.67	9.95	12.55	(1.85)	1.00	2.35
Philippines	63.12	75.03	0.50	(1.56)	1.38	2.35	2.25
Sri Lanka	18.10	9.84	3.91	4.45	0.42	2.9	-1.40
Thailand	36.34	33.18	1.83	2.07	1.37	1.10	1.00
Viet Nam	33.14	30.61	1.73	1.91	1.33	1.00	1.00

According to the AsiaFish analysis, exports and imports of fish are expected to increase in all Asian countries studied by The WorldFish Centre (2005) with some exceptions. Changes in imports range from -3.85%/year in the Philippines to 15.72%/year in Malaysia. The anticipated change in projected exports shows a range of - 2.67% in Malaysia to 8.68% in Bangladesh. The study also suggests that changes will occur in the relative importance of

regions in terms of exports. The FAO indicated in 2001 that China, South Asia and Southeast Asia accounted respectively for 5.6, 42.17 and 52.23% of total exports of the nine selected countries. According to AsiaFish projections, China's share of total exports will increase to a level that is higher than the total Southeast Asia share, reaching 51.8% by 2020 (The WorldFish Centre, 2005). However, factors such as the imposition of food safety standards may restrict trade and affect exports (Briones *et al.*, 2004)

Projections under different scenarios

Developing countries are vulnerable to internal and external shocks. In order to understand the impacts of these potential changes, simulations generated by the WorldFish Centre using the AsiaFish model provide an indication of future consumption, supply and trade under various scenarios. The identified scenarios can be summarised into four categories:

Category One: Productivity changes in aquaculture

- Scenario 1 – improvements in the productivity of low-value aquaculture fish
- Scenario 2 – productivity improvements in high-value aquaculture fish

Category Two: Changes in production and productivity in capture fisheries

- Scenario 3 – effects of reducing fishing effort in capture fisheries
- Scenario 4 – impacts of improvements in the resource base for capture fisheries

Category Three: Downstream interventions in fisheries, i.e., in marketing and processing

- Scenario 5 – compliance with multilateral agreements on food safety
- Scenario 6 – effect of reducing marketing margins in fish trade

Category Four: Events external to the fisheries sector

- Scenario 7 – faster income growth
- Scenario 8 – faster rate of urbanisation

In the selected countries, faster technical progress in aquaculture is a realistic scenario, making analysis of Scenarios 1 and 2 particularly pertinent to a clear understanding of potential supply and demand of fish in the future. Results from the analysis show that high productivity of freshwater aquaculture leads to faster overall growth of output. However, the results for exports are mixed: only in Malaysia is there a significant export boost from more rapid technical progress in aquaculture. Also in Malaysia, there is no change in fish consumption with productivity growth. In all other countries, consumption increases with productivity, implying a welfare gain, especially to the poor (Dey *et al*., 2004).

Results for Scenario 2 are broadly similar to those of Scenario 1 with higher productivity leading to faster growth of output. However, the effects on exports are positive and larger than in scenario 1, as brackish water and marine culture tends to be more export oriented than freshwater culture. A growth in consumption is also expected, although to a lesser extent than seen in Scenario 1. These findings suggest that improved food security would be best served by targeting increased growth in freshwater aquaculture.

The effects of either reduced fishing effort or an improved fisheries resource base show little impact compared to the baseline trend in most countries. As could be expected, Scenario 3 leads to some reduction in fisheries output and a concomitant expansion in fish culture to offset the fall in production. This effect is particularly apparent in Thailand, where demand for fish and exports is affected. However, for some species, e.g. tilapia aquaculture, production and exports increase. Under Scenario 4, some slowing of culture output from freshwater is experienced in Bangladesh as a result of improved freshwater resources and capture fisheries output, otherwise trends are altered little from the baseline.

Downstream interventions primarily have an impact when countries seek to comply with multilateral agreements on food safety. Typically, a slow-down in export growth is seen, particularly in the Philippines, where compliance makes a serious dent in overall exports. In Sri Lanka, there is a significant slow-down in exports, particularly of cultured prawn and large pelagics. As a result, output growth slows and prices increase faster.

Faster income growth and urbanisation tested in Scenarios 7 and 8 lead in most cases to the expected directions of effect in terms of higher output, consumption and prices, with little impact on overall patterns of supply and demand as seen in the baseline. However, in Bangladesh, these changes are also accompanied by a change in composition of output amongst fish types. Indian Major Carps take over other carps as the dominant species produced, and show an increase in price.

6. SUMMARY

Population growth is putting increasing pressure on aquatic resources, leading to dramatic growth in aquaculture. This growth has been led by Asia, which currently contributes 90% to the world output of aquaculture, and is continuing to expand. This article provides an overview of the development of aquaculture in selected Asian countries. The aquaculture industry is considered from an economic perspective, analysing both current and projected trends in fisheries supply, demand and trade in Asia. An economic analysis of alternative aquaculture technologies indicates that fish farming is generally a profitable system in Asia, although costs and returns vary substantially with production environment, type of technology and species cultured, and across countries. This profitability has led to the expansion of the industry, which is predicted to increase in fisheries output in the majority of Asian countries analysed with particularly high growth in China (4.69%/yr), Malaysia (4.45%/yr) and Thailand (4.01%/yr). Aquaculture will also increase its relative share of total output; in China and Bangladesh, this share may account for up to three-quarters of their total fresh fish output for 2020. In contrast, capture fisheries are expected to decline or remain static, with particular cause for concern in the Philippines and Bangladesh. High-value species from mariculture are an important export commodity catering to consumers both in the developed world, and the emerging Asian middle-class. However, the effects of the anticipated higher productivity on exports are mixed, with the only increase in exports as a result of higher productivity occurring in Malaysia. In other countries, increased productivity of freshwater fish leads to higher consumption levels within the country, providing an increase in welfare for the poor. Findings suggest that as the market for freshwater fish is less

export-oriented than for marine fish, targeting further development in freshwater aquaculture will contribute greatly to food security in Asia.

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