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A review of stock enhancement practices in the inland water fisheries of Asia

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A review of stock enhancement practices in the inland water fisheries of Asia

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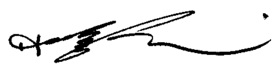
Foreword

The contribution of inland fisheries to the livelihoods and food security of the peoples of Asia has long been achnowledged. Inland fisheries are one of the last open access natural resources and provide both income and food to some of the poorest rural inhabitants of the region. In Asia, inland fisheries are mostly rural, artisanal activities catering to rural populations and providing an affordable source of animal protein, employment and household income.

In more recent years, Asian inland fisheries have been seen to decline as environmental degradation, increasing fishing and population place pressure on these resources. This review looks at the resources and practices of management and enhancement of some key inland fisheries and how these resources can be enhanced to continue to provide food and income. Stock enhancement is an integral component of many inland fisheries. Indeed, new avenues of production such as culture-based fisheries are being increasingly adopted and are seen as a way forward in most countries. Inland fishery activities also have a distinct advantage in that their development is usually less resource intensive than is conventional aquaculture.

This review provides suggestions and recommendations on what needs to be done to improve current enhancement practices and the institutional and practical issues that relate to this. The effect of enhancement on wild fish stocks and the implications for hatchery management of stocks and stocking strategies are also covered.

Attention is now returning to inland fisheries as we increasingly appreciate their often hidden values to rural livelihoods. This review contributes to a better understanding of what needs and can be done and will hopefully serve as a catalyst for further work on the enhancement of inland fisheries.



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ABSTRACT

Inland fisheries contribute only about ten percent to global fish production. Asia is the leading producer of inland fish, accounting for over 80 percent of the total production. Until recently, the inland fisheries sector had taken back stage in fisheries development plans, particularly so, given the emphasis being placed on aquaculture development throughout the world, including Asia. This report evaluates the inland fishery practices in a number of Asian countries according to habitat type, role in overall foodfish supplies and development trends. Special emphasis is laid on stock enhancement in inland fisheries in Asia, and only those fisheries in which some form of stock enhancement is practised are considered in this report.

In Asia, inland fisheries are mostly rural, artisanal activities catering to rural populations and providing an affordable source of animal protein, employment and household income. Stock enhancement is an integral component of many inland fisheries. With recent developments in artificial propagation techniques for fast-growing and desirable fish species and the consequent increased availability of seed stock, such activities are beginning to affect inland fishery production in most Asian countries. Indeed, new avenues of production such as culture-based fisheries are increasingly adopted and seen as a way forward in most countries. Inland fishery activities also have a distinct advantage in that their development is usually less resource intensive than is aquaculture.

The economic viability of stock enhancement of large lacustrine waterbodies and rivers has not been demonstrated in any of the Asian countries, the fisheries of such waterbodies being dependent on naturally recruited stocks. The most successful stock enhancements in Asia are in floodplain beels and oxbow lakes in Bangladesh where the use of small waterbodies that are not capable of supporting natural fisheries has led to culture-based fisheries having stock and recapture rates that are very high. Culture-based fisheries are not resource intensive and are community-based activities. However, their success requires major institutional changes, and these are affected by national and local governments. In general, they can be considered to have the greatest potential for further development.

A major concern related to stock enhancements in inland waters is their possible effects on biodiversity. This is for two reasons: firstly, most countries depend wholly or partially on exotic species for stock enhancement and secondly, freshwater fishes are known to be among the most threatened of vertebrates. Major studies should be undertaken to evaluate the current situation so that remedial steps can be taken, if needed, without causing serious harm to some of the stock enhancement practices that are gaining momentum.

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1. Introduction

Fishing has always been and for the foreseeable future will remain, a major source of food and income for society. However, its importance relative to other food production systems has evolved, especially over the last half century, as a result of the way fisheries are exploited (FAO 1997). This is especially true of fishery activities in inland waters.

Although the diversification of aquatic resource use through aquaculture is prevalent in most developing countries, in some countries its impacts have been less widely felt than in others, and fishing for food has remained a sustainable activity. It is evident that in many developing countries, capture-based fisheries are also under threat from development, and shifts in fishery management activities to support production from culture-based fisheries and aquaculture are occurring. In this context, capture and culture fisheries must be seen as complementary activities and not as alternatives, as this could potentially lead to reduced production from a particular waterbody (Cowx *et al.* 2004).

1.1 Contribution of fish to food security and human nutrition

A significant proportion of the world's people use the living aquatic resources of inland waters for food and recreation. Recent evidence indicates that the number of people dependent on these resources is far greater than previously thought. Studies also show fish to be particularly important in the livelihoods and diets of the poor, providing an inexpensive source of animal protein and essential nutrients not available from other sources.

Fish is an important dietary component in Asia, where its contribution as a percentage of the animal protein intake is the highest in the world (Figure 1), amounting to 23.3 percent as opposed to the world average of 15.9 percent. This situation is to be expected for at least two reasons:

- Fish production, from both capture and culture fisheries and aquaculture, is higher in Asia than in other continents. For example, the most recent data available (that for the year 2000) show that six of the top-ten countries in terms of marine and inland capture fisheries production

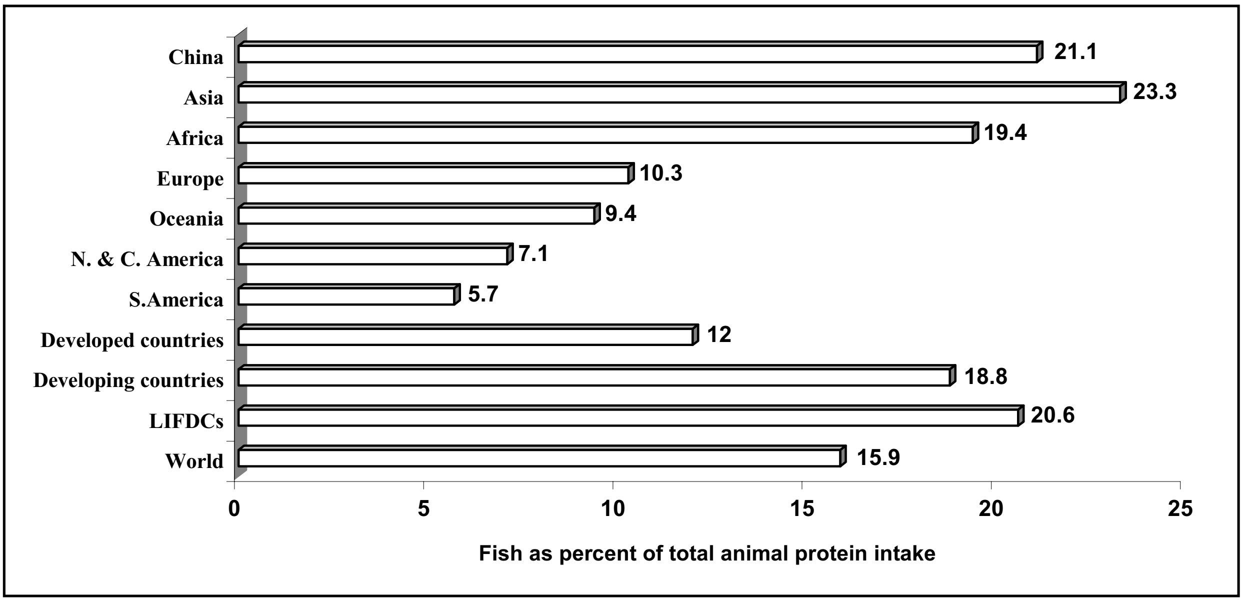

Figure 1. Contribution of food fish, as a percentage of total animal protein intake, to human diet: 2000. Redrawn from FAO (2003)

were Asian, and that these six countries accounted for 34.5 million tonnes (55 percent) of the total landings of the top-ten countries, and 91.3 percent (41 724 469 tonnes) of the global aquaculture production (2002 figures from FAO FISHSTAT 2004); and

- There is cultural affinity for fish in many Asian countries. This dates back to some of the earliest civilizations in the region, possibly as a result of the establishment of major communities alongside major rivers (Asia has a relatively high river index, and the great bulk of the river lengths fall within the tropical region). Wet-rice cultivation was also developed by these early civilizations and, to this day, rice fields have strong association with the harvesting of fisheries products. As these societies developed, their water management and irrigation practices developed to increase rice production and associated fishery benefits. An idea of this can be gained from Plate 1, which depicts a 2000-year-old Sri Lankan inscription indicating the taxation laws in force on inland fish harvests and a stone mural from the Bayon Temple, Siem Reap, Cambodia, depicting fish being consumed at a festival.

Possibly the best evidence of the continuing importance of fish in the diet in some of the poorer countries in Asia is the amounts consumed in regions/countries such as Siem Reap Province in Cambodia (80-85 kg/caput/yr), Bangladesh (48.3 kg/caput/yr) and Sri Lanka (54.3 kg/caput/yr) (Table 1). Note that in many cases this fish consumption is derived primarily, if not entirely, from inland fishery resources and not from marine capture fisheries, as is the case for Pacific island countries or developed countries with good transport infrastructure.

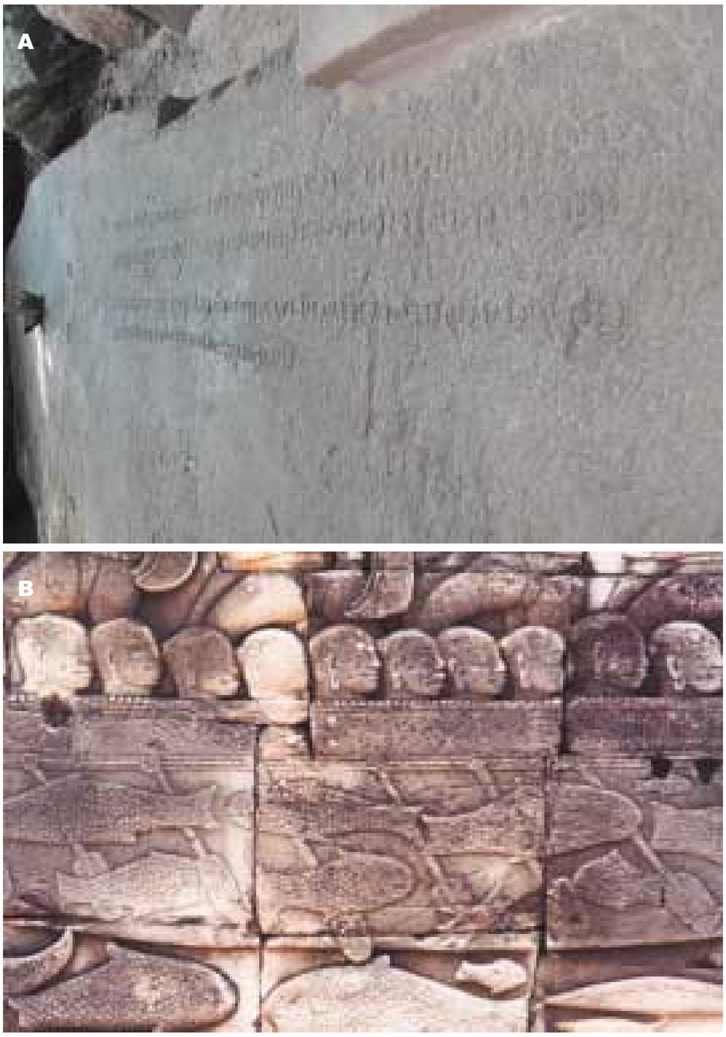

Plate 1. (A) 1800 to 2000 year old inscription depicting the prevailing tax laws on inland fishing, Anuradhapura, Sri Lanka (B) Rock mural (12/13th century) in Bayon Temple, Siem Reap, Cambodia depicting fish and associated festivities

In most of Asia, and particularly in the Lower Mekong Basin, fish and other aquatic animals are the most important source of animal protein and thus a major support to food security, particularly for rural populations. Apart from fish, frogs, tadpoles, snails, molluscs, shrimps, crabs, snakes and other reptiles and water birds from wetland habitats are considered “aquatic animals”. Average basin-wide consumption of fish and other aquatic animals is estimated at 56 kg/capita/yr (Hortle and Bush 2003). In high-yielding fishing areas such as in rural communities of the floodplains around the Great Lake (Tonle Sap) in Cambodia, fish consumption is as high as 71 kg/capita/yr (Ahmed *et al.* 1998). Even in mountainous regions like Luang Prabang in the

Table 1. Fish consumption in some of the poorer countries in Asia (data from Van Zalinge *et al.* 2004)

	Population (million)	Average per capita consumption (kg)	Total fish consumption (tonnes)	Capture fisheries catch (tonnes)	Reservoir fish catch (tonnes)	Aquaculture production (tonnes)
Cambodia	11.0	65.5	719 000	682 150	22 750	14 100
Lao PDR	4.9	42.2	204 800	182 700	16 700	5 400
Thailand	22.5	52.7	1 187 900	932 300	187 500	68 100
Viet Nam	17.0	60.2	1 021 700	844 850	5 250	171 600
Total LMB	55.3	56.6	3 133 400	2 642 000	232 200	259 200

1 LMB = Lower Mekong Basin.

Lao PDR, which present physical-geographic conditions similar to those of the central highlands in Viet Nam, northern Thailand or northeastern Cambodia, fish and other aquatic animals account for 55 percent (29 kg/capita/yr) of the total animal protein intake of the human population in rural areas (Sjorslev & Coates 2000). In An Giang Province in the Vietnamese Mekong Delta, consumption of fish, other aquatic animals and their processed products is reported to be as high as 58 kg/capita/yr (Van Zalinge *et al.* 2004, Hortle *et al.* 2004).

Although contributing only 2.63 percent to Sri Lanka's gross national product (GNP), locally produced fish products and imported dried marine fish account for more than 65 percent of the total per capita animal protein consumption (NARA 2000), rising to an estimated 81 percent in rural areas (Nathaniel 2000). Compared to similar rice-growing areas in Southeast Asia, poor families in Sri Lanka are much more reliant on purchasing fish than on harvesting aquatic animals from rice fields and waterbodies themselves. In rural areas, demand is predominantly for locally produced, highly fresh and low-cost tilapias (Murray *et al.* 2001).

Fish is a food of excellent nutritional value, and it makes a very significant contribution to the diet of many fish-consuming communities in both the developed and developing world. Fish provides high quality protein and a wide variety of vitamins and minerals, including vitamins A and D, phosphorus, magnesium, selenium and iodine. Fish is also a valuable source of essential fatty acids, and its protein is easily digestible. The protein and calorific supply from fish to the global diet has increased marginally over the last two decades, and now contributes about 16 and 7 percent, respectively (Table 2).

Table 2. The contribution of fish to human nutrition (source: Barbara Burlingame, Nutrition Department, FAO, Rome)

Nutrient	Low	High	Recommended adult daily intake
Protein (g)	8	25	
Fat (g)	<1	>25	
Saturated fatty acid (g)	<0.5	>5	
PUFA (g)	<0.5	>12	
Calcium (mg)	20	1 200	1 000
Iron (mg)	<0.5	>10	9-20
Thiamine (mg)	<0.01	>0.4	1.1

Apart from supplying protein and calories to human nutritional well-being, fish is the main source of a number of fatty acids that are often lacking in red meat. These fatty acids, in particular, are eicosapentanoic acid-EPA (20: 5n-3), docosahexaenoic acid-DHA (22: 6n-3) and arachidonic acid-AA (20: 4n-6). The human body is incapable of synthesizing these fatty acids and they must be supplied in the diet. Fatty acids are crucial to life, and apart from being energy sources, some of the long-chain n-3 and n-6 series fatty acids (commonly known as polyunsaturated fatty acids or PUFAs) perform a number of physiological functions, such as:

- providing the structural elements of cell membranes;
- acting as precursors to eicosanoids, a heterogenous group of highly active "local hormones";
- contributing to osmoregulation;
- influencing reproduction and egg quality;
- being important for brain development; and
- being important for development of vision.

It is now well documented that deficiencies of some these PUFAs are associated with major health risks (Stansby 1990, Ulbricht and Southgate 1991, De Deckere *et al*. 1998), and some diseases and clinical conditions can be alleviated by the supplementation of PUFA (Hunter and Roberts 2000). As a result of this increasing awareness on the importance of fatty acids in the human diet, there is a general upsurge in fish consumption in many societies, particularly in the developed world.

The evolutionary development of the human brain has also been linked to food sources rich in n-3 (DHA) and n-6 (AA) PUFAs, Indeed, there is emerging evidence suggesting that *Homo sapiens* evolved not in a savana habitat, but in a riparian or coastal habitat that was rich in fish and shellfish resources (Crawford *et al.* 1999). There is increasing evidence from medical studies indicating the positive effect of fish in the diet on human health, growth and general well being. No attempt will be made to review this in detail, but suffice it to say that man's current nutritional requirements reflect an early dependence on fish and other aquatic animals in the diet.

1.2 Sourcing foodfish requirements

The Asia-Pacific region is the world's largest producer of fish, from both aquaculture and capture fishery sectors. In 2002, this amounted to 46.9 million tonnes from aquaculture and 44.7 million tonnes from capture fisheries. The total inland fisheries production of the region in 2002 was reported as 3.4 million tonnes. South Asia and Southeast Asia contributed the greatest production as compared with other subregions (Sugiyama *et al*. 2004).

It is generally recognized that marine capture fisheries, which witnessed a period of major growth following the Second World War, have now reached the point where they are no longer increasing and indeed, several are in decline. This is not surprising given the status of the major stocks of marine fish and the fact that nearly 45 percent of these stocks are already fully exploited (Figure 2).

Global marine capture fisheries are influenced by climatic events, such as El Niño and La Niña, which are known to affect the world's biggest single-species fishery (the Peruvian anchovy fishery) once every few years. Apart from heavy fishing effort in marine capture fisheries, ecosystem degradation is also an important factor contributing to declining fisheries production (Jackson *et al*. 2001, Myers and Worm 2003).

It is within the above context that a concerted attempt has been made since the 1960s to develop aquaculture by transforming it from an art to a science. Globally, this attempt has been successful,

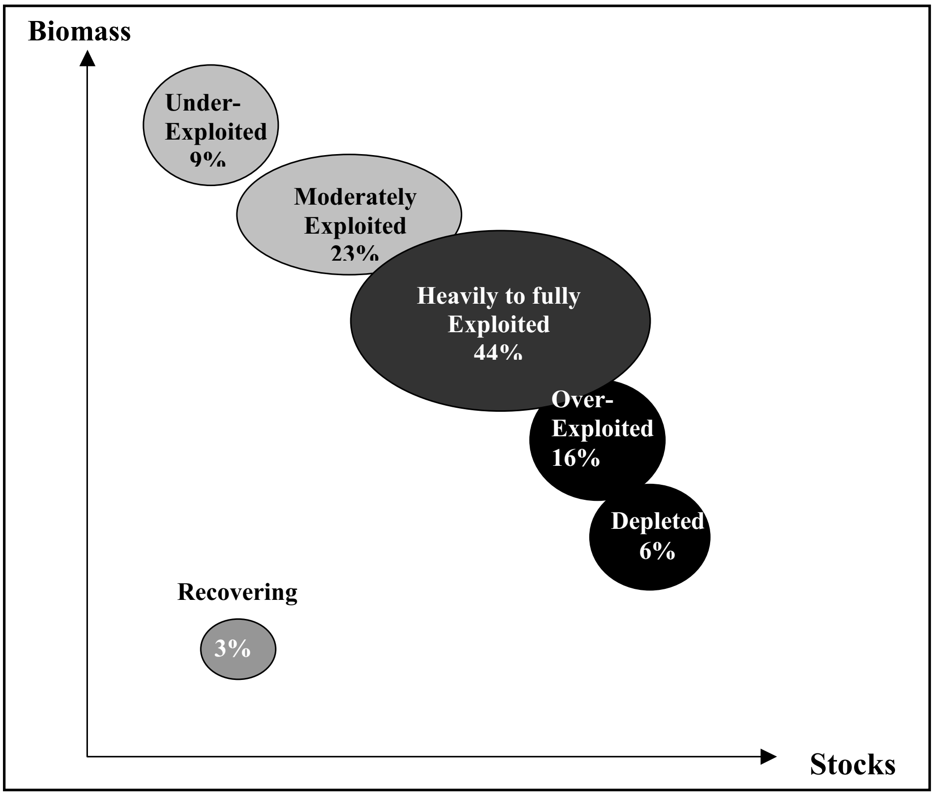

Figure 2. A schematic representation of the status of the exploited fish stocks in relation to fishing mortality and biomass (re-drawn from Botsford *et al.* 1997)

when one considers that the total aquaculture production in year 2000 was 45.7 million tonnes and that aquaculture has grown at an annual rate of 8.9 percent/yr since 1970 (Tacon 2003). Currently, aquaculture accounts for 33 percent of every kilogram of aquatic products consumed in the world. Although aquaculture has been the fastest growing food production sector, the question arises whether this pace of growth can be sustained and for how long. It has been shown (De Silva 2001) that the rate of production is declining in all continents except South America. A number of reasons for this trend have been recognized, including the fact that land-based aquaculture must increasingly compete for land, water and feed resources with other agricultural sectors and that parts of the sector are reliant on marine fishery-based resources (e.g. fishmeals). These factors influence the economic feasibility and competitiveness of aquaculture with respect to the other animal protein production sectors.

Inland fisheries are increasingly being re-evaluated as an economically efficient and equitable way to contribute to foodfish supplies, particularly in developing countries (Welcomme and Bartley 1998, De Silva 2000, Lorenzen *et al*. 2001).

Production from inland fisheries is currently reported to account for about 10 percent of global fish supply (Figure 3). While this contribution may seem to be relatively low in comparison to marine capture fisheries, there is a general consensus that inland fisheries production in many regions is grossly under-estimated. A recent estimate of the potential range of production for some Southeast Asian countries suggests that these under-estimations are in the order of 2.5 to 3.6 times greater than those reported (Coates 2002). This suggests that the contribution of inland fish to the world's fish supplies is significantly higher than the estimated 10 percent and consequently, that the role of fish in the nutrition of the rural poor is also greatly undervalued.

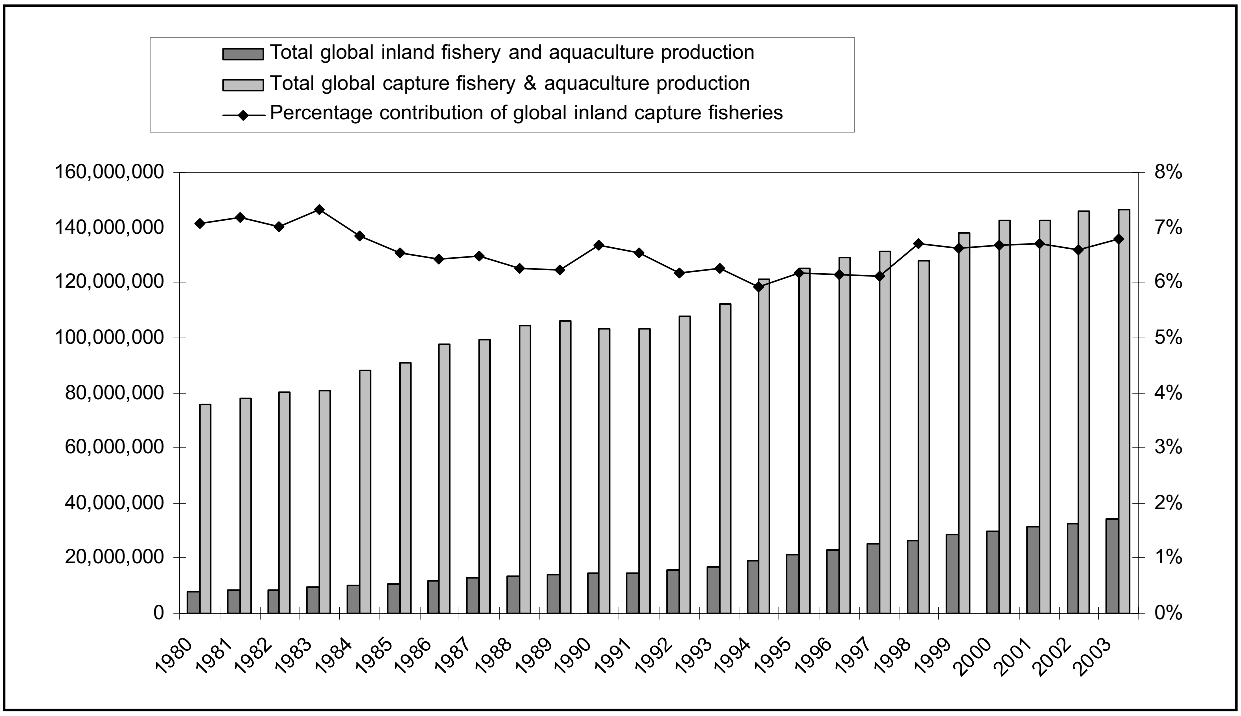

Figure 3. Total global and inland fisheries (capture & aquaculture) production and the percentage contribution if global inland capture fishery production

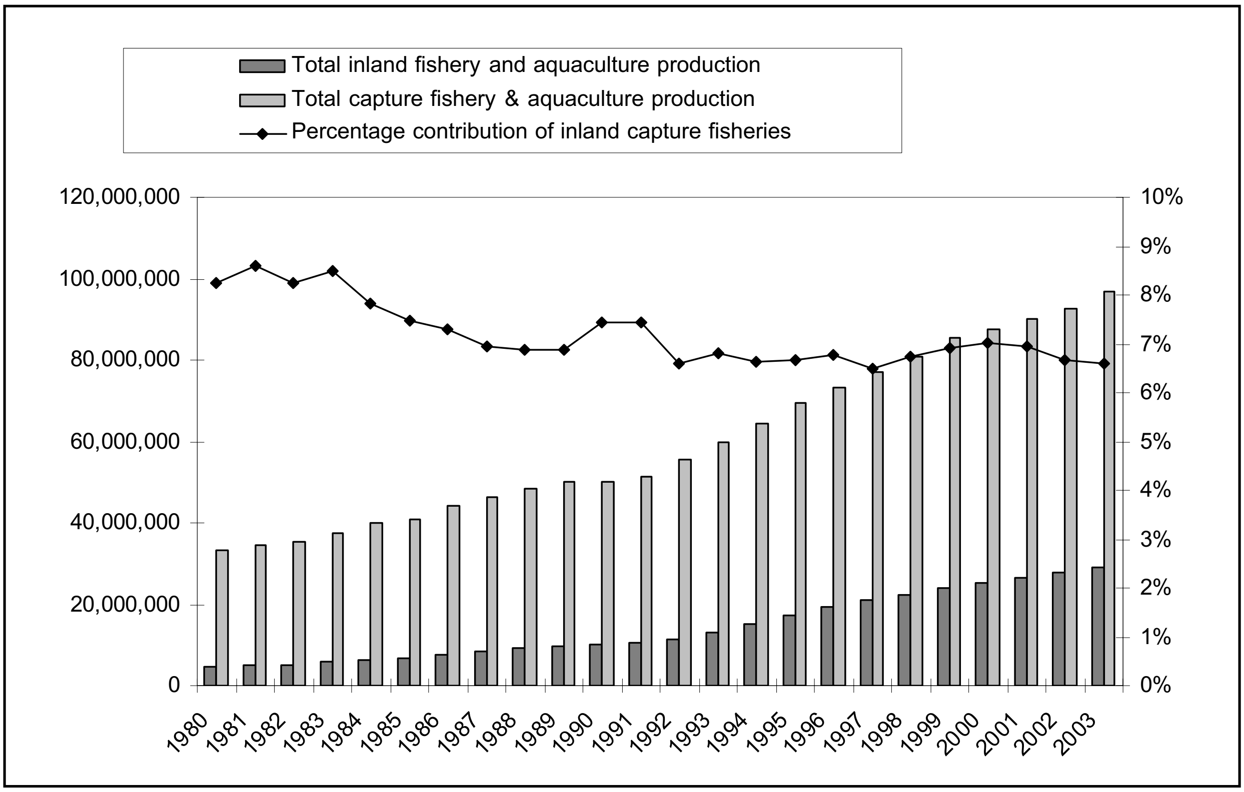

Figure 4. Total Asian fishery production and total Asian inland fishery production (aquaculture and capture fisheries) and the relative percentage contribution of inland capture fisheries (source: FAO FISHSTAT 2004)

Plate 2. (A) An example of the variety of processed freshwater fish products, and (B) a woman vendor dealing on a variety of dries freshwater fish products in a market in Myanmar

The fact that inland fisheries production is underestimated does not mean that the fisheries are in good condition. There are consistent published and anecdotal reports that most riverine fisheries in the region are in decline. For example, since 2000 fishing bans have been imposed in different sections of the Yangtze River, PR China during certain times of the year to make provision for the different spawning periods of the major fish species (Anon 2003). In Bangladesh, riverine fish production declined from 207 000 tonnes in 1983 to 124 000 tonnes in 1998, and during this period the landings of indigenous major carps decreased by 77 percent (De Graaf 2003).

Although inland fish production is undoubtedly important in Asia, its increasing contribution to the fish supplies is masked by the substantial increases in aquaculture production, particularly in PR China (Figure 4). Increasing production from inland fisheries is not confined to Asia. There has also been a relatively recent upsurge in inland fish production in the tropical countries of South America, particularly from reservoirs (Petrere 1996, Quiros 1998). This apparent increase in production also reflects an improved assessment of the real participation of rural people in inland fisheries and their consumption of inland fishery products (Hortle *et al.* 2004, Almeida *et al.* 2004)

Apart from their contribution to the total fish production per se, inland fisheries and aquaculture are important to food security in many other ways. Notably, inland fisheries production:

- directly supplies inland rural populations with an affordable source of high quality animal protein;
- is almost entirely used for direct human consumption (Plate 2);
- is rarely converted into feed ingredients for farmed animals, including those used in aquaculture (unlike marine fish production), of which nearly 25 percent is converted into fishmeal.
- enables persons with minimal skills to be engaged in resource exploitation at a subsistence level (although global figures for inland fishers are rather low, they typically under-estimate the seasonal or occasional nature of inland fishing and therefore, grossly under-estimate actual participation and dependence upon inland fisheries).

Plate 3. (A) & (B) Examples of simple traps used in rice paddies to catch small fish

Inland fisheries provide direct employment to rural populations through production and indirect employment through processing and trading in fishery products. Importantly, inland fisheries also provide significant opportunities for integration into rural farming livelihoods, help to buffer against shortfalls in agricultural production and provide alternative sources of food and income. Most inland fisheries require very little entry capital and are often practiced as part-time activities. Examples include the operation a few traps in a paddy field or a channel (Plate 3) and children foraging for shellfish and other aquatic animals in paddy fields and wetland areas. Such exploitation is often conducted as part of the farming system and is often environmentally non-destructive.

1.3 Purpose of this review

As inland fisheries decline through habitat changes that accompany agricultural and land developments and intensifying exploitation, it becomes increasingly important to consider ways and means to sustain the availability of fish to rural populations. One of the main strategies that has been employed in most Asian countries to improve inland fish production is the stock enhancement of inland waters, particularly lacustrine waterbodies. Although stocking has been practiced in many countries in the region, its cost-effectiveness and impacts on rural communities have been rarely evaluated. This document will review and evaluate the following aspects of inland fishery enhancement:

- the diversity of enhancement practices that are employed in the region;
- the impact of these practices in relation to the type of waterbody and management structures in operation;
- the cost-effectiveness of enhancement practices in relation to the nature of the waterbodies;
- the organizational structures/institutions that are needed to sustain the practices;
- the biological and ecological impacts of current enhancement practices, including their effects on biodiversity; and
- the impacts of enhancement practices on rural livelihoods.

Specific examples of inland fisheries enhancement are drawn from Bangladesh, India, Indonesia, Myanmar, Sri Lanka, Thailand and Viet Nam. In view of the diversity of inland waters, this review will also consider the water resources in Asia and the suitability of different types of waterbody for adoption of enhancement and management strategies to enhance fish production.

2. Inland water resources of Asia

Fish and water are inseparable, and it is necessary to consider the water resources in Asia, particularly those resources that are likely to benefit from some form of stock enhancement. Global water resources are diverse, but crucially for inland fisheries, there are only limited freshwater resources available to fisheries. The earth's freshwater resources amount to about 35 029 000 km^3 or approximately 2.5 percent of the earth's total water resources (Shiklomanov 1993). More than 75 percent of the earth's freshwater resources occur as glaciers and permanent ice cover, and about 23 percent is locked in ground water. This leaves les than 3 percent of the total that mightbe available for freshwater fisheries.

The Asia-Pacific region accounts for 36 percent of the global freshwater runoff, but its average per capita amount of available freshwater is the lowest in the world, amounting to only 3 690 m^3/yr (UNEP 2002). This low per capita availability of water highlights the limited nature of this primary resource and consequently, competition for water will shape the future development of inland fisheries and aquaculture. The water resources available to fisheries can be categorized into: riverine resources (rivers and their floodplains), natural lakes and man-made impoundments (reservoirs).

2.1 Riverine resources

Global riverine runoff (which excludes polar glaciers and ice) is estimated to be 44 500 km^3 (Shiklomanov 1993), and that of Asia is 14 410 km^3, approximating 32.4 percent of the total. This is the highest among the continents, and Asia also has the largest number (49) and the highest cumulative river channel lengths (about 90 000 km). This is more than double that of North America or Africa (Kapetsky 1998).

Asia has a number of major rivers with international river basins, such as:

- the Mekong River,
- the Irrawaddy River,
- Ganges-Brahamaputra-Megna river system,
- the Indus River and
- the Red River.

Although major fisheries exist in all these river systems (Coates 2002), stock enhancement has been rarely practiced to contribute to fisheries in the river channels *per se* in Asia. In contrast, floodplain fishery enhancement is a common practice in Bangladesh and Myanmar. The seasonal floodplains in Myanmar are estimated to be about 8 million ha, mostly in the Irrawaddy system (with a discharge of 13 500 m^3/sec (Coates 2002). Bangladesh, which is essentially a huge delta, has a seasonal floodplain of about 2.8 million ha (Rahaman 1987). In Bangladesh, the floodplains also contain deep depressions (beels), amounting to about 114 700 ha (Rahaman 1987). Also relevant to the present study are the oxbow lakes commonly found in Bangladesh (referred to locally as "baors"). Oxbow lakes are perennial waterbodies and are the remnants resulting from natural shifting of the original river channels.

2.2 Natural lakes

Asia has relatively few natural lakes, with only about 15.4 percent of the global total of 1.236 million km^2. Most of these Asian lakes are confined to the volcanic areas of the continent, primarily the Indonesian and Philippine archipelagos and northern India. There is one major exception, the Great Lake (Tonle Sap) in Cambodia, a lake that expands from 2 000–3 000 km^2 in the dry season to 10 000–12 000 km^2 in the flood season, as a result of the reverse flow of the Tonle Sap River. The major lakes (>5 000 ha) in Indonesia and the Philippines have a total area of 257 968 (nine lakes) and 89 820 ha (five lakes), respectively (Baluyut 1999). Indeed, the limited number of natural lakes in Asia has been linked to its relatively poor lacustrine fish fauna and consequently, the ease with which tilapias of African origin have been able to predominate in some of the lacustrine waters of Asia (Fernando 1980, Fernando and Holcik 1982).

2.3 Reservoirs

There is an ancient tradition of reservoir building for irrigation and water storage in some Asian countries such as in Sri Lanka, where this activity was an integral part of the civilization and dates back nearly 2 500 years (De Silva 1988). Elsewhere in Asia, modern reservoir building is a post-Second World War phenomenon. Large reservoirs are constructed for purposes of irrigation, hydropower generation and/or flood protection. More recently, modern large reservoir construction has come under increasing scrutiny and remains a controversial issue in most countries. A central feature in the argument relating to large reservoir construction is the relative financial and socio-economic benefits and/or impacts to the nation and impacted communities. It is not uncommon to see such issues taking centre stage in the political arena (McCully 1995, Roy 1999), and this is reflected in the establishment of the World Commission on Dams. Reservoirs are never or very rarely constructed for fisheries development, although the economic potential of fishery development is often cited as a mitigating factor to offset impacts to riverine fisheries that result from dam construction. Most typically, fisheries development in reservoirs is a secondary activity that is subsidiary to the primary purpose of the dam, which is usually hydropower or irrigation. This review will consider only the fisheries-related biological and environmental aspects of pre-existing reservoirs and not the more complex issue of the impacts of dam construction on riverine fisheries.

A

B

Plate 4. Reservoirs may be very diverse in form, function and fish productivity. (A) An old irrigational reservoir, that supports a significant artisanal fishery, Sri Lanka. (B) The dam of a modern, deep, relatively low productive reservoir in Viet Nam

The reservoirs of Asia can be loosely divided into large impoundments resulting from the damming of large rivers and smaller impoundments that depend on rainfall and the runoff from local catchments (Plates 4 and 5). The aggregate reservoir resource in Asia is large (Figure 5), and currently accounts for over 40 percent of the global capacity of large reservoirs (>0.1 km^3). In addition to the large reservoirs, there is a very large area of medium and small reservoirs, which tend to be located in rural areas and are primarily intended for irrigation. The distribution of different types of reservoirs in the seven main river basins of PR China is given in Table 3. It is estimated that developing countries in Asia have 66 710 052 ha of such reservoirs (FAO 1999). PR China is estimated to have 86 526 medium (66.7 to 677 ha) and small-sized (<66.7 ha) reservoirs (Table 3, Huang *et al*. 2001). Similarly, Sri Lanka is reputed to have over 10 000 small reservoirs, which are non-perennial and retain water up to six to nine months in the year (De Silva 1988).

Plate 5. Small reservoirs which are being increasingly used for culture-based fisheries. (A) Sri Lanka & (B) Viet Nam.

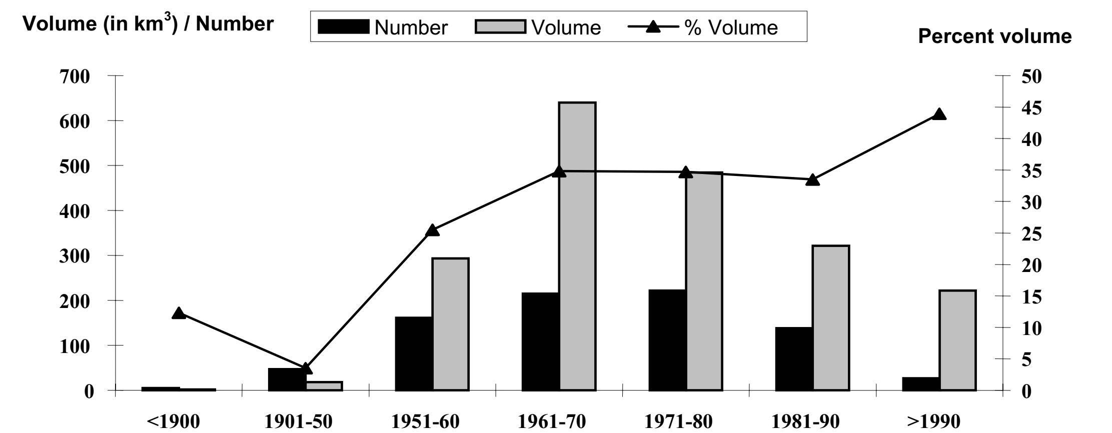

Figure 5. Reservoir number and volume (in km^3) in Asia at different time periods and the Asian reservoir volume expressed as a percentage of world reservoir volume. Reservoirs >0.1 km^3 capacity are included [based on data from Avakvan and Lakovleva, 1998]

Table 3. Number of reservoirs of each type, and the total storage capacity in the seven main river systems in PR China (from Huang *et al.* 2001)

River system	Category/Number					Capacity	
	Large	Medium	Small 1	Small 2	Total	x 10^6 m^3	%
Changjiang	101	864	6 700	40 881	48 546	1 186.6	37.3
Huanghe	14	141	848	2 567	3 570	569.5	17.9
Huaihe	36	149	905	4 317	5 407	393.9	12.4
Hai-luan	26	108	343	1 481	1 958	228.3	7.2
Zhujiang	35	327	1 907	7 300	9 569	465.1	14.6
Songhuajiang	17	97	425	942	1 481	198.9	6.3
Liaohe	16	67	208	460	751	136.9	4.3

3. Inland fisheries of selected countries in the region

There are few Asian inland fisheries that can be considered to be “industrial” type fisheries. Such inland fisheries utilize large boats or large gears and land large quantities of fish with a degree of regularity. Good examples of “industrial” inland fisheries of Asia are the Cambodian “dai” fishery in the lower Mekong Basin and the “fishing lots” in the Great Lake. The important features of these fisheries, which are mostly very seasonal, including aspects of marketing and processing, have been dealt with previously (Sverdrup-Jensen 2002). In the Cambodian dai fishery, most of the catch is processed into various fish pastes and sauces, a portion is dried, and the rest is consumed locally as fresh fish, with a small proportion (of high-valued species) exported to neighbouring countries. On the other hand, most inland fisheries are truly artisanal; fishers operate in small crafts, on average ranging in length from about 5 to 8 m (Plate 6), which may be motorized (mostly with outboard engines) or unmotorized. Consequently, the catch per craft is relatively small, and more often than not, it is disposed of on the same day. However, the *modus operandi* of the respective fisheries differ markedly, both between countries and between waterbodies within a country. In general, the marketing

Plate 6. Examples of the different types of craft used in inland fisheries in Asia. (A) Indonesia, (B) Myanmar, (C) Sri Lanka, (D) Cambodia, (E) Thailand

aspects of inland fisheries have not received the attention that they deserve, except with respect to some countries (Murray *et al*. 2001), and are an area that warrants urgent attention.

It is relevant to consider the inland fisheries of selected countries in the region prior to evaluating the strategies that are adopted to sustain them and before considering strategies to enhance production. The inland fishery production in most countries, as in the case of Asia as a whole (Figure 3), has been steadily increasing (Figure 9). In Figure 9, inland capture fishery production is compared with that from aquaculture. These two fishery sectors are sometimes in competition for primary resources such as water but more often, it is the loss of inland fishery resources as a result of water management or habitat degradation that leads to increasing interest in aquaculture. Thus, declining wild fish availability, increasing demand and rising fish prices mean that aquaculture often becomes more economically viable.

In almost all the countries considered presently, except perhaps in Indonesia (Figure 6), the inland capture fishery has increased over the years, the most significant increase being in Cambodia[1]. It is also evident that aquaculture is becoming increasingly important in most countries, although this sector is not always located in the same geographical area as inland capture fisheries and it may not be producing the same type of product (i.e. relatively low-value fish for domestic consumption). Even so, inland fisheries contribute more than 40 percent to the total inland fish production in six of these ten countries: Bangladesh, Cambodia, Lao PDR, Myanmar, Sri Lanka and Thailand. These trends are also reflected in per caput captured and cultured fish production (Figure 7). The current inland fish production per caput, and hence availability, varies widely among countries, ranging from about 2.2 for Sri Lanka to 28.2 kg/caput/yr for Cambodia (FAO 2003), with only Bangladesh, Cambodia, China and Lao PDR exceeding 10 kg/caput/yr[2].

It is also generally recognized that because of its artisanal nature, the inland capture fishery production of most countries is usually under-estimated (FAO 2003; Coates 2002). Other factors that may contribute to this under-estimation are the reluctance of some countries to include the production of certain species (e.g. tilapia production in India), and the inclusion of production from culture-based fisheries under aquaculture (e.g. PR China). Also, non-finfish resources that are exploited in inland waters are often incompletely recorded. One good example in this regard is the fishery for the small shrimp *Macrobrachium nipponensis* in most lacustrine waterbodies in Viet Nam. This resource is exploited using small traps and/or liftnets and is marketed, through middle-persons, to processing centres (Plate 7). Many hundreds of livelihoods are dependent upon this fishery in each waterbody, but very little is known of the total return and/or the biology of the species.

3.1 Inland fishing gear

This subject warrants a special study in itself and because its relevance to stock enhancement is not direct, the types of fishing gear used in inland fisheries in Asia will not be reviewed in detail. An excellent text on the fishing gears of the Cambodian Mekong River has been produced by Deap *et al.* (2003) and similarly for Lao PDR by Claridge *et al.* (1997). There is a great diversity of fishing gear used in inland capture fisheries, ranging from simple traps, to large (many kilometers long) fences

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[1] This huge increase in Cambodian production is the result of a change in estimation of the production of the fishery. Earlier figures did not account for a significant production from artisanal fishing, and estimates of this have now been incorporated into national statistical reporting, resulting in an apparent upsurge in production. In fact, production probably has not increased – merely the statistics have been adjusted to reflect the actual total that is currently being taken from the fishery.

[2] These FAO figures are based on ‘apparent consumption’ and are typically under-estimated in those countries with large inland fishery resources. Research in several Asian countries has shown that these figures can be substantially higher.

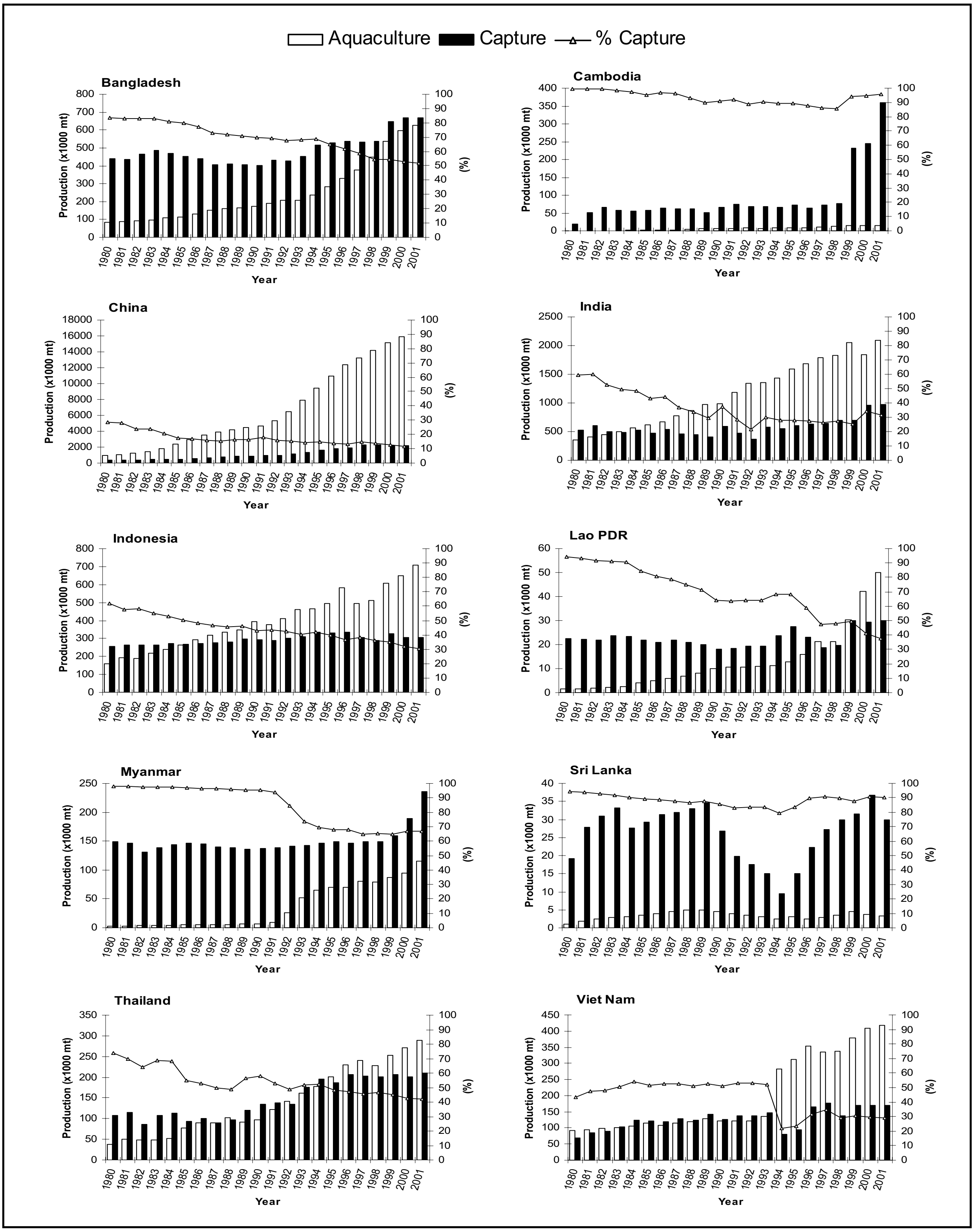

Figure 6. Changes in yearly inland capture fishery and aquaculture production in selected Asian countries, and the percent contribution of the capture fishery to total inland fish production (based on FAO data)

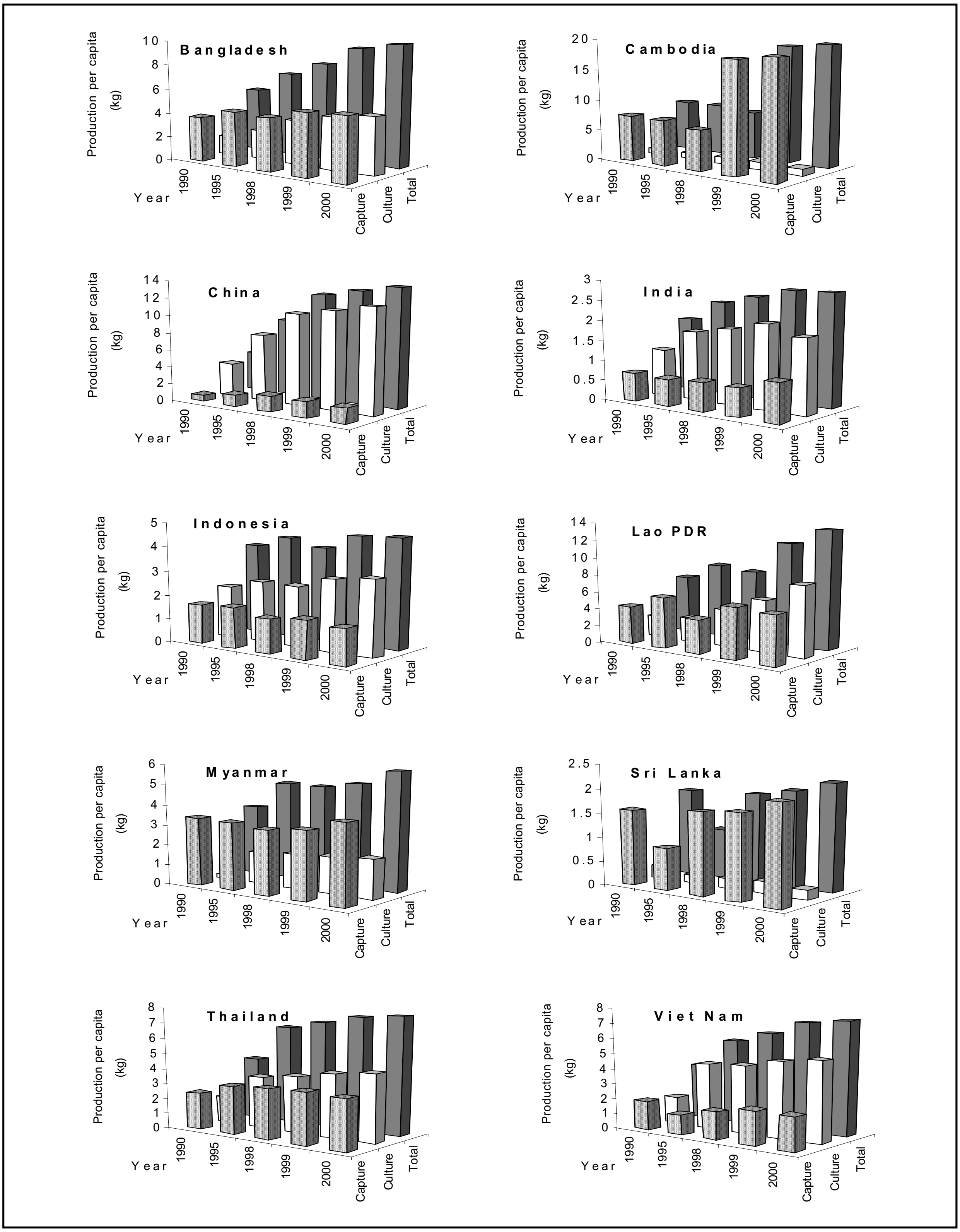

Figure 7. Production per capita of the inland capture, culture and total fishery in selected Asian countries in selected years

Plate 7. (A) Small traps commonly used in the shrimp fisheries in vietnamese reservoirs. (B) A woman fisher with her day's catch (from ThacBa reservoir, Yen Bai Province, Northern Viet Nam; about 11 kg; farmgate price- 5 500 VND per kg; 1 US$ = 14 000 VND). (C) Activities at a shrimp processing site, Yen Bai. Viet Nam

with associated large, stationary fishing traps, as in the Great Lake, Cambodia, to the large bagnets or stationary trawls in the Mekong River dai fishery in Cambodia (Sverdrup-Jensen 2002), to the more traditional and common gears such as gillnets, castnets etc. Purse seines and trawls are also used in some fisheries, e.g. in Ubolratana Reservoir, Thailand and Tonle Sap, Cambodia, but this is more the exception than the rule. In China, a technique referred to as the integrated method, which basically consists of the operation of two very large seinenets acting in the form of a trammelnet, is used to harvest stock-enhanced fisheries (details are given in Li and Xu 1995). Typical gear types used in stocked enhanced fisheries are gillnets and/or trammelnets, seinenets, castnets and liftnets. In inland fisheries, dragging gear such as trawls is rarely used, principally due to the uneven nature and obstacles on the bottom.

3.2 Catch composition

Only a limited number of fish species and/or species groups are recorded as contributing significantly to the inland fish production of most countries. To some extent, this could reflect the fact that inland catches, in general, tend to be under-estimated, and that most inland fisheries occur in isolated waterbodies where it is often difficult to obtain reliable statistics. The inadequacy of the reporting of freshwater fisheries catches is best exemplified by the data given in Table 4. In the inland catches of the ten countries used in this study, only nine finfish and two crocodiles were recorded to the species level. Another five finfish, two crustaceans and one mollusc were recorded as species groups. The category "freshwater species *nei*" (an FAO term meaning "not elsewhere identified"), used to denote nonspecific groups, was common to all countries and often topped the species list of most countries. Indeed, this category accounted for less than 40 percent of the total inland fishery only in three countries (Indonesia, Sri Lanka and Thailand) and in five countries, it accounted for over 80 percent of the total. The implications of this relatively inadequate species or species-group collation of statistics on stock enhancement, which necessarily depends on one or two species, will be appraised further in the forthcoming sections.

Table 4. The top six species and/or species groups contributing (tonnes) to the inland fishery of each of ten selected countries, based on the landings reported for 2001. The number of species and or species groups recorded for each country, if exceeding those cited in the Table is given in parentheses (extracted from FISHSTAT, the FAO Fishery Statistics Web site http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp)

Species/species group	Bangla-desh	Cam-bodia	PR China	India	Indonesia	Lao PDR	Myanmar	Thailand	Sri Lanka	Viet Nam
FW crustaceans[1]		400	586 985							1 000
Decapods[1]				17 625						
FW molluscs[1]			529 645							
FW fish[1]	590 000	359 600	1 033 302	591 550	107 180	25 500	235 376	67 710	2 640	169 000
Asian barbs[1]								42 800		
Common carp								7 310		
Cyprinids[1]				148 622		4 500				
FW siluroids[1]				76 809						
Hilsha shad	80 000									
Java barb					17 080					
Kelee shad				54 554						
Kissing gourami					18 320					
Mozambique tilapia					19 550					
Nile tilapia								41 740		
Snakeheads[1]				58 856	31 820					
Striped snakehead								21 400		
Snakeskin gouramy					21 260					
Torpedo-shaped catfish[1]								20 470		
Tilapia[1]									27 230	
Estuarine crocodile		25 000								
Siamese crocodile		30								
No. species/ groups recorded				(14)	(25)			(11)		

[1] Refers to species groups and denoted as nei in FAO statistics.

4. Stock enhancement: general considerations

The term "stock enhancement" is often broadly used to describe most forms of stocking, irrespective of purpose. From a fisheries view point, this can be somewhat misleading, even though the ultimate goal of every enhancement practice is to increase stock size and thereby, the fishable stock. Welcomme and Bartley (1997) recognize four major types of stocking intervention based on the objective of the intervention:

- compensation – to mitigate a disturbance to the environment from human activities;
- maintenance – to compensate for recruitment overfishing;
- enhancement – to maintain fisheries productivity of a waterbody at the highest possible level; and
- conservation – to retain or replenish stocks of a species that is threatened or vulnerable.

For the purpose of this review, "enhancements" are separated into two types:

- ***Stock enhancement of wild fisheries*** – The enhancement of stocks of an existing wild, open-access fishery with species that may or may not be self-recruiting. This category includes the stocking of relatively large inland waterbodies where there are no property rights to the stock. Generally the recapture rate of stocked fish is low and repeated enhancement is not always necessary to maintain the fishery.
- ***Culture-based fisheries*** – The stocking of small waterbodies is a form of enhancement that is typically undertaken on a regular basis and the stocking activity is the only means of sustaining the fishery. Typically, a person or a group of persons and/or an organization will have property rights to the stock. The source of stock for the enhancement may be derived from capture, but more typically is obtained from a hatchery operation. These features collectively amount to a form of aquaculture that according to the FAO definition (FAO 1997), is referred to as culture-based fishery.

Apart from the above differences, the objectives for stock enhancement may differ markedly between developed and developing countries. Welcomme (1996) characterized the differing strategies with regard to management of inland waters for fish production, and these are equally applicable, with minor modification, to stock enhancement in inland waters (Table 5). The primary purpose of stock enhancement of floodplains, large reservoirs and lakes in Asia is to increase the foodfish supplies and is in contrast to that in developed countries, where it is to enhance recreational fisheries and for conservation purposes (Cadwallader 1983, Welcomme 1997, Miranda 1999).

Stock enhancement in developing countries may be based on one of four broad strategies, or combinations thereof:

- ***Use as a seeding mechanism for replenishing depleted "breeding stocks"*** – e.g. the case of Indonesian reservoirs particularly using species that are indigenous to the country, but not necessarily to a particular waterbody (See Section 4.1.2 and Table 6).
- ***Replacement of existing, self-recruiting species/stocks, with species/stocks with more desirable traits (such as higher growth rate, reduced tendency to stunt etc.)*** – e.g. the endeavours to replace *Oreochromis mossambicus* with *O. niloticus*, a practice that has become increasingly popular over the last three to four decades in most Asian lakes and reservoirs. More recently, there have been attempts to replace the original stocks of *O. niloticus* with the "GIFT" strain of *O. niloticus* (GIFT-genetically improved farmed tilapia).

Table 5. Differing strategies for management of inland waters for fish production through stock enhancement (modified from Welcomme 1997)

	Developed countries	Developing countries
Main objectives	• Conservation • Recreation	• Provision of food • Employment • Political
Mechanisms	• Sports fisheries • Habitat restoration • Environmentally sound stocking • Intensive, discrete, industrialized aquaculture	• Food fisheries • Enhancement through intensive stocking (and management of ecosystems?) • Extensive/semi-intensive (+ integrated) rural aquaculture; culture-based fisheries
Economic	• Capital intensive	• Labour intensive

- ***Regular stocking of species with a view to sustaining a fishery*** – In most instances, such stocked species are unlikely to form breeding populations in the waterbodies concerned. This is due to the stocked species requiring migration to a riverine habitat for breeding. Typical species used for this purpose include the Chinese and Indian major carps.
- ***Regular stocking of floodplains*** – as a form of compensation for reduction in recruitment resulting from developments related to flood control (e.g. in Bangladesh) and to increase fish yields, and/or develop new fisheries to enhance fish supplies (e.g. in Myanmar).

4.1 Stock enhancement of inland waters in Asia

4.1.1 Rivers and floodplains

The enhancement of riverine stocks for fisheries development in Asia is relatively rare compared with developed countries. Stocking programmes for the Mekong giant fish species – the giant barb *(Catlocarpio siamensis),* the giant catfish *(Pangasianodon gigas),* isok barb *(Probarbus jullieni),* thicklip barb *(P. labeamajor)* and thinlip barb *(P. labeaminor)* are some of the few instances of riverine stock enhancement in Asia. Stocking of these species, some of which are endangered, is planned and/or in progress as a component of an integrated management strategy for improving the status of wild stocks (Mattson *et al.* 2002).

In developed countries, there are few (if any) remaining artisanal freshwater river or floodplain fisheries. Riverine stock enhancement in these countries is carried out primarily for sport fishery development and for the conservation of indigenous stocks. A secondary purpose in some rivers is stocking for the control of aquatic weeds.

Riverine stocking with exotic species for the purpose of developing recreational fisheries, often associated with the promotion of tourism, has taken place in some Asian countries. These exotic species are typically salmonids, and the countries where this has taken place include India, Pakistan and Sri Lanka. This activity is still continuing to some degree, despite its potential negative affects on indigenous flora and fauna. Some enhancements have had negative impacts on native flora and fauna, such as the introduction of brown trout *(Salmo trutta)* and rainbow trout *(Oncorhynchus mykiss)* into New Zealand in the late 1800s, which is purported to have negatively impacted the native galaxiid stocks (McDowall 2003).

It is disheartening to note that the riverine stocking of exotic species has not been objectively evaluated and has attracted very little attention from the scientific community in the region. Indeed, attempts to justify culturing such exotics (Nepal *et al*. 2002) in the mountainous areas in the region have generally ignored the availability of local species that are equally or even better suited for this purpose (e.g. some species of *Tor* are excellent sportfish) and the increasing body of evidence of negative impacts on native fauna (Petr 2002).

Stock enhancement of the giant river prawn, *Macrobrachium rosenbergii,* has been attempted in some rivers, large waterbodies and reservoirs in Thailand over a fairly long period of time; however, reliable data on stocking are available only since 1998. This is one of the relatively uncommon examples of stock enhancement with a non-finfish species. During the period 1998–2003, 15 Thai rivers were stocked in one or more years, with nearly 70 million postlarvae. The most intensely stocked river was Pak Panang in southern Thailand, which was stocked with 26 million postlarvae in 1999. Songkhla Lake has also been repeatedly stocked (in 2002, 11 million tiger prawn postlarvae, 7 million banana prawn postlarvae and 14 million giant river prawn postlarvae were stocked) (Choonhapran *et al*. 2003). Regrettably, however, there are few statistics available on the returns from these stock enhancement attempts. Although Choonhapran *et al*. (2003) report some increased production following the stocking activities, no evaluation as to whether this was a direct result of the stocking activity could be made. Stock enhancements for giant river prawn have also been conducted in reservoirs (see Section 6.7.2).

Floodplains are wetlands that retain an association with the parental river and are typically inundated for part of the year during annual floods. These wetlands are very productive ecosystems and also provide crucial habitats for the spawning of some riverine species. The inundated parts of floodplains also provide important feeding grounds for fry and fingerlings of most riverine species. The floodplains of Bangladesh, Cambodia, Myanmar and several other Asian countries support substantial artisanal fisheries. In Bangladesh and Myanmar, some of these floodplain fisheries have stock enhancement strategies. In some cases, parts of the floodplain have been cut off from the parental river by damming for fishery enhancement and management. These fisheries are obviously managed in a more intensive manner and are more akin to “culture-based fisheries” (see Section 8).

4.1.2 Lakes and reservoirs

There are relatively few natural lakes in the Asian region, and the emphasis of stock enhancements has been mostly directed at reservoir stocking. Most of the natural lakes are not stocked regularly, and the available evidence indicates that stocking has been confined to self-recruiting exotic species such as tilapias (*Oreochromis* spp.) and common carp *(Cyprinus carpio).* In some countries such as Thailand, there may be an increasing trend towards the stocking of indigenous species capable of forming self-sustaining populations in large waterbodies. Details on such introductions and stock enhancements in Indonesian lakes are given in Table 6. It is evident from Table 6 that in most instances, translocated indigenous species were not successful in establishing self-recruiting populations. In contrast, introduced exotic species such as Mozambique tilapia *(O. mossambicus)* and common carp were able to establish self-recruiting populations in almost all the lakes and have subsequently become the dominant species in their respective fisheries.

Due to their limited numbers, lakes are less significant in terms of fish production (except Tonle Sap Lake in Cambodia) and are not regularly stocked or enhanced. The stock enhancement of reservoirs is a major management strategy adopted for increasing fish production in these man-made waterbodies.

Table 6. Stock enhancement/introductions into Indonesian Lakes (extracted from Sarinita 1999)

Region/ Lake	Size (ha)	Species (Year introduced)	Re-stocked	Comments
Sumatera				
L. Toba	112 000	*Cyprinus carpio* (1905)	na[1]	Contributes about 2%
		Oreochromis mossambicus (1940s)	na	Dominant in the fishery
Sulawesi				
L. Tondano	5 600	*Trichopterus trichopterus* (1925) *C. carpio* *O. mossambicus*	na	Yields of 340 kg/ha/yr; *T. trichopterus* contributed about 10% to the yield but declined after the latter introductions
L. Limboto	7 000	*O. mossambicus* (1944)		30% of the yield (330 kg/ha/yr) in 1985-1991
L. Lindu	3 500	*O. mossambicus* (1950s)	na	Yields of 120 kg/ha/yr; contributes about 75-80% of the yield
L. Tempe	10 000 to 30 000	*Trichogaster pectoralis* (1937)	1940	Dominated the fishery until about 1948
		Clarias batrachus (1939)		Established
		H. temmincki (1925) *Barbonymus gonionotus* (1937)	Repeated since 1937	*H. temmincki* dominated the fishery for a few years but declined rapidly with the introduction and repeated stocking of *B. gonionotus,* which accounted for most of the production (900 kg/ha/yr); but since 1982 yields are about 600 kg/ha/yr
Irian Jaya				
L. Sentani	9 360	*Osphronemus gouramy* (1937) *T. pectoralis* (1937) *H. temmincki* (1937) *C. carpio* (1937) *O. mossambicus* (1951) *B. gonionotus* (1966)	1958 1951 na 1957 na na	Apart from *O. mossambicus,* other species have not established self-recruiting populations and do not contribute significantly to the fishery, which yields about 42 kg/ha/yr
L. Ayamaru	2 200	*O. gouramy* (1937) *T. pectoralis* (1937) *H. temmincki* (1937) *C. carpio* (1957)	na na na na	All introduced and/or translocated species, except *O. gouramy* are established in the Lake and *C. carpio* is the dominant species in the fishery (60%)

[1] na – not available.

The range of sizes of Asian reservoirs that are used for fishery activities requires that stock enhancement strategies of large (>600 ha), medium (<600 to >100 ha) and small (<100 ha) reservoirs are best considered separately. This is justified for the following reasons:

- The fisheries in large reservoirs in the region are usually “open access” and are not typically dependent upon stocking. These fisheries are based upon self-recruiting populations that may be “seeded” by stocking at irregular intervals.
- In small and medium reservoirs, the fisheries are almost always dependent on stocking, as natural recruitment is too small to sustain a fishery, even on a very small scale, and fishing pressure on the stocks is typically high.
- Fishery activities in small and medium reservoirs that are based entirely on a stocking and recapture strategy often also have well defined ownership. In such cases they are referred to as culture-based fisheries.

5. Stock enhancement of floodplain fisheries

Floodplains are seasonal wetlands formed by overspill of floodwaters from the rivers to which they are connected. Welcomme (2000) suggested that living aquatic resources in floodplain rivers have to be extremely robust, as they need to tolerate wide-ranging annual variations in the duration and extent of flooding, as well as being capable of surviving prolonged periods of drought. The natural productivity of floodplains is typically very high, and they act as nursery grounds for many riverine species. Indeed, some commercially important fishes such as indigenous minor cyprinids, catfishes etc. spawn in the floodplains. The importance of floodplains in the lifecycles of riverine fish has been comprehensively dealt with by Welcomme (1985, 2001) and others.

In Asia, significant stock enhancements of floodplains are restricted to Bangladesh and Myanmar. The floodplain fisheries in both countries are important not only from a fisheries production viewpoint, but also socio-economically, sustaining the livelihoods of large numbers of people. In Bangladesh, developments related to flood control and the related changes in habitat and inundation have resulted in declining natural recruitment of fish stocks and consequently, in reduced fish yields. Stock enhancement has been undertaken as a form of mitigation for this loss of natural recruitment. In some floodplains, sections may be completely cut off from the parental river by damming, thereby creating a perennial waterbody (this also happens naturally in the formation of oxbow lakes). Such waterbodies may not receive the same annual influx of nutrients from flooding, and the water regime comes under greater human control. Recruitment is also different, as the connectivity to the river is often lost and these fisheries are effectively culture-based fisheries (Section 8).

5.1 Bangladesh

Fish products account for 6 percent of the gross domestic product (GDP), 12 percent of export earnings and 70–85 percent of the animal protein intake in Bangladesh (De Graaf 2003). Freshwater fish account for more than 50 percent of dietary fish intake, and inland fisheries provide a source of employment to nearly 13 million people living in the floodplains.

Bangladesh, with a total area 143 998 km^2, is essentially a huge delta formed by three principal river systems, the Brahamaputra (Jamuna), the Ganges (Padma) and the Megna and their tributaries, with a combined watershed exceeding 1 million km^2. Bangladesh has no natural lakes and only one large inland waterbody, Kaptai Lake (58 300 ha), created by the damming of the Karnafuli River in 1961.

From about June to October, annual monsoon rains inundate approximately 2.83 million ha, resulting in vast floodplains that account for nearly 60 percent of all inland open waters in the country. These nutrient-rich floodplains provide a multitude of niches for aquatic organisms and are important as spawning and/or nursery grounds for many riverine fish species.

The annual floods fill relatively deep and large depressions in the floodplain, commonly referred to as “beels” and/or “haors”, which tend to be perennial waterbodies. The area of such beels (Plate 8) is estimated to be around 115 000 ha (Rahaman 1987). The size and other morphometric features of the beels vary greatly. As a result of the development of flood protection schemes, most of the beels are dyked and remain as separate entities, but may be connected through channels. In addition, the floodplain may be excavated by individuals, depending on land availability, to trap fish from the receding floods. These excavations are referred to as “kuas”.

Up to about the 1990s, river and floodplain fish production showed a decline, and the relative contribution of open-water fisheries to total inland fish production decreased from 63 percent in

Plate 8. (A) & (B) General views of two beels in Bangladesh. Note the large lift net set for catching young. Photos courtesy of Dr. M.R. Hassan

1983–1984 to 47 percent in 1995–1996 (Ahmed 1999). This decline in river and floodplain fisheries has been attributed to a number of causes, the most important being overfishing and reduction and modification of floodplain habitats resulting from developments for flood control. In an effort to reverse this decline, Bangladesh embarked on a stock enhancement strategy for the floodplains.

5.1.1 Stock enhancement of floodplains and beels

Stocking of the floodplains and beels was initiated in 1989 as donor-supported development programmes. The objective of these stock enhancement programmes was to increase fish production, provide employment opportunities and enhance the foodfish supplies to the large population living in the floodplains. In the very early stages, floodplains were stocked with 5-8 cm carp fingerlings, and although the impact of these stock enhancement attempts was not monitored, there were indications of increased fish production (Ali 1997). This initial encouraging result led to many donor-supported, controlled stock enhancement programmes to be undertaken as part of the First, Second and Third Fisheries Projects. No attempt will be made to summarize the results of each of these projects, but it is worth detailing some of the considerations that were attached to these programmes. It was considered that stock enhancement of the floodplains:

- would only be sustainable if the financial and economic rate of returns were not less than 25 and 12 percent, respectively;
- should improve the income of fishers in the floodplains;
- should permit genuine fishers greater access to the fishery;
- should create new employment opportunities related to producing seed stock, marketing etc., and encourage the involvement of the private sector in such activities;
- should induce changes in income distribution; and
- should assist in poverty alleviation of the floodplain community (Ali 1997).

In the following sections, the results of stock enhancement undertaken during the Third Fisheries Project will be presented, with a view to evaluating the outcome of the strategy adopted in Bangladesh.

5.1.2 Species used and production

The species stocked varied between floodplains. The typical stocking is shown in Table 7. The floodplains chosen were mostly dyked and consequently, there was minimal natural recruitment of Indian major carps. The details on stocking, which was done in incremental steps over a six-year period when a total of 149 500 ha (26 floodplains) was stocked with 2 524 tonnes of carp fingerlings, are given in Table 8. The species composition and the stocking densities to be used were based on the pilot study conducted in 1991/1992 (Table 8).

Table 7. Typical species stocked and their stocking proportions for enhancement of floodplain fisheries in Bangladesh. (data from Islam 1999)

Common name	Scientific name	Stocking proportion (percentage)
Silver carp	*Hypophthalmichthys molitrix*	0-5
Common carp	*Cyprinus carpio*	25-30
Rohu	*Labeo rohita*	16-30
Catla	*Catla catla*	20-29
Mrigal	*Cirrhinus cirrhosus*	9-16
Kalibous	*Labeo calbasu*	0-1.6
Java barb	*Barbonymus gonionotus*	10-13

The significant observations (Islam 1999) regarding the strategy adopted in the floodplains (beels) were:

- An incremental yield of 20 000 tonnes of stocked fish was obtained through the conservation measures introduced under the stocking programme (e.g. limitations on gear and effort during post-stocking).
- A concurrent increase in wild fish yield of 13 000 tonnes was obtained in individual floodplains. The yield ranged between 49 and 281 kg/ha, with an average of 241 kg/ha and an average incremental yield of 234 kg/ha.

According to Payne (1997), the total yield from the open floodplains ranged from 300–800 kg/ha, of which over 75 percent was wild fish. Payne (1997) also reports that although silver carp performed very poorly, common carp often performed well, with increments in excess of 30 times being achieved and individuals of 2 kg occurring in the catches after only four months in the floodplain. The relatively poor performance of silver carp (in contrast to that seen in oxbow lakes see Section 7) was attributed to poor phytoplankton biomass in the floodplain and this species' highly migratory behaviour.

5.1.3 Fingerling/seed supplies

The size of fingerlings at stocking ranged from 7 to 16 cm for the major carps and from 5 to 11 cm for Java barb. These sizes were determined as optimal and were also relatively easily to procure. Fingerlings required for stock enhancement of floodplains were procured in two ways. The most effective way was to use the beels in the floodplains as nurseries, which then automatically disperses the fingerlings when the beels connect with the floodplains during monsoonal flooding. It is believed that such fingerlings will survive better than those brought from elsewhere because they will be acclimated to the environment. An alternative source is hatchery-nursed fingerlings.

Table 8. Summary results of floodplain stocking in Bangladesh under the Third Fisheries Project (modified from Islam 1999)

	91-92	92-93	93-94	94-95	95-96	96-97	Total
Area (ha)	3 000	23 000	24 000	24 000	32 000	43 500	149 500
Fingerlings stocked							
Weight (tonnes)	73	392	418	418	596	628	2 524
kg/ha	24.3	17.0	17.4	17.4	18.6	14.4	16.9
Baseline yield (tonnes)							
Stocked species	6	184	184	195	130	282	979
Wild species	426	4 798	5 091	4 606	2 465	1 357	18 742
% stocked	1.4	3.7	3.5	4.1	5.0	17.2	5.0
Incremental yield (tonnes)							
Stocked species	688	504	2 700	3 988	5 093	6 280	19 254
Wild species	-19	630	2 983	2 390	2 628	4 005	12 617
% stocked		44.5	47.5	62.5	66.1	61.1	60.4
Production costs (Tk x 10^6)							
Fingerlings	4.7	34.8	52.1	41.5	56.4	48.7	238.2
Other	0.5	3.7	3.9	3.9	5.2	8.5	25.7
Total	5.2	38.5	56.0	45.4	61.6	57.2	263.9
Value of incremental production (Tk x 10^6)							
Stocked species	2.07	15.12	81.0	119.6	152.7	188.4	558.9
Wild species	-0.05	1.6	7.4	6.0	6.5	10.01	31.4
Total	2.0	16.7	88.4	125.6	159.2	198.4	590.3
Retrieval rate (%)	10	10	13	15	15	15	

Fish price per kg; stocked carps Tk 30, wild species Tk 25.
1 US$ = 48.36 Taka (1999)

Survival during the nursery stage in the beel is low, and overall, it is estimated that 10 percent of beel-reared stocks versus 25 percent of introduced seed stock are recoverable. The cost of seed stock is quite different, with beel-nursed fingerlings costing 0.78 Tk as compared to hatchery-nursed fingerlings costing 4.10 Tk. The floodplain stock enhancement programmes have resulted in an increased number of private hatcheries operated by local entrepreneurs, rather than increased employment of the poor. In the long term, the cost of fingerlings is expected to decrease and with flow-on, indirect benefits should accrue to floodplain fishers, which is essential in order to justify continued investment in the floodplain stock enhancement programmes.

5.1.4 Economic analysis

A number of economic analyses have been conducted on the stock enhancement of the floodplains in Bangladesh, in most instances using the same databases. The most comprehensive analysis, that of Islam (1999), is based on eight floodplains/beels (out of a total of 26 stocked during the period 1991–1997), which is purported to yield sufficient and statistically significant data. In this analysis, the rates of return were estimated for each beel for the duration of the trial and then projected over a 20-year period assuming there would not be any further stocking after 1996. The estimated returns ranged from 16 to 23 percent and 28 to 122 percent, respectively. The details on average costs and benefits for the eight beels are given in Table 9, and the losses in the initial four years are counted against the positive returns of the last two. The economic internal rate of return for the 20-year projected period was estimated to average 38 percent and that for the duration of the trial as 29.7 percent.

Table 9. Results of the economic analysis of floodplain stock enhancement of selected beels in Bangladesh. Stocking was completed in 1996, and the basis for the projections is given in the text (modified from Islam 1999)

Parameter	1991	1992	1993	1994	1995	1996	1997	20 year projected
Stocking								
Area stocked (ha)	3 700	13 200	14 700	22 200	14 200	22 200		22 200
Density (kg/ha)	20	19	17	19	19	15		16
Seed cost (Tk/kg)[1]	66	88	119	99	89	84		87
Incremental catch (tonnes) (a)[2]	0	695	511	2 181	4 373	3 339	3 708	4 117
Catch (kg/ha)	0	188	39	148	197	235	167	185
Avg. value (Tk/kg)		26	30	34	34	32	35	35
Costs (Tk x 1 000)								
Stocking	4 855	22 419	29 559	42 284	23 624	27 313		31 148
Fisher labour	634	5 696	8 645	10 991	9 922	11 591		11 591
Fishing equipment	912	8 731	13 458	18 167	14 688	20 026		20 026
Administration	2 065	9 557	14 263	18 012	11 799	17 430		17 430
Total financial (b)	8 666	46 403	65 927	89 466	59 936	76 360		80 195
Total economic (c)	7 366	39 442	56 036	76 046	50 947	64 906		68 166
Benefits (Tk x 1 000)								
Total financial (d)	0	18 086	15 676	73 659	150 336	107 970	128 931	142 369
Total economic (e)	0	15 373	13 239	62 610	1 277 877	91 775	109 591	121 014
Net economic (f)	(7 366)	(24 069)	(13 436)	76 840	26 868	41 426	52 848	52 848

[1] Tk 42 020 000 = US$ 1 million in 1996 prices; economic internal rate of return: 29.7%.

[2] d = a (avg. value per kg); c = 85% of b; f = 85% of e; d is based on incremental catch value.

5.1.5 Administrative arrangements/management of stock-enhanced fisheries

The majority of floodplains in Bangladesh are government owned, but portions of the plains may be owned by individuals. In view of the importance of the floodplain fisheries to the national economy and in providing employment, many changes in management have taken place over the years. The effective introduction of management measures is further complicated by the social hierarchies based on caste and religion that exist in Bangladesh. For example, the bulk of fishers were purported to be “low-caste” Hindus, and in general, irrespective of caste etc., fishers represent one of the poorer parts of the community.

The major changes in floodplain fisheries management that have been introduced over the years, with the primary aim of increasing fish production and attaining equity, as far as possible, among the fishers can be summarized as follows:

- From 1950–1986, waterbodies were leased to the highest bidder, conferring a fixed-term property right to the lessee. The lessee, in turn, collected tax from fishers to cover the lease cost and accrue a profit. This process resulted in a relatively high degree of exploitation of fishers.
- In the mid-1960s, preference to lease was given to cooperatives, but this was not entirely effective, as the same group of individuals controlled both the cooperatives and the fishery.
- In 1986, the new Fisheries Management Policy was introduced, with the management being handed over to the Department of Fisheries, which in turn introduced a licensing system to “genuine fishers” specific to the gear used and the waterbody.

- In 1995, leasing was abolished (this was done independently by the Ministry of Land). At present, there is free access, leasing to powerful individuals, leasing to fisher cooperatives and administration by the Department of Fisheries of certain waterbodies (Thompson and Hossain 1997).

5.1.6 Socio-economic impacts

A total of 85 000 fisher households benefited from the stock enhancement programme. This total comprised 22 percent full-time, 28 percent part-time and 50 percent subsistence fishers (Islam 1999). A summary of the socio-economic benefits emanating from stock enhancement in three floodplains is given in Table 10. It is evident from the data that all the indices considered were positively impacted during the post-stocking period, although to varying degrees. The greatest observed impact in all three floodplains was on fishing income. Such increases in household income through fishing are also considered to impact positively families indirectly and potentially, result in longer-term benefits. Based on these criteria, the official assessment was that stock enhancement could potentially lead to an improved quality of life for fisher households.

In contrast to the assumption that the increased income was an overall benefit, the perceptions of the fishers regarding the benefits of stock enhancement varied considerably (Table 11). In general, fishers/owners of fish aggregating devices and kuas (ditches) in the floodplains benefited the most.

Table 10. Economic impact of stock enhancement of floodplains on fishers, based on pre- and post-stocking over the six-year period 1991 to 1996 (modified from Islam 1999)

Indicator Assets (Tk/houshold)		Floodplain		
		Chanda	BSKB	Halti
Land	Pre-enhancement	60 688	72 644	121 893
	Post-enhancement	63 020	83 548	128 571
	% increase	**4**	**14**	**5**
Housing related	Pre-enhancement	11 570	10 361	1 877
	Post-enhancement	12 487	11 579	11 176
	% increase	**7**	**11**	**2**
Fishing rights	Pre-enhancement	3 881	5 209	3 698
	Post-enhancement	7 946	6 026	3 967
	% increase	**104**	**15**	**7**
Movables	Pre-enhancement	2 800	3 016	4 580
	Post-enhancement	3 451	4 023	5 210
	% increase	**23**	**33**	**13**
Fishing gear	Pre-enhancement	1 896	1 316	1 239
	Post-enhancement	2 100	1 346	1 275
	% increase	**10**	**2**	**3**
Livestock	Pre-enhancement	4 678	5 086	4 441
	Post-enhancement	6 138	5 136	4 991
	% increase	**31**	**1**	**12**
Fishing income	Pre-enhancement	1 126	2 822	2 763
	Post-enhancement	7 324	5 810	6 843
	% increase	**550**	**105**	**147**
Per caput consumption day (g)	Pre-enhancement	20.3	5.6	8.7
	Post-enhancement	48.8	18.1	24.8
	% increase	**140**	**222**	**180**

Average number of people per household was 6.1; All values in 1994 Taka.

Table 11. A summary of measurable impacts on households (%) and perceived impacts of stock enhancement on fishing communities in southwestern Bangladesh (based on data from Nabi 1999)

Beels/fisher type	Increased		No impact	Loss attributed
	Income	Consumption		
Stocked normal beels				
Professional, traditional[1]	68	9	22	21
Professional, non-traditional	79	10	16	16
Casual, marginal	42	48	16	10
Casual, non-marginal	15	61	14	6
Stocked waterlogged beels				
Professional, traditional	45	2	28	38
Professional, non-traditional	83	6	15	13
Casual, marginal	48	40	15	0
Casual, non-marginal	39	70	6	8

[1] Professional, traditional – have been dependent on fishing at least for two generations; casual, marginal – households owning <0.2 ha of land and dependent on fishing as the primary source of income.

This group was then followed by professional fishers, with minimum benefits accruing to casual, marginal fishers. The benefits from the fishery were also linked to conflicts between fishers and landowners. In waterlogged beels, 30 percent of traditional fishers believed there was no benefit, and a further 40 percent reckoned that there was actually a loss attributable to stocking (Nabi 1999). In conclusion, there was no universal agreement that stock enhancement was beneficial to all fishers, and the complex social interactions within the fishery had a strong impact in the way that the benefits of stock enhancement were distributed.

On the basis of the available information, it appears that enhancement has worked against the interest of the poorest fishers, and that it may, in effect, bring about negative impacts and the exclusion or marginalization of poor fishers from a waterbody. According to Thompson and Hossain (1997), the existing distribution of benefits from open-water fisheries reflect the local power structure, the property rights on the individual fishery and the pattern of ownership of the means of production. These authors argued that the same factors would determine the likely beneficiaries with a change in management system, including stock enhancement.

Toufique (1999) dealt with the pros and cons of the changing regulations and the reasons why the intended objectives of the administrators/government have not been realized. He considered why the "true fishers" have not been able to embrace fully the changes and why they have not benefited from the changes made. To date, most of the stock enhancement programmes that have been carried out have been attempted under co-management strategies that have not adequately taken into account social factors and access rights. A prerequisite for the effective co-management of individual fisheries of each waterbody is that fishers hold property rights over the fishery resources, which has yet to become a reality (Toufique 1999). Further, success in development of these enhancement programmes and their sustainability depend upon:

- resolving issues on property rights of the fishery resources;
- increasing the degree of involvement of fishers and other stakeholders in determining suitable management strategies for individual waterbodies;
- enhancing fishers' perceptions on the positive impacts of stock enhancement; and
- enhancing appreciation among the major stakeholders of the value of maintaining habitat integrity.

5.2 Myanmar

The total reported fish production of Myanmar in 2001 was 1 283 490 tonnes, of which inland capture fisheries, the sector considered to have the highest potential for development, accounted for 18.4 percent. Fish is the main source of animal protein for the people of Myanmar, with an average consumption of 22.7 kg/caput/yr, and is particularly important in the rural areas. Overall fish consumption in Myanmar is believed to be grossly under-estimated, and it has been suggested that consumption could range between 26-34 kg/caput/yr (FAO 2003). Myanmar has four large river systems: the Ayeyarwaddy (Irrawaddy, 2 150 km), the Chindwin (a major tributary of the Irrawaddy, 844 km), the Sittaung (563 km) and the Thanlwin (2 400 km), as well as a small section of the Mekong River and associated large floodplains (estimated total area 8.1 million ha).

Most of the inland fisheries in Myanmar are covered by a traditional leasable fishery type administrative structure known as an "inn". These were the subject of a monograph by Khin (1948), which is paraphrased below. The leasable fisheries (inn leasable fisheries) of Myanmar have a long history and were originally (pre-1864) hereditary properties based upon fixed rents. Under the Burma Fishery Act (1864), the leasable fisheries passed from the ownership of individuals into state control. This was considered necessary at the time so that the leasable fisheries could be effectively administered. There were continuing problems with the effective administration of the leasable fisheries that resulted in the investigation of the fisheries and related problems by Colonel Maxwell in 1895 and culminated in the Burma Fishery Act (III) in 1905, which contained a number of recommendations from the investigation. These covered:

- conservation of fisheries resources;
- prevention of deterioration of fisheries by siltation; and
- modification of the inter-relations between fisheries lessees and the relationship between government and the lessees.

- ***Conservation***

The recommendations of the investigation were the subject of dispute, especially those regarding the creation of "reserves". The reserves were places where fishing was prohibited, except for the taking of predatory fish. These sites were intended to be "an annual source of natural stock for replenishing leased fisheries". At the time, the discussion related to the perception that overfishing was not apparent and that revenues from the fisheries were in fact increasing, indicating that catches were increasing (although this was misguided, as prices were increasing and therefore, actual catch may not have been). Similarly, increasing consumption was attributed to greater access to the marine fishery catch due to improvements in transportation and preservation, rather than inland fisheries improvement. There was still no evidence, however, that the inland fisheries catch was actually declining. As a result, the reserves degenerated into open-access fisheries, thereby denying the government revenue. The fishing methods were, in some cases, the same as those employed when the fisheries were leased, however, there was a range of prohibited fishing methods and there were certain restrictions that related to migrations of fish.

- ***Prevention of deterioration by siltation***

This recommendation related primarily to the avoidance of bunding of rivers and streams in order to prevent siltation of water courses. It was also suggested that "weed clearing of stream beds and afforestation of waste lands in the catchment be organized".

- ***Modification of relationships***

The relationship between lessees in the deltaic areas was problematic when dealing with common stocks and the network of streams and flooded areas, and the study essentially recommended that "custom" should prevail.

The change from "hereditary property on fixed rents" to the allotting of leases "by favour or by lots at very moderate rent" that occurred in the early days of British rule had several effects. The income that could be generated from the lots led to competition for the leases, and there was subsequent problems in the transparency of the allotment process. As a result, the auction system was introduced. This led to a great increase in fishery revenues and "gambling bids", and auction prices increased greatly around 1900. An additional effect was the subdividing fisheries leases, as the administration of the time focussed on trying to increase this revenue. To reduce the effect of the auction system and increasing bids, an annual lease was imposed, but the short-term nature of the leases meant that lessees had little incentive to reinvest or conserve stocks and encouraged the maximization of the catch.

In 1918, there was an attempt to introduce a system of leasing fisheries to "cooperative groups of fishermen", but this was found to be "unworkable". In 1926, the introduction of "fair rents" was aimed at controlling this process, but the establishment of a "fair rent" for a fishery that varied hugely every year in terms of impacts of flooding and production also proved unworkable. While the annual lease led to over-exploitation and a short-term outlook by the lessees, a long-term lease also led to the lessees making good money in good fishing years and then defaulting on their lease payments during a bad year.

Prior to Second World War, there were 4 006 inn-leasable fisheries, but post-war this had declined to 3 710. By 1948, although there was still no settlement on the best system for issuing of leases for leasable fisheries, a pragmatic policy was in place that prescribed a number of alternative methods:

- public auction or public sale by diminishing offers;
- invitation to tenders;
- extension of existing leases; and
- provision for the Deputy Commissioner to grant leases of up to five years for "fisheries of a fairly constant value".

The conclusion was that the management suggestions made by Maxwell were too theoretical and were contrary to the pragmatic system of management that was employed, and that further investigation and development of sound legislation coupled to an efficient fishery administration were required.

By 1999, the number of leasable fisheries had further reduced to 3 474, with some of the leasable fisheries sites being converted to agriculture. If the agriculture subsequently failed, the land essentially becomes an "open fishery" or available for exploitation by local business interests. According to the Department of Fisheries (DoF), there are currently (2002) 3 722 such floodplain leases in Myanmar, of which 3 490 are still exploitable. Of the exploitable floodplain fisheries, 52.3 percent are located in the Ayeyarwaddy system, which has a discharge of 13 500 m^3/sec and a catchment of 424 000 km^2 (Welcomme 1985). These lease fisheries operate through the erection of barrage fences around the lease area, which retains the fish as they grow on the floodplain food resources. Over the years, some of these lease fisheries have been developed into permanent waterbodies through the construction of dams or dikes (Plate 9). The resulting fisheries in these waters are based on both naturally recruited and introduced stocks.

5.2.1 Stock enhancement of floodplain fisheries

Stock enhancement strategies, where adopted, vary significantly among the different waterbodies. The three examples presented in this section are considered to be representative of the floodplain fishery practices in Myanmar related to managed leasable fisheries (inns).

- ***The lease fishery managed by U Thin Mynt***

Approximately 10 km south of Mandalay is a good example of an inn-lease fishery that has been recently developed through stock enhancement. The total area when flooded is approximately 220 ha (Plate 9), which now includes a diked area of approximately 4 ha of water. The dike is used for nursing fry of the stocked species (common carp, bighead carp and silver carp) to fingerling size. In a typical year, about 800 000 fry are purchased from a hatchery in April and stocked in the diked |area. The nursery pond is given supplemental feeding. During the monsoonal season, as the water floods the lease fishery, the fingerlings are released to the open water.

Plate 9. Two different types of leases in the floodplains of Myanmar; (A) a non-perennial floodplain lease in south Mandalay; in the foregroud is a pond created by an embankments for rearing of fry and fingerlings to be be released with the floods, and (B) a large perennial water body in the floodplains (Thaung Tha Ma; 600 ha) in the process of being fished. The latter has been dyked and consequently the water body is perennial

Harvesting commences from about early December as the flood recedes, and in a good year this inn yields up to 150 tonnes (approximately 682 kg/ha/yr). The average weight of common carp at harvest is 1.5 kg, and bighead carp of up to 10 kg may be caught. Naturally recruited species, mainly minor cyprinids and catfishes (*Mystus* spp.) account for about 20-25 percent of the total yield. The fishery and associated activities (agriculture in the floodplain in the dry season etc.) are managed by 40 families, all of whom live on-site.

- ***Kan Daw Gyi lease fishery***

The current lessee commenced management of this peri-urban fishery in 1990 when stock enhance-ment was not practiced and the yield was entirely dependent on natural recruitment. Stock enhancement commenced with a general clean up of the waterbody and the introduction of netpens in 1995/1996, and the area under pen culture increased from 4 to 40 ha in the space of three

Plate 10. (A) The day's landings of tilapia *(O. niloticus),* one of the main constituent species, of the Thaung Tha Ma leasable fishery, and (B) the women folk, drawn from the village, purchasing their quota of fish (15 to 20 kg per individual vendor) for sale in the village

years. Subsequent local-authority regulations banned netpen cages and the lessee converted the inn into a perennial waterbody by building a dike. At the same time, the lessee commenced stock enhancement.

Currently, the waterbody is stocked annually with 2–3 million fingerlings of common carp, bighead carp and silver carp, and 500 000-600 000 grown animals are fished annually, the average weights ranging from 1.5-2.0, 5 and 3-4 kg, respectively. The operations are run through a tightly knit unit comprised of a fishing team and hatchery and feed technicians. The stock is fed three times each day. Fish kills have occurred on two occasions in the last five years, probably as a consequence of heavy feeding exacerbated by sewage runoff from the surrounding urban area.

- ***Thaung Tha Ma lease fishery***

This lease fishery involves a 600 ha perennial waterbody that still maintains a connection to the river through the construction of a weir. The fishery was initially based on stock enhancement using rohu, mrigal, bighead and common carp, and naturally recruited species, which accounted for about 35 percent of the yield. However, over the last three to four years there has been a major change in the fishery, and it is currently based primarily on seeding/self-recruitment of Nile tilapia *(Oreochromis niloticus)* accompanied by enhancement with rohu. The latter are mostly reared in dyked ponds at the leeward portion of the waterbody, and are supplemented by natural recruitment of the species from the river. Nile tilapia account for about 60 percent of the current production, the landing size ranging from 400–600 g.

Fishing is done by men drawn from the surrounding villages who work in teams, except from June to September, and the catches are landed at one of the four landing sites. The daily catch ranges from 5 to 10 tonnes, and accordingly, the annual productivity of this waterbody is estimated to be about 2 800 kg/ha/yr. The day's catch is purchased by the lessee and/or his agents, at a price lower than the existing market price. The landings are then sold to womenfolk of the villages (Plate 10), each being allocated a quota of 15 to 20 kg, depending on the quantity landed. These women, in turn, then take their allocated quota of fish to the adjacent village markets or move from house to house selling fish, with a modest mark up of about 15-20 percent. For example, Nile tilapia is sold to the women vendors at 400 Kyats/kg and they in turn sell to the consumer at about 480 Kyats/kg (850 Kyats = 1 US$).

The fishing operations and the marketing are well organized, and there appears to be extensive community involvement in both processes. The lessee has designated areas identified as tilapia breeding grounds, and these are no-fishing zones. Illegal fishing is minimized by involving the villages surrounding the inn in the fishing and marketing of the product. Employees of the lessee also monitor potential illegal fishing. One other management strategy that is adopted is feeding during the flood recession, which is purported to prevent or discourage fish from migrating back into the river.

Plate 11. An artisanal fisher in the Thaung Tha Ma leasable fishery with a catch of naturalluy recruited species (mostly small sized cyprinids)

Unlike in the fishery of Kan Daw Gyi lease, this fishery, by virtue of the fact that it maintains its connection with the river and the rest of the floodplain, experiences significant recruitment of small-sized fish, mostly cyprinids. The lessee sub-contracts artisanal fishers (Plate 11) to exploit this resource on a profit-sharing basis, and as such, permits a few fishers to be employed. These catches are sold fresh and/or processed into fish sauces and pastes.

Although this fishery is effectively controlled by a single lessee, it is an excellent example of how broader community involvement can be achieved through provision of employment and income generation opportunities. Approximately 5 000 persons drawn from 12 adjacent villages are estimated to benefit directly from this stock-enhanced fishery. Apart from direct monetary benefits to individual families and their livelihoods, there are other flow-on indirect benefits to the community. The lessee claims to contribute to local village events, thereby reinforcing the legitimacy of his control over the fishery with the villagers.

5.2.2 Fingerling supplies

In Myanmar, production of seed stock is mostly carried out in government hatcheries, with very few inn fisheries having their own hatcheries. The establishment of small “backyard” hatcheries is being encouraged by the government, mostly to meet the increasing demand for fry and fingerlings for pond culture, although they can also supply fry to the lease fisheries (Plate 12). Generally, the demand for fingerlings for the inn fisheries stocking means that large quantities of fry are produced and then nursed to fingerling size (see Plate 10) in a diked area of the lease.

5.2.3 General observations

The stock enhancement system of floodplain fisheries in Myanmar is quite different to that in Bangladesh. The examples presented above clearly indicate that in Myanmar, enhancement of fisheries is essentially a culture-based system, with well-defined ownership of the stock. The enhancement may not always be effective, as stocking of the inn fisheries is also partly a requirement for the continuing extension of the lease. This means that the principal purpose of the restocking is

Plate 12. (A) A small “back yard” hatchery in Mandalay District, Myanmar, and (B) homestead broodstock ponds of Indian major carps

to ensure lease extension rather than yield improvement. The result is that the contribution of the enhancement to the overall yield of the inn may not be that significant.

Unlike in Bangladesh, individual fisheries are not co-managed, and access is controlled by the lessee. In spite of these differences, there are many direct beneficiaries from the individual fisheries, and perhaps more involvement of fishers in the activities of the inn fisheries in Myanmar as compared to Bangladesh. It is quite evident that the greatest beneficiary of the Myanmar inn fisheries is the lessee of each fishery, as much as the main creditor to the fishers is the main beneficiary in the Bangladesh situation (Toufique 1999). More importantly, the differences in access to the benefits reflect the cultural and traditional differences prevalent in the two countries. In Myanmar, there is currently no explicit attempt to change the existing system of leasing of floodplain inns. This is partly due to the ease of revenue generation for the state under the existing system, as well as the inevitable restriction on access that the lessees place on their individual inns. Since these two objectives are principle goals of most inland fishery management schemes, it could be said that the existing leasable fishery system in Myanmar is relatively sustainable from the perspective of biological yield. The equitable distribution of the benefits of these fisheries is no more questionable, due to access limitations and the transparency of the auction and lease extension process.

Unfortunately, there has not yet been any rigorous evaluation of the impact of enhancements or a cost-benefit analysis of stock enhancement of floodplain fisheries. Such a study, coupled with an appropriate analysis of the socio-economic impacts of the existing system of management of the leasable fisheries, would be highly desirable, as it is quite a unique system.

The management interventions, costs incurred on some items, estimated production and the value of production of the example three stock-enhanced fisheries in Myanmar are summarized in Table 12. The leases of the three fisheries have been in effect for eight to nine years without a change of the lessees. Perhaps this is a very good indication that the fisheries are profitable to the lessees. If not, one would expect a change in the lease, especially taking into account that the lease value of all leases has increased over the years. The issue of lease duration also confronts any system of management. Since leases that are issued annually tend to result in maximal extraction with no re-investment, longer-term leases are considered to be an incentive for lessees to reinvest in their operation in activities such as habitat restoration/maintenance and stock enhancement.

Table 12. A summary description of the three stock enhanced floodplain (lease) fisheries in Mandalay District, Myanmar (FAO 2004, all information based on interviews and should be considered approximate). (Market exchange rate in April 2003: 850 Kyats = 1 US$)

South Mandalay (222 ha)		
Continuous lease (yrs)	8	• Small seasonally flooded area • Agricultural/in the dry season • Fry nursed in dyked area • Supplementary feed used • Fingerlings released into the flooded area • Main stocked fish – common carp • Harvesting & marketing fish • Guarding/patrolling the lease • 40 families involved in activities
Lease cost (Kyats/yr)	1st yr: 17 000 8th yr: 500 000	
Feed fed (tonnes/yr)	4	
Feed cost (Kyats/yr)	740 000	
Production weight (tonnes/yr)	151 (680 kg/ha) Poor season: 100 (450 kg/ha)	
Production value (US$)	$30 000	
Kan Daw Gyi (300 ha)		
Continuous lease (yrs)	9	• Permanent waterbody • Area increased from about 40 ha initially • Receives urban run off; appears to be very eutrophic • Stock advanced fingerlings of Chinese & Indian major carps, approximately $2\text{-}3 \times 10^6$ • Own hatchery & feed mill • Intensively fed • Netting/feeding crew
Lease cost (Kyats/yr)	45 000	
Feed fed (tonnes/yr)	~1 095 (3 tonnes/day)	
Feed cost (Kyats/yr)	~ 480 000 000	
Production weight (tonnes/yr)	1 260 (4 200 kg/ha)	
Production value (US$)	$630 000	
Thaung Tha Ma (600 ha)		
Continuous lease (yrs)	9	• Permanent waterbody with connection to the river • Stocking of 1×10^6/yr • Introduced Nile tilapia, the mainstay of the current fishery • Tilapia breeding grounds protected • Two fisher teams harvest; paid 20% of catch; four landing sites • Closed season – June to Sept. • Marketing done through village womenfolk; each a quota of 15-20 kg/day • A few artisanal fishers permitted to use small gear; catches mainly naturally recruited riverine species • A large number of villages involved in operations & estimated 5 000 direct beneficiaries
Lease cost (Kyats/yr)	5 000 000	
Feed fed (tonnes/yr)	Some seasonally	
Feed cost (Kyats/yr)	12 000 000	
Production weight (tonnes/yr)	1 680 (2 800 kg/ha)	
Production value (US$)	$840 000	

6. Stock enhancement practices in large lakes and reservoirs

It was noted in Section 2 that the majority of the lacustrine water resources in Asia are man-made lakes or reservoirs, and that there are relatively few natural lakes. In this section, stock-enhanced fisheries in large lakes and reservoirs in the region are considered. This will be dealt with on a by-country basis, followed by an evaluation of the general issues pertaining to stock-enhanced fisheries in large lacustrine waters in the region. "Large lacustrine waters" refers to lacustrine waterbodies that have a surface area larger than 1 000 ha. While this is a subjective classification, in can be generalized that smaller waterbodies tend to have some form of ownership or rights attached to their fisheries. In contrast, large lacustrine waterbodies in Asia are typically open access. This basic difference has a strong influence on the sort of strategy that can be used to enhance fish yields, and the overall yield that can be expected. Also, there is a significant difference in how revenue is generated and the type of fishers that utilize the resource.

6.1 Bangladesh

Bangladesh has no natural lakes and only one reservoir – Kaptai Lake (58 300 ha), impounded primarily for hydroelectricity generation in 1961. The fishery has developed since about 1965, and yields ranging from 55 to 113 kg/ha/yr with a mean of 80.0±17.3 kg/ha/yr for the period 1986–1999 having been reported (Halder *et al*. 2002). This reservoir has witnessed many changes in the commercial landings over the last four decades. Currently, a small pelagic clupeid, the Ganges River sprat *(Corica soborna),* dominates the fishery, accounting for about 60 percent of the landings (Ahmed *et al*. 2001).

The reservoir was stocked with Indian major carps immediately after impoundment, and thereafter at regular intervals. Stocking of Indian major carps has intensified since about 1985 (Halder *et al*. 2002). Between 1981 and 1985, 1.6 million fingerlings of common carp (686 550), silver carp (914 142) and grass carp (7 216) were stocked with a view to filling vacant food niches (Halder *et al*. 2002). Although, in the initial years following impoundment, the Indian major carps accounted for 50 to 80 percent of the landings, the contribution of stocked fish to the fishery has been less than 5 percent over the past three decades. Ahmed *et al*. (2001) reported a negative correlation between the amount stocked and the amount caught, and that this correlation increased further when the moving average for stocked fish was used. These authors suggested that stocking of major carps in Kaptai Lake has been both unproductive and uneconomical. The above observations also conform to the findings of Halder *et al*. (2002). The former authors attempted to evaluate the reasons for the lack of apparent positive impact of stocking on fish yield, among which were:

- indiscriminate fishing and overfishing resulting in stocked fingerlings being fished early;
- the inability of the stocked species to establish breeding populations in the reservoir; and
- a general deterioration of the reservoir habitats through siltation etc.

The experience from Kaptai Lake favours the contention that stock enhancement of large lacustrine waters based on species that are unlikely to establish breeding populations and thereby contribute to yearly self-recruitment is unlikely to be viable or economical. Major carps, both Chinese and Indian, need very specific riverine conditions to breed. These conditions are highly unlikely to be encountered in lacustrine waters, except in one or two very rare instances (see Section 6.6.2). The general consequences of this biological trait of Chinese carps and its impact on stock enhancement in lacustrine waters will be dealt with in Section 6.6.2.

6.2 India

India has vast areas of lacustrine waters, the great bulk of which are man-made except for a few natural lakes in the high elevations in the north. The latter are of marginal importance from the viewpoint of foodfish production, being used primarily for recreational fisheries for exotic salmonids and indigenous *Tor* spp. On the other hand, the vast hectarage of reservoirs in India constitutes the main lacustrine resources utilized for foodfish production.

In India, reservoirs are classified as small (0–1 000 ha), medium (1 001–5 000 ha) or large (>5 000 ha). The estimated hectarage of each type is 1 484 557 (n = 19 134), 527 541 (n = 180) and 1 140 268 (n = 56), respectively (Sugunan 1995). The distribution of Indian reservoirs varies greatly between states. The largest number and hectarage of small reservoirs occurs in the southern state of Tamil Nadu, whereas the greatest area of large reservoirs is in the southeastern state of Andhra Pradesh. In this section, only the stock enhancement fisheries of medium and large-sized reservoirs will be considered, and that of small reservoirs will be dealt with in Section 8.

6.2.1 Inland fisheries

Inland fisheries in India contribute about 27% of the availability of freshwater fish in the country (Figure 6). The inland capture fisheries in India contribute about 13 percent to the total Asian inland capture fishery (Figure 8), and are thus a significant contributor to Asian inland fisheries. On the other hand, the inland fishery in India contributes about 21 percent to the country's overall fish landings from capture fisheries (Figure 9). More importantly, the contribution of inland fisheries to total landings has been increasing over the years, albeit slowly. The yield from inland capture fisheries has nearly doubled in the between 1992 and 2003 (from 373 287 to 777 273 tonnes). This

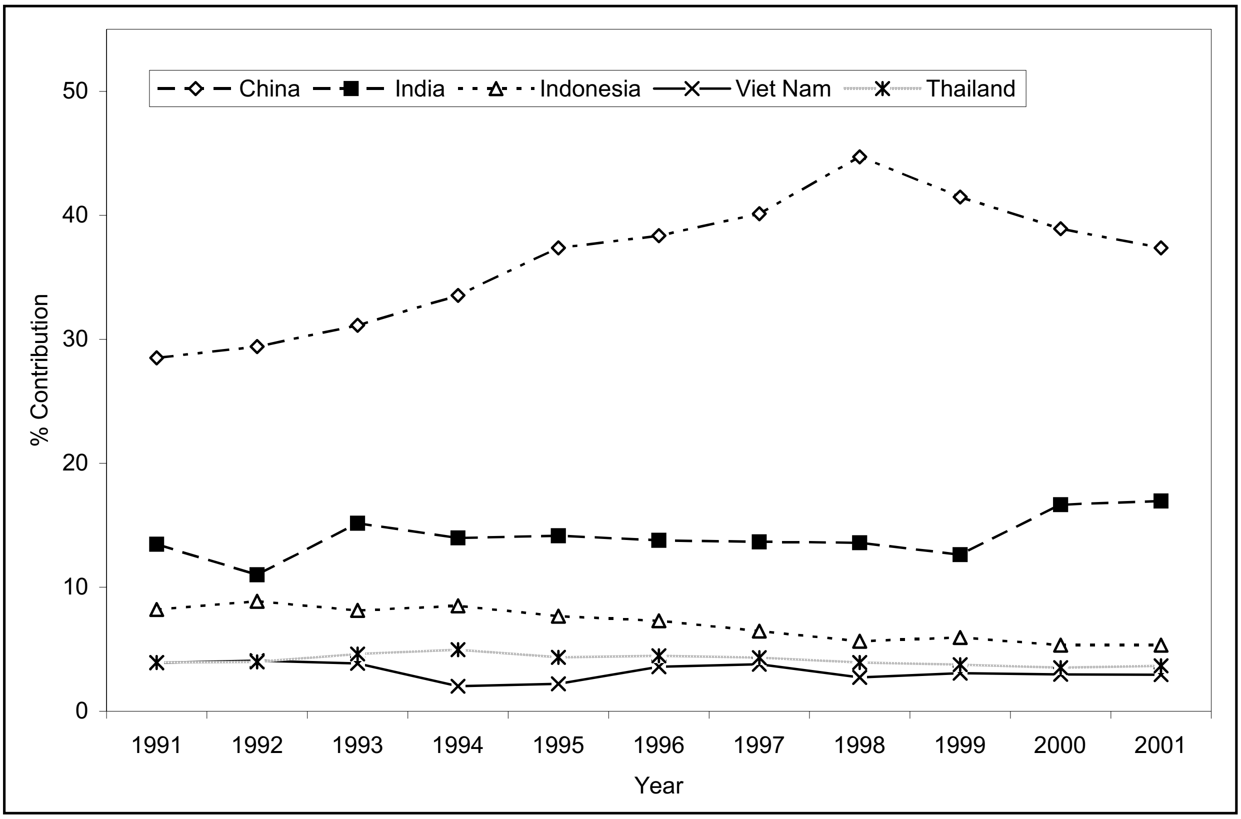

Figure 8. The percent yearly contribution of inland capture fishery of selected countries (PR China, India, Indonesia and Viet Nam) to the total Asian capture fishery production between 1991 to 2001 (based on FAO Statistics, 2003)

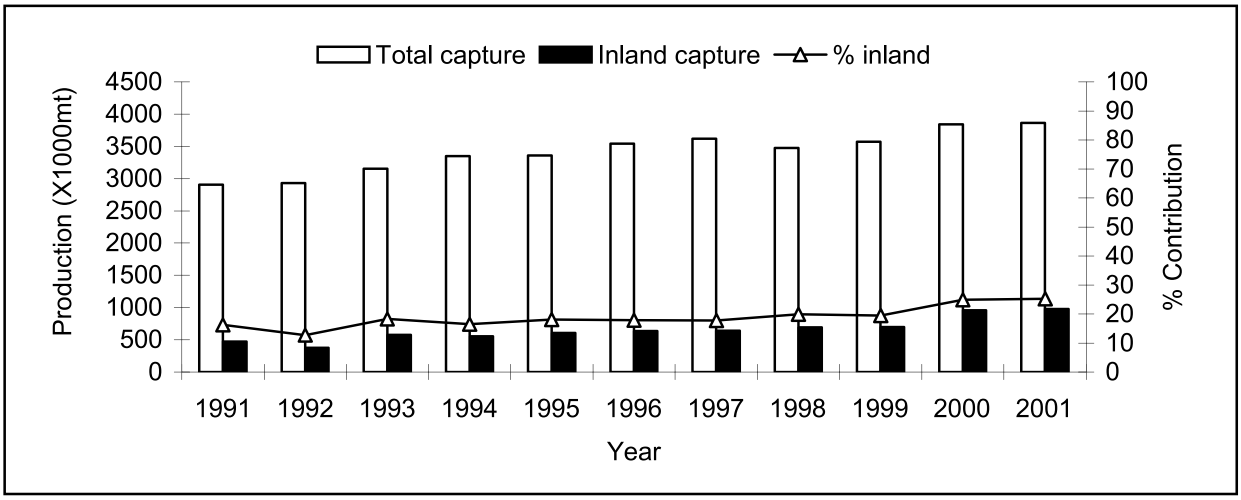

Figure 9. The overall capture fishery and inland capture fishery production between 1991 to 2001, in India, and the percent contribution of the inland capture fishery yield to the latter

increase in production has occurred despite the virtual collapse of some fisheries, such as those based on diadromous species such hilsa (*Tenulosa* spp.). The collapse of the hilsa fisheries is considered to be due to the damming of major rivers and general habitat degradation. It is also generally agreed that most riverine fisheries (e.g. those for Indian major carps) have declined considerably over the last two decades. Although, based on currently available data, it is impossible to separate accurately the contribution of the different habitats or waters to inland fisheries production, a conservative estimate is that the country's lacustrine waters, primarily the reservoirs, contribute in excess of 30 percent of this total.

Sugunan (1995) recognized the deficiency in data collation on catches and related effort in reservoir fisheries in India and suggested that this is the weakest link in the database on reservoirs in India. The difficulties on data collation for reservoir fisheries, according to Sugunan (1995), were primarily due to:

- the multiplicity of agencies owning fishing rights that pose difficulties for state agencies to gather data;
- highly scattered and unorganized market channels, which are mostly controlled by illegal money lenders who are reluctant to provide information to state authorities;
- ineffective fisher cooperative arrangements;
- the diverse licensing/royalty/crop sharing systems practiced by different state governments, which provide little scope for catch data gathering; and
- inadequate and poorly trained manpower that is incapable of following statistically valid sampling procedures.

It has been pointed out on many occasions that the estimated fish production in medium and large reservoirs in India is generally far below the average production observed elsewhere in Asia in comparative climatic regimes (De Silva 2000). For example, the annual mean fish production in medium and large-sized reservoirs was 12.3 and 11.4 kg/ha/yr, respectively (Table 13) (Sugunan 1995). The complexity of the problem is evident when one considers the productivity of some large reservoirs. The fish yield in the large Tungabhadra Reservoir (37 418 ha), impounded in 1953, was estimated to range from 91 to 185 kg/ha/yr (mean of 136) in the period 1980–1987 (Singit *et al.* 1988), which was far above the national average. Although this reservoir is an exception, it is certainly indicative of the potential that could be achieved.

Table 13. Fish production in selected reservoirs in India (modified from Sugunan 1995)

State	Medium-sized reservoirs			Large reservoirs		
	Number	Production (tonnes)	Yield (kg/ha/yr)	Number	Production (tonnes)	Yield (kg/ha/yr)
Tamil Nadu	8	269	13.7	2	294	12.7
Uttar Pradesh	13	156	7.2	1	50	1.1
Andhra Pradesh	29	1 306	22.0	3	800	16.8
Maharashtra	12	314	11.8	4	794	9.3
Rajasthan	17	600	24.5	2	120	5.3
Kerala	2	17	4.8	–	–	–
Bihar	3	7	1.9	1	0.8	0.1
Madya Pradesh	20	625	12.0	3	1 184	14.5
Himachal Pradesh	–	–	–	2	1 453	35.6
Orissa	6	163	12.8	3	925	7.6

The current low levels of fish production have been attributed to ineffective management and poor enforcement of regulatory measures. Despite this, the enhancement of stocks in medium and large reservoirs is one of the strategies adopted to increase fish production for these reservoirs and has been practiced for a considerable length of time.

The major species assemblages of the reservoir fisheries in India are categorized as follows:

- the Indian major carps (e.g. *Labeo rohita, Catla catla, Cirrhinus cirrhosus*);
- the mahseers (e.g. *Tor* spp.);
- the minor carps (e.g. *Puntius* spp.);
- large catfishes (e.g. *Pangasius hypophthalmus*);
- featherbacks (e.g. *Notopterus* spp.);
- air-breathing catfishes (e.g. *Heteropneustes fossilis*);
- murrels or snakeheads (e.g. *Channa* spp.);
- weed fishes (generally of low commercial value, e.g. *Ambassis* spp.); and
- exotic species (e.g. *Oreochromis* spp., Chinese major carps).

6.2.2 Stock enhancement strategies

Almost all stock enhancement strategies in Indian reservoirs have been based upon the Indian major carps or the major Indo-Gangetic carps, viz. *Labeo rohita, L. calbasu, L. fimbriatus, Cirrhinus cirrhosus* and *Catla catla*. Occasionally these species have been supplemented with minor carps such as *L. bata*, *Barbodes sarana* etc. and catfish species.

Although isolated stock enhancement practices in Indian reservoirs have often been cited in the literature, regrettably, no concerted attempt has been made to evaluate critically the impact of these practices. Indeed, the present authors were unable to find any information on cost-benefit effects for any of the stocking practices with reference to even a single reservoir in India. For this review, an attempt is made to determine the effectiveness of stocking in a group of reservoirs for which data were available for more than five years (Table 14), using the published data of Sugunan (1995).

Table 14. Stocking and yield data on selected reservoirs in India. The statistical relationships indicate the relationship between the numbers stocked per ha (x) and the yield in kg per ha (y) in year of stocking and a year +1 after stocking (correlation coefficient = R^2). Those relationships that are significant are shown in bold

Reservoir, state (size in ha)	Years of data	Mean SD (no/ha)	Mean yield (kg/ha)		Relationship between: numbers stocked/ha (x) and yield in kg/ha (y)	R^2	Species stocked
Aliyar, Tamil Nadu (650 ha)	1985-90	352.8	126	Yr 0 Yr +1	y = -0.0663x + 133.28 y = 0.0928x + 54.458	0.095 0.985	*Cyprinus carpio, Cirrhinuscirrhosus, cirrhosus, Catla catla, Labeo rohita, Hypophthalmichthys molitrix*
Malampuzha, Kerala (2 213 ha)	1981-92	203.0	5.3	Yr 0 Yr +1	y = -0.0023x + 5.7228 y = 2E-05x + 5.4082	0.146 0.000	not available
Meenkara, Kerala (259 ha)	1966-92	393.7	39.5	Yr 0 Yr +1	y = 0.0613x + 15.406 y = 0.0629x + 5.6874	0.551 0.841	not available
Peechi, Kerala (1 263 ha)	1985-92	344.2	11.4	Yr 0 Yr +1	y = -0.0035x + 12.622 y = -0.0028x + 11.951	0.152 0.106	not available
Chulliar, Kerala (159 ha)	1983-92	802.2	123.6	Yr 0 Yr +1	y = 0.0791x + 60.134 y = 5E-05x + 93.129	0.22 0.000	not available
Nagarjunasagar, Andhra Pradesh (28 474 ha)	1971-79	11.6	4.0	Yr 0 Yr +1	y = 0.079x + 3.1194 y = -0.0074x + 4.1257	0.203 0.002	*C. carpio, C. cirrhosus, C. catla, L. rohita*
Gandhisagar, Mathar Pradesh (66 000 ha)	1962-75	5.1	0.004	Yr 0 Yr +1	y = -1E-05x + 266.96 y = 0.0003x + 164.81	0.000 0.095	*C. carpio, C. cirrhosus, C. catla, L. rohita*
Vallabhasagar, Gujarat (52 000 ha)	1975-80; 1983-89	50.8	43.7	Yr 0 Yr +1	y = 6.7935x - 17.25 y = 5.5113x - 12.121	0.824 0.823	not available
Getalsud, Bihar (3 459 ha)	1976-81	177.6	1 096	Yr 0 Yr +1	y = -0.3654x + 1 161.2 y = -5.8396x + 1 932.8	0.002 0.487	Indian Major & minor carps
Gumti, North East (4 500 ha)	1978-93	245.1	31.5	Yr 0 Yr +1	y = -0.0211x + 36.659 y = -0.0133x + 36.961	0.091 0.043	not available

The results of the analysis are somewhat confusing and not uniform. For example, in the instances where the relationship between stocking density and yield was significant, there were cases in which the relationship was negative (Getalsud Reservoir). The most promising was the results of stock enhancement in Vallabhasagar Reservoir in Gujarat, where the yield was highly correlated to stocking density in a year one (n) as well as year n+1. This is particularly encouraging, because this reservoir is one of the largest in the region; however, the reasons for the apparent success of the stock enhancement programme are not clear. In none of the reservoirs was the correlation valid in years n+2 onwards, indicating that in all probability, the effects of stock enhancements are not evident two years after stocking. The inconclusivity of the analysis of this limited data set highlights the fact that the evaluation of the impact of stocking practices in Indian reservoirs is an area that warrants further study. This may also allow a more rational and cost-effective stocking programme.

6.3 Indonesia

Inland fisheries in Indonesia provide approximately 1.6 kg/caput/yr to the fish availability in the country, which approximates about 33 percent of the availability from the total fish production in inland waters (Figure 6). The inland capture fisheries in Indonesia contribute about 6 percent to the total Asian inland capture fishery (Figure 8). On the other hand, the inland fishery in Indonesia contributes about 7 percent to the overall fish landings from capture fisheries in the country (Figure 10). The inland capture fishery in Indonesia increased only marginally over the last ten years, particularly in comparison with the increase in overall landings from capture fisheries (287 183 tonnes in 1991 versus 306 560 tonnes in 2001, as compared to 2 818 538 tonnes versus 4 247 591 tonnes for capture fisheries over the same period).

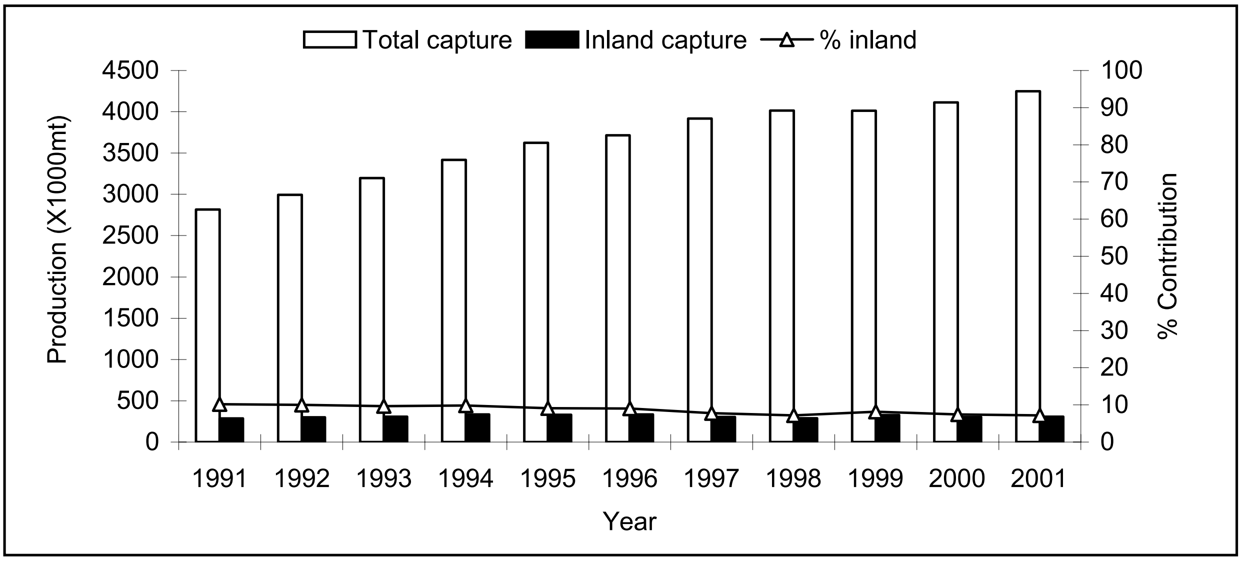

Figure 10. Total capture fishery and inland capture fishery production in Indonesia and the percentage contribution of the latter to the total (based on FAO statistics 2003)

A summary of the stock enhancement practices in Indonesia is given in Table 6, and it is evident that here also, only those species that have the ability to establish spawning populations have had an impact on the fisheries. As with other countries in the region, no information is available on the cost of stocking or the cost-benefits of the stock enhancement practices adopted.

In contrast to stock enhancement in reservoirs, cage-based aquaculture has been promoted in relatively recently impounded large reservoirs, such as Jatiluhur (1967, 8 300 ha), Saguling (1985, 5 607 ha) and Cirata (1987, 6 210 ha) of the Citarum watershed in west Java.

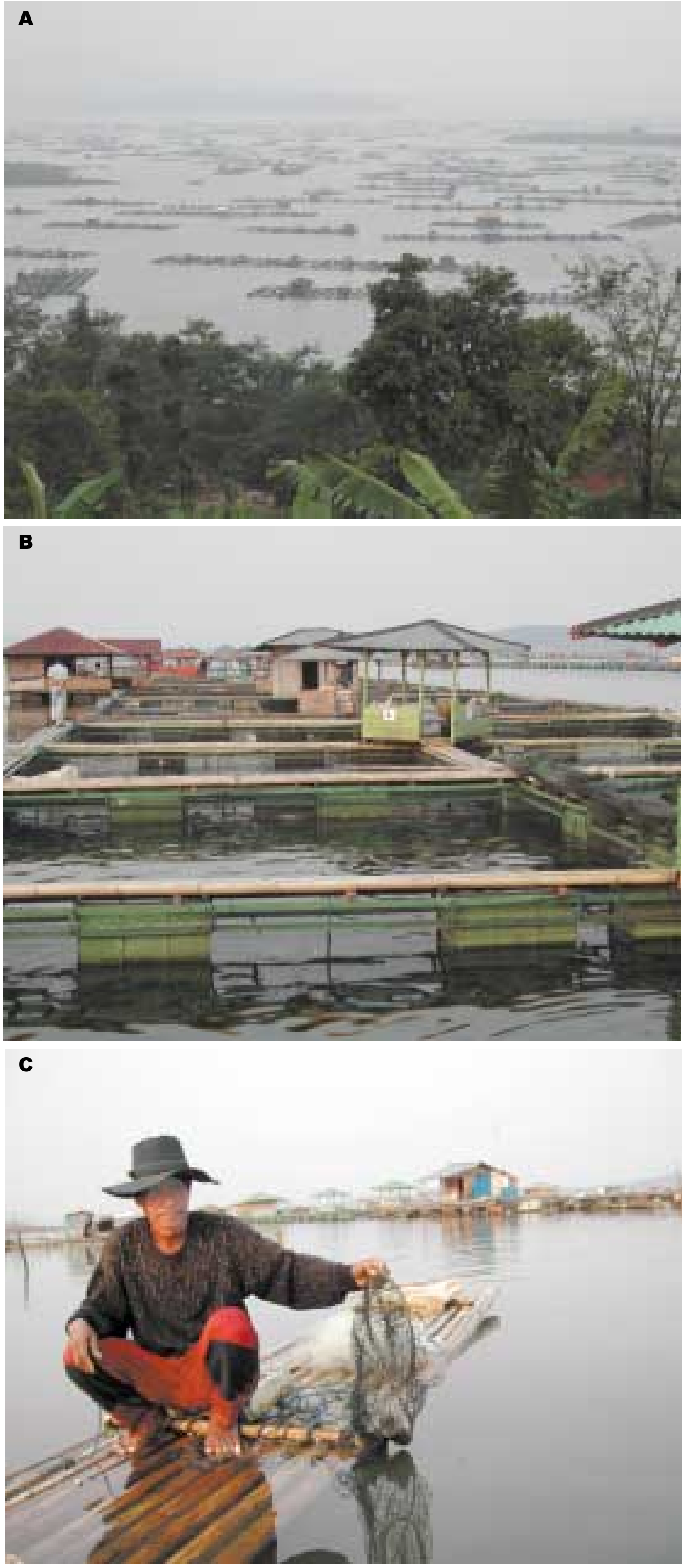

Plate 13. (A) The “industrial sacle” cage culture activities in Cirata reservoir, and (B) an artisanal fisher with his catch

Cage culture was encouraged as an alternative means of livelihood for displaced persons. Cage culture activities were initially subsidized, and as result of good returns (at least in the initial phase), these activities expanded and intensified to “industrial” proportions (Plate 13). This tended to occur without proper planning or consideration for environmental aspects such as carrying capacity. Consequently, there have been regular fish kills that have not only resulted in cagefish mortalities, but also in mortalities in the naturally occurring stocks, upon which a large number of artisanal fishers are dependent for their livelihoods. These artisanal fishers have to find alternative livelihoods following fish kills until the natural stocks recover, which results in conflicts between the two groups of resource users.

Although these reservoirs were initially stocked with Nile tilapia and common carp, there was no regular programme of stock enhancement. It is thought that escapees from netcages and the natural recruitment of the two species are sufficient to sustain the artisanal fishery, albeit at a relatively low level.

6.4 Myanmar

In addition to its vast riverine and floodplain resources, Myanmar has significant lacustrine water resources. These include a number of natural lakes, most notably lakes Logotok, Inle, Er Hai and Indawgyi, and a large number of reservoirs, amounting to a total area of approximately 115 867 ha. Although artisanal fisheries exist in the lakes and contribute significantly to the foodfish supplies (Plate 14) of the nearby townships and villages,

Plate 14. A weekly fish market in a twonship on Inle Lake shores which deals almost exclusivley with catches from the lake, estimated to yield about 500 mt of fish per year

there have been no attempts at their stock enhancement. A recent government policy resulted in a ban on fishing in reservoirs, although the basis for this decision does not appear to have a scientific or fisheries justification.

6.5 PR China

Inland fisheries in PR China provide approximately 2.0 kg/caput/yr to the fish availability in the country, which equals about 14 percent of the availability from the total fish production in inland waters (Figure 6). The inland capture fisheries in PR China contribute about 30 percent to the total Asian inland capture fishery (Figure 8), but in PR China, the inland capture fisheries contribute only about 10 percent to the overall fish landings from capture fisheries in the country (Figure 11). The inland capture fishery in PR China more than doubled over the last ten years, as did the overall landings from capture fisheries (998 961 tonnes in 1991 versus 2 149 932 tonnes in 2001, as compared to 7 674 809 tonnes versus 16 971 730 tonnes for overall landings from capture fisheries over the same period).

Apart from its seven major river systems (Changjiang, Huanghe, Huaihe, Hai-luan, Zhujiang, Songhuajiang and Liaohe), PR China also has a large resource of inland, lacustrine waters. These include natural lakes (e.g. Tahiu) and a large number of reservoirs (about 86 000), built since the 1950s (Table 15). In PR China, unlike anywhere else in the world, fisheries activities were taken into consideration during reservoir planning and construction. The result of this planning is that fishery management bureaus are established for each of the medium and large reservoirs, and for most other reservoirs (De Silva *et al.* 1991). In addition, fishery activities are coordinated with other downstream activities and water management, thereby generating a high degree of synergy that is beneficial to all stakeholders and reduces conflicts over the management of reservoir water.

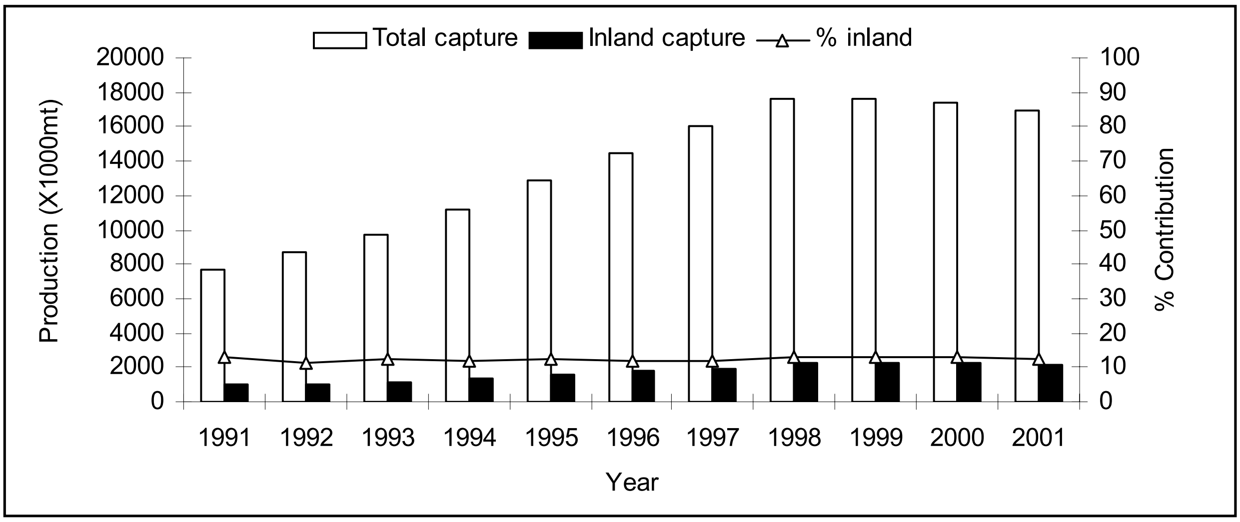

Figure 11. Total capture fishery and inland capture fishery production in PR China and the percentage contribution of the latter to the total (based on FAO statistics 2003)

Table 15. The reservoir resources of PR China (modified from Huang *et al.* 2001)

Reservoir size	Number	Storage (x 10^6 m^3)	Percent
Large (>677 ha)	326	2 975	72.0
Medium (66-677 ha)	2 298	605	14.7
Small – 1 (<67 ha)	14 108	366	8.9
Small – 2	70 120	184	4.4

One of the earliest analyses of stocking and related yields in Chinese reservoirs was conducted De Silva *et al*. (1992). In this analysis, the authors attempted to develop relationships of stocking rates to yields etc. from the aggregated results for reservoirs of all sizes in three different regions (Table 16). It is evident that the fish yields were related to both stocking rates and the reservoir area. Consequently, the authors developed multiple regressions incorporating these two independent variables to fish yield, for the three groups of reservoirs (Table 17).

Although the above analysis remains the only detailed study available on Chinese reservoirs, the fact that the authors used aggregated data for all size groups in each area makes it that much harder to determine its more general application. This is particularly so because the fishery management

Table 16. Statistical relationships between stocking rates, area and yield (SR_n and SR_w refer to stocking rate in numbers and in kg/ha, respectively; A= area in ha; Y= yield in kg/ha/yr; modified after De Silva *et al.* 1992)

Relationship(s)	n	r	p<
Guandon Province:			
$Y = 661.84\ A^{-0.468}$	64	-0.48	0.05
$Y = -17.63 + 0.084\ SR_n - (7.32 \times 10 - 16\ SR_n^{\ 2})$	64	0.68	0.01
$Y = 0.14\ SR_n - 88.44$		0.83	0.01
Jianling County & Hubei Province:			
$Y = 213.89\ (A/D)^{-0389}$	14	0.57	0.05
$Y = 35.42 + 2.71\ SR_w$	11	0.86	0.01
Reservoirs from other provinces (4):			
$Y = 5\ 220.4\ A^{-0.653}$	6	0.79	0.01
$Y = 20.14 + 0.039\ SR_n$	6	0.94	0.01

practices in Chinese reservoirs have changed significantly over the last decade. Among the major changes adopted (Li and Xu 1995), particularly in respect of small reservoirs, are:

- more controlled stocking in relation to selected limnological features of the smaller waterbodies;
- use of a standard-sized fingerlings (12.7 to 13.5 cm); and
- use of different species combinations to match the limnological features.

These modified management measures will be covered later in the section on culture-based fisheries (Section 8).

Table 17. Multiple correlations depicting the fish yield to other independent variables, as given in Table 16, for the three groups of Chinese reservoirs (modified after De Silva *et al.* 1992)

Relationship(s)	n	r	p<
Group I: $Y = -22.44 + 1.58x\ 10^{-3}(A) + 6.89\ SR_w$	56	0.76	0.01
Group 2: $Y = 63.78 – 0.318\ (A) + 2.21\ SR_w$	10	0.87	0.01
Group 3: $Y = -9.86 + 0.021\ (A) + 0.043\ SR_n$	7	0.94	0.01

6.6 Sri Lanka

Sri Lanka has no natural lakes, and its inland fishery is dependent on the multitude of reservoirs that are scattered throughout the dry zone – the region that receives <187 mm of annual rainfall. Sri Lanka has one of the highest, if not the highest, densities of reservoirs in the world, estimated to be about 3 ha/km^2 (De Silva 1988). However, the area of large reservoirs in which capture fisheries is prevalent is estimated to be about 136 590 ha, and includes major irrigation reservoirs, medium-scale irrigation reservoirs and hill country hydroelectric reservoirs.

6.6.1 The inland fishery

The inland fishery of Sri Lanka is based almost exclusively on reservoir capture fisheries. Current production is about 27 000 tonnes/yr and is still in recovery after a period of decline starting in the early 1990s resulting from the removal of governmental patronage (Amarasinghe and De Silva 1999). According to De Silva (1988), the inland fishery of Sri Lanka is characterized by three main features (Plate 15):

- it is confined to large, medium and small reservoirs;
- it involves the use of non-motorized fibreglass canoes (5 m) with an outrigger, operated by two fishers;
- it is dominated by introduced exotics – *Oreochromis mossambicus,* which is gradually being replaced by *O. niloticus*, and is purported to have developed to present levels only as a result of the introduction of *O. mossambicus* in the early 1950s.

6.6.2 Stock enhancement

The fishery is essentially dependent on self-recruiting populations of the exotic cichlids *O. mossambicus* and *O. niloticus* (since the 1980s, the reservoirs have been "re-seeded" with the latter, due to its more desirable traits). These two exotics hybridize relatively easily, and the reservoir populations have varying amounts of the parental species and hybrids (De Silva and Ranasinghe 1989). Amarasinghe and De Silva (1996) have pointed out that such hybridization could also affect the fishery in the long term by reducing the reproductive capacity of the stocks.

Since the mid-1980s, there has also been a concerted attempt to stock selected reservoirs with Chinese and Indian major carps. The results of an experimental stocking in Giritale Reservoir, a medium-sized irrigation reservoir of 338 ha, are given in Table 18. In this example, the authors failed to consider the cost of production of fingerlings and consequently arrived at very high rate of return that would make a stocking a very viable proposition. In contrast, the data from the stocking of 17 reservoirs with Chinese and Indian major carps do not appear to be encouraging (Jayasekera 1989). These reservoirs ranged in size from 262 to 6 300 ha. A re-analysis of this data (Table 19) indicates that over a five-year period 6 241 580 fingerlings were stocked, but the resulting yield of stocked fish was only 420 tonnes out of a total yield of 17 634 tonnes, or a return of only 2.4 percent. Details on the performance of stocked fingerlings in some of the reservoirs are given in Table 20, and strongly indicate that enhancement of major Asian carps in Sri Lankan reservoirs is not a viable strategy. Among the species stocked, *Labeo rohita*, an Indian carp, yielded the best results.

Table 18. Details on stocking and returns of major carps in Giritale Reservoir (308 ha), Sri Lanka (modified from Chandrasoma and Wijeyaratne 1994)

Stocking / Species	Stocking	Harvest		% recapture	Harvest per 100 stocked		Rate of return (%)
	Number	Total (kg)	Number		Weight (kg)	Value (Rs)[1]	
Bighead carp	365 000	89 300	71 440	19.6	24.5	244	482
Mrigal	56 000	12 900	10 320	18.4	23.0	230	448
Rohu	148 000	38 540	30 832	20.8	26.0	260	519

[1] Rs = Sri Lankan rupees. 1 US$ = 49.00 rupees

Table 19. Summary on stocking and resulting yield of Chinese and Indian major carps in 17 Sri Lankan reservoirs ranging in size from 262 to 6 300 ha, between 1983 to 1987 (based on data from Jayasekera 1989)

Species	Stocking (number)		Total harvest (tonnes)
	Reservoirs	Fingerlings	
Ctenopharyngodon idellus	4	213 850	2.0
Aristichthys nobilis	9	3 889 300	72.2
Hypophthalmichthys molitrix	7	167 950	nil
Catla catla	3	80 150	2.3
Labeo rohita	12	1 217 030	340.1
Cirrhinus cirrhosa	10	668 300	3.3
Total		**6 241 580**	**419.9**

Table 20. Data on the stock and recapture of Chinese and Indian major carps in a number of Sri Lankan reservoirs. Where relevant, the years are given in parentheses (based on data from Jayasekera 1989)

Reservoir/species	Stocking		Production		Return (%)
	Number	Year	Tonnes	Year	
Udawalawe (3 374 ha) Total production – 532 tonnes (85/86)					
Ctenopharyngodon idellus	54 000	(78/79)	–		
	157 000	(86)[1]	1.7	(85/86)	0.3
Aristichthys nobilis	147 300	(78/84/85)	–		–
	2 968 000	(86)[1]	–		–
Hypophthalmichthys molitrix	13 400	(84/86)	–		–
Catla catla	8 400	(83/84)			
	65 750	(86)[2]			
Labeo rohita	252 680	(83/86)	35.1	(85/86)	6.6
Cirrhina cirrhosus	51 450	(84/86)	–		–
	23 400	(86)[2]			
Bathalagoda (262 ha) Total production – 217 tonnes (83/86); 100 tonnes (83/86)					
C. idellus	1 200	(85)	0.3	(85/86)	–
A. nobilis	1 700	(85)	0.1		–
H. molitrix	2 750	(85/86)	–		–
L. rohita	19 300	(83/85/86)	9.6	(83/86)	9.6
C. cirrhosus	7 150	(85/86)	3.2	(85/86)	3.2
Kandalama (780 ha) Total production – 727 tonnes (86); 248 tonnes (84/86); 299 tonnes (83/86)					
A. nobilis	97 800	(85)	5.7		4.4
L.rohita	337 000	(83/85)	106.5		42.9
C. cirrhosus	171 000	(86)	–		–
Parakrama Samudra (2 262 ha) Total production – 5 786 tonnes (78/86); 343 tonnes (86)					
C. idellus	1 250	(86)	–		–
A. nobilis	55 500	(78/86)	–		–
H. molitrix	33 800	(78/86)	–		–
L. rohita	223 600	(86)	4.6		–
C. cirrhosus	47 200		–		–
Minneriya (2 551 ha) Total production – 1 176 tonnes (86)					
C. cirrhosus	135 000	(86)	0.15		–
Maduruoya (6 300 ha) Total production – 2 585 tonnes (83/87)					
A. nobilis	131 000	(83)	–		–
L. rohita	64 000	(83/86)	–		–
Giritale (2 262 ha) Total production – 194 tonnes (85/87)					
A. nobilis	365 000	(84/87)	62.4		32.1
H. molitrix	25 000	(84)	–		–
L. rohita	148 000	(84/85/87)	36.6	(85/87)	18.8
C. cirrhosus	2 000	(85)	–		–
Tabbowa (500 ha) Total production – 2 856 tonnes (84/87)					
A. nobilis	27 800	(82/87)	–		–
H. molitrix	5 000	(87)	–		–
L. rohita	30 800	(83/87)	136.2	(84/87)	4.8
C. cirrhosus	18 180		–		–

[1] postlarvae [2] fry

Why was stocking of Sri Lankan reservoirs with Chinese and Indian carp not a successful strategy?

A number of reasons have been suggested for the apparent failure of use of Asian major carps for stock enhancement in Sri Lankan reservoirs. Foremost among these are:

- The stock enhancement programme conducted was relatively ad hoc;
- The size of the seedstock was less than desirable, even fry being stocked in some years. (Table 20);
- All the food niches were already occupied by the existing exotic cichlids and indigenous, self-recruiting species;
- The gear used in the fishery is not appropriate for catching Asian major carps; and
- None of the stocked species were able to form breeding populations in the reservoirs and/or influent waters.

In some Sri Lankan reservoirs, notably Udawalawe Reservoir (2 386 ha), a reservoir located in the vicinity of an Asian major carp governmental hatchery, there are reports of the appearance of juvenile *Catla catla* in the artisanal fishery catches on a regular basis (see Plate 15). Similarly, there are reports that large-sized catla (>10 kg) occur in catches on a fairly regular basis in Mahaaluthgamara Wewa, a medium-sized reservoir (400 ha). Both these reservoirs were stocked with this species in the 1980s, but the latter only once in 1989. At this juncture, it is difficult to determine that if breeding populations of the species have established, either in the reservoirs or in the influent rivers, and this should certainly be investigated. If breeding populations of catla have established in Sri Lankan waters, this would be a very rare occurrence where an Indian major carp species has been able to reproduce naturally beyond its normal range of distribution.

6.7 Thailand

Inland fisheries in Thailand provide about 3 kg/caput/yr to the fish availability in the country, equalling about 38 percent of the availability from the total fish production in inland waters (Figure 6). The inland capture fisheries in Thailand contribute about 5 percent to the total Asian inland capture fishery, and this has not changed significantly since 1991 (Figure 8). The inland fisheries in Thailand currently contribute about 7.3 percent to the country's overall fish landings from capture fisheries (Figure 12). Fish yield from inland fisheries increased from 138 146 tonnes in 1991 to 209 977 tonnes in 2000, this increase accounting for nearly 27 percent of the increase in capture fisheries production in Thailand over the same period of time.

Thailand has three major natural lakes, Bung Borapet in the central plain (13 000 ha), Nong Harn in the northeast (12 500 ha) and Kawn Phyao in the north (2 100 ha), as well as the freshwater/ brackishwater Songkhla Lake (96 000 ha) in the south (Pawaputanon 1992). The natural lakes have fisheries, and Songkhla Lake, in particular, has an extensive fresh and brackishwater fishery that has been studied fairly extensively. There have been few studies on the fisheries of the freshwater lakes. Thailand has about 316 690 ha of reservoirs (23) larger that 1 000 ha (Verdegem 1999), and a total of 1 745 reservoirs totalling 425 500 ha (Pawaputanon 1992). Bernacsek (1997) reports that Thailand has 28 reservoirs of over 1 000 ha, totalling 336 605 ha. Almost all of Thailand's reservoirs have been impounded in the second half of the 20th century. Fisheries exist in all the reservoirs at varying degrees of intensity. These fisheries are almost entirely artisanal, and a diverse range of gear is used, depending on the nature of the reservoir.

Plate 15. Features depicting some main cahracteristics of the inland fishery in large reservoirs in Sri Lanka (A) a common catch; note the predominance of exotic cichlids (B) A rare instance when a large stocked cyprinid *(Catla catla)* is caught (C) Vendors waiting for the fishers at a landing site and (D) a village vendor

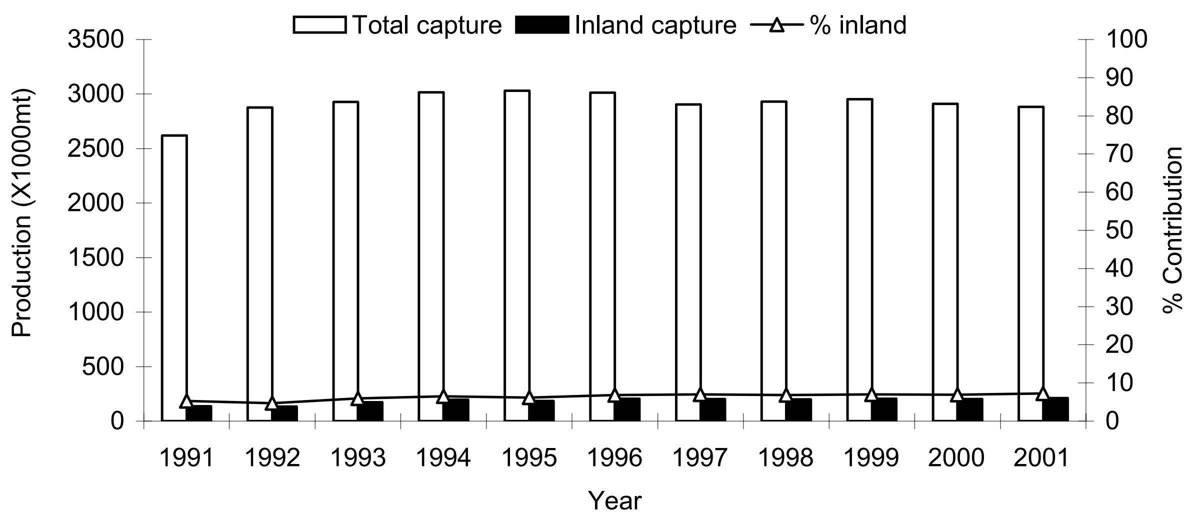

Figure 12. Total capture fishery and inland capture fishery production in Thailand and the percentage contribution of the latter to the total (based on FAO statistics 2003)

6.7.1 Inland fisheries

The inland fisheries in Thai reservoirs are very diverse, and individual fisheries may differ from each other with respect to:

- overall fish yield;
- predominant gears used;
- dominant species in the catches;
- impact of exotics and stocked species on the individual reservoir fisheries; and
- utilization of the catches.

Over 150 fish species have been recorded in inland catches, but only about 20 of these are known to be economically important (Pawaputanon 1992). In recent years, there have been many accounts of the fisheries of individual reservoirs in Thailand (Plate 16), for example on Rajjaprabha (Chookajorn *et al*. 1999), Ubolratana (Pholprasith and Sirimongkonthaworn 1999) and Sirinthorn reservoirs (Jutagate *et al*. 2003). The mean fish yield from 11 reservoirs managed by the Electricity Generating Authority of Thailand ranged from approximately 7–52.2 kg/ha/yr for the years 1987 to 1998 (Table 21). This rather random selection of reservoirs, representative of the varied climatic regimes in the country, provides insight into a number of features of the reservoir fisheries in Thailand. The most significant and relatively obvious deductions that could be made are:

- the wide range in yields between years in each of the reservoirs;
- the apparent lack of correlation (generally expected to be negative) of fish productivity to reservoir surface area (for example, one of the highest mean yields was recorded for Ubolratana Reservoir, which is one of the largest in the country);
- the general dominance of indigenous species: cyprinids, nandids, notopterids, bagrids, channids etc. in almost all the fisheries;
- the fishery on clupeids (the Thai river sprat) being restricted only to a few reservoirs; and
- the general lack of dominance and/or significant contribution of stocked/introduced species to the fisheries in most reservoirs (these species contributed significantly only in those reservoirs that were relatively small, most notably in Mae Chang (tilapia) and Nam Phung (tilapia and rohu).

6.7.2 Stock enhancement

Stock enhancement of inland waters, in particular, in reservoirs, has been carried out since the early 1950s, commencing with the stocking of *Trichogaster pectoralis* and *Oreochromis mossambicus* into natural swamps (Pawaputanon 1992). Subsequently, exotic species such as common carp, rohu, Nile tilapia and Chinese carps were used in the stocking programmes. According to Pawaputanon (1992), stocking programmes have shifted strategy over time to target indigenous species, either for improvement of fish yields in reservoirs, using species such as *Barbonymus gonionotus* (Java barb), or towards conservation or repopulation of economically important indigenous species such as *Pangasius hypophthalmus*, *Pangasianodon gigas*, *Probarbus jullieni*, *Chitala chitala* and *Osphronemus gouramy*. The authors estimate that nearly 100 million fingerlings of various fish species are stocked yearly in reservoirs; however, in the large reservoirs the return is probably less than one percent.

As noted for other countries in the region, a comprehensive analysis of stocking and returns and the cost-effectiveness of these programmes has not been carried out for Thai inland waters. Bhukaswan

Plate 16. Some features of the reservoir fisheries in Thai reservoirs. (A) Typical gears and traps used in fisheries. (B) A typical catch showing the diversity. (C) A lift net for catching the Thai river sprat and (D) a haul of Thai river sprat.

(1988) attempted to assess the effectiveness of cyprinid stocking in large inland waterbodies in Thailand. He concluded that over a ten-year period 42 232 700 cyprinids/yr (approximately 61.4 percent of all fish stocked), costing 2.96 million Baht/Yr (US$ 1 = 25 Baht), were stocked into large inland waterbodies. Although indigenous and exotic cyprinids (principally *Labeo rohita* and *Cyprinus carpio*) accounted for about 25 to 40 percent of the landings and a similar proportion in value, this author concluded that it was impossible to assess the effectiveness of stocking, as there was no mechanism to discern between landings of naturally recruited and stocked fish; large scale stocking continues to the present time. It should be noted that in this analysis the author did not comment on the exotic Chinese carps that were stocked, which is unfortunate since these landings were unlikely to be augmented by natural recruitment.

Table 21. Mean yield (and range), dominant species in the fishery and species stocked in 11 reservoirs in Thailand. The yield data are based on catches from 1987 to 1998 (from the Electricity Generating authority of Thailand). Other information is based on data from Bernacsek (1997). The years for which the indigenous fish contribution to the catch is available are given in parentheses

Reservoir/ coordinates	Size (ha)	Mean yield (kg/ha/yr)	Dominant species	Species stocked	Contribution of indigenous species (%)
Mae Chang 18°18′N; 99°48′E	1 230	19.5 (4.3-23.5)	*Oreochromis niloticus, Notopterus notopterus, Barbonymus gonionotus*	*O. niloticus, Aristichthys nobilis, Cyprinus carpio, Labeo rohita, Hypophthalmichthys molitrix, Ctenopharyngodon idellus*	51.8 (1985)
Bhumipol 17°14′N; 98°58′E	31 600	15.9 (0.3-91.2)	*Puntioplites proctozysron, Hemibagus nemurus, Kryptopterus cryptopterus*	*A. nobilis, L. rohita, H. molitrix, O. niloticus*	94.6 (1992)
Sirikit 17°46′N; 100°34′E	26 000	17.7 (14.4-22.0)	*Rasbora spp., Clupeichthyes aesarnensis, Pangasius macronema, P. proctozysron*	*C. carpio, L. rohita, O. niloticus*	97.4 (1992)
Nam Phung 16°38′N; 103°56′E	2 165	52.2 (12.3-86.3)	*Osteochilus hasselti, O. niloticus, L. rohita, H. molitrix*	*L. rohita, C. cirrhosus, O. niloticus*	76.4 (1992)
Chulaphon 16°32′N; 101°39′E	1 200	29.1 (10.2-58.5)	*O. hasselti, H. molitrix, Channa striata, Ompok bimaculatus*	*O. niloticus, A. nobilis, C. carpio, L. rohita, C. cirrhosus, C. idellus*	46.3 (1992)
Ubolratana 16°13′N; 102°37′E	41 000	35.8 (25.4-45.2)	*P. proctozysron, Cirrhinus jullieni, C. aesarnensis, O. hasselti*	*O. niloticus, A. nobilis, C. carpio, L. rohita, H. molitrix, C. idellus*	97.4 (1969/92)
Sirinthorn 15°12′N; 105°25′E	28 800	15.4 (6.4-25.7)	*C. aesarnensis, Labeobarbus lineatus, N. nopterus, Pristolepis fasciata*	*O. niloticus*	98.8 (1991/94)
Sri Nagarind 14°24′N; 99°07′E	41 900	7.0 (3.0-10.4)	*P. fasciata, O. hasselti, H. molitrix, Osphronemus gouramy*	*L. rohita, O. niloticus*	96.2 (1992)
Khao Laem 14°47′N; 98°37′E	38 800	13.4 (7.8-20.6)	*H. molitrix, C. aesarnensis, Channa micropeltes, H. nemurus*	*Cirrhinus molitorella, L. rohita*	98.3 (1985)
Rajjaprabha 8°58′N; 98°47′E	18 400	17.6 (12.8-24.3)	*C. micropeltes, Hemibagrus wyckii, C. lucius, N. notopterus, L. rohita*	*L. rohita, A. nobilis, C. molitorella*	87.5 (1992)
Banglang 6°19′N; 101°16′E	5 090	17.3 (9.8-35.9)	*Cyclocheilichthys apogon, H. molitrix, P. fasciata*	*L. rohita, O. niloticus*	99.7 (1992)

The fisheries in Thai reservoirs are somewhat different to others in the region, particularly in the importance of indigenous cyprinids, nandids (featherbacks), bagrids (catfish) and channids (snakeheads) in the landings. Also, unlike in the rest of Asia, the dominance of introduced cichlids is still relatively limited. De Silva *et al*. (2004) demonstrated that the *Oreochromis niloticus* in the landings (Y, in kg/ha/yr) in Thai reservoirs were related to reservoir size (ha) under the following statistical relationship:

$$Y = -1.794 \ln (X) + 18.53 \qquad (r = 0.70;\ p < 0.05)$$

There is still very little known of the role of exotic cyprinids that are stocked yearly into most reservoirs, although the stocking of these species is typically confined to the smaller reservoirs, as they are not expected to establish breeding stocks (Dr. Maitree Pawaputanon pers. comm.).

Thailand is one of the few countries that practice stock enhancement of a crustacean species, the giant river prawn, *Macrobrachium rosenbergii*. This species is regularly stocked in some Thai reservoirs, for example in Pak Mun Reservoir (4 910 ha), which has a run-of-river type dam[3]. Sripatrprasite and Lin (2003) reported that this reservoir has been regularly stocked with giant river prawn since 1995, totalling 22 million fry up to 2000. The giant river prawn catches (16 646 kg/yr) contributed 53.8 percent to the total fish catch by weight, but 97 percent to the economic value of the landings. These authors demonstrated that despite the low return from stocking (only 1 percent), the high price of the captured prawns (US$ 5.4/kg) resulted in an economic rate of return of 43 percent, making the practice economically viable. *Macrobrachium rosenbergii* is also regularly stocked into Songkhla Lake; however, it is impossible to determine whether the captured shrimp are from the wild populations or from returns from enhancement.

6.8 Viet Nam

Inland fisheries in Viet Nam provide about 2 kg/caput/yr to the fish availability in the country, which approximates to about 25 percent of the availability from the total fish production in inland waters (Figure 6). Viet Nam's contribution to the inland capture fisheries of Asia is one of the lowest of the countries considered in this section and has remained at this level (about three to five percent) throughout the last decade (Figure 8). The inland fishery in Viet Nam currently contributes only about 11 percent to the overall fish landings from capture fisheries in the country (Figure 13) and more importantly, this contribution has been slowly decreasing over the years. For example, it decreased from about 16.5 to 11.4 percent between 1991 and 2001 (136 822 versus 170 000 tonnes as compared to 831 070 versus 1 491 123 tonnes for overall landings for capture fisheries over the same period[4]).

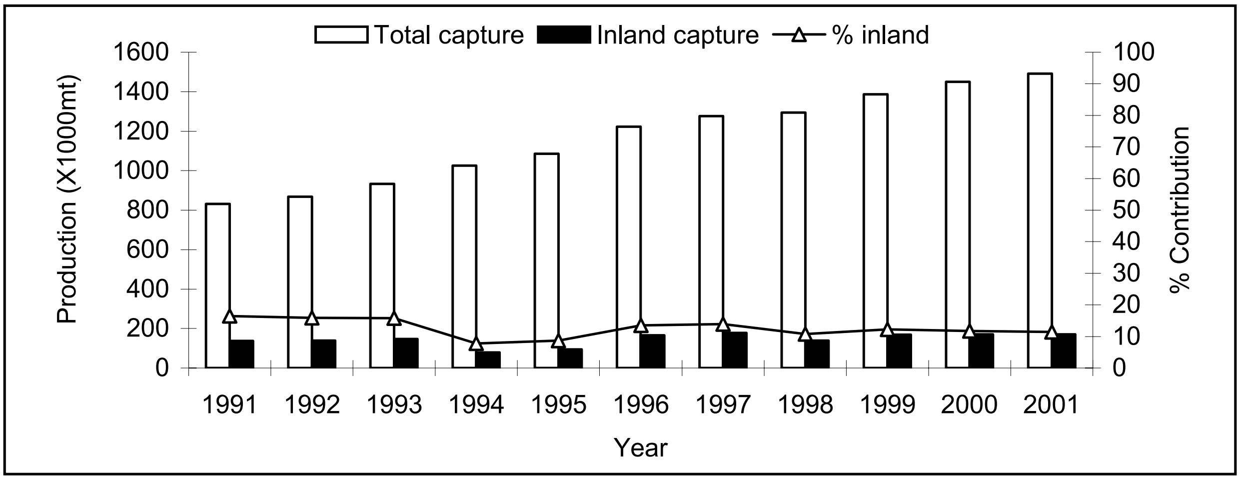

Figure 13. Total capture fishery and inland capture fishery production in Viet Nam and the percentage contribution of the latter to the total (based on FAO statistics 2003)

Viet Nam has very limited natural lake resources. The biggest lake, ThiNai Lake, has an area of 5 060 ha, and almost all the others are less than 500 ha. Some of these lakes are heavily silted, and as a result have gradually been transformed into wetlands. An example of this is Dak Lak Lake in the central highlands (Plate 17). Consequently, open-water fishery activities are limited, and the commonest gears are traps and fence nettings. Generally, very little is documented on the fisheries of natural lakes in Viet Nam (Thai *et al*. 2001).

[3] A "run of the river" type dam is one that does not create a large reservoir behind it.

[4] This is capture fisheries only and does not include aquaculture production.

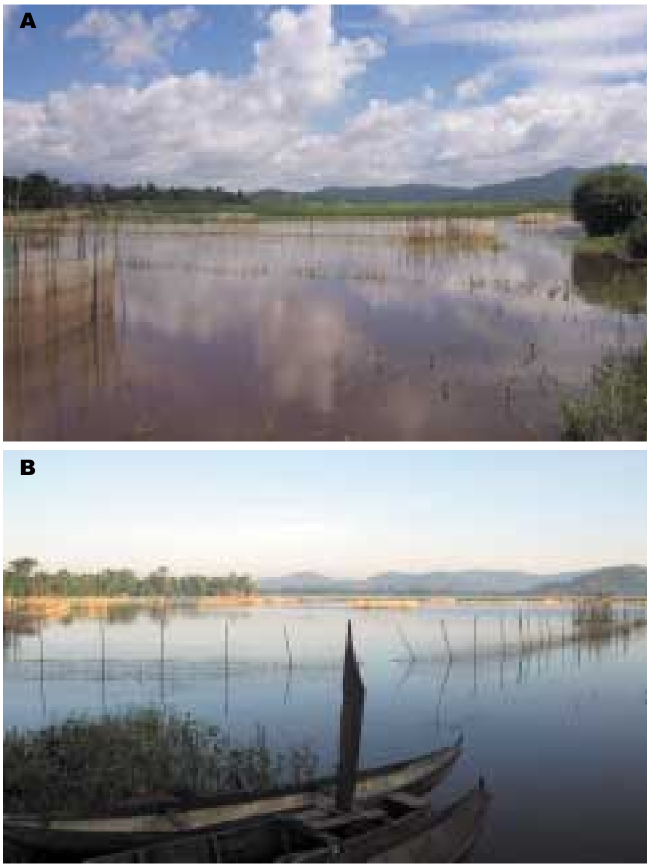

Plate 17. (A) & (B) A general view of Lak Lake, Dak Lak Province, in the central highlands of Viet Nam, showing the general transformation of the lake into a wetlands, that restricts the fishing to traps and fence nets

The inland fisheries of Viet Nam are mostly dependent on the river systems and reservoirs, and are artisanal in nature, as elsewhere in Asia (Plate 18). The reservoir resource in Viet Nam was estimated to be 181 167 ha in 1993 (Nguyen 2001), but it is accepted that with the impoundment of a few large reservoirs in the last decade the area is now close to 300 000 ha. The inland fishery activities and their management, particularly in large waterbodies, have undergone major changes in the last ten years, reflecting the changes in the economic *milieu* of the country. Bui The Anh (RIA No. 1, Viet Nam, personal communication) divided reservoir (= inland) fishery developments in Viet Nam into three phases:

- early development period – all fishery activities were subsidized by the government (up to 1985);
- declining period (1986–1995); and
- recovery period (1995 to date).

With economic liberalization and the consequent adoption of a free-market policy, all government subsidies were effectively withdrawn in 1985. This led to a period of uncertainty and hence, to a decline in inland fisheries between 1986–1995. During the recovery period, new management regimes came into being, and reservoir fishery development in Viet Nam is being revitalized. Indeed, the Government of Viet Nam has made a policy decision to utilize reservoir fisheries for poverty alleviation and to provide employment. The aim is to increase foodfish supplies, at an affordable price, to the poor sectors of the community, and the government has targeted a total production of 210 000 mt by 2010.

According to Bui The Anh (RIA No. 1, Viet Nam, personal communication) there are currently three forms of management in operation:

- government line management (managed by fishery centres of the Government of Viet Nam and/or provincial government (PG));
- cooperative line management (mostly applicable to medium-sized reservoirs where a cooperative will lease the waterbody from the PG); and
- private sector line management (leased and managed by individuals).

Details on the effectiveness of the different management strategies are yet to be evaluated in this new era. The reservoir/inland fishery development is being gradually transformed into a “user-pays basis”, with governmental stocking subsidies withdrawn and/or curtailed. Consequently, fisheries developments are going through a phase of uncertainty. A general lack of scientific (and possibly economic) information has made it difficult for the government to develop meaningful strategies.

Plate 18. Some features of the reservoir fisheries in Viet Nam. (A) Landing site at ThacBa reservoir; note the predominance of involvement of women. (B) A wholesaler operating in the middle of the HaoBin reservoir. (C) Shrimp traps being transported for sale at fishing vilages.

There have been only isolated attempts to assess and objectively analyze the effectiveness and cost-benefits of stocking in Vietnamese reservoirs, resulting in the current situation of the adoption of ad hoc measures.

6.8.1 Stock enhancement strategies

Viet Nam has a rich, indigenous freshwater fish fauna, dominated by cyprinids (Nguyen and Ngo 2001), a feature also reflected in most reservoirs (Ngo and Le 2001). Despite this, the reservoir fisheries, barring a few exceptions, are largely based on stocked species such as the Chinese carps, common carp and the Indian carps (rohu and mrigal) and on some larger indigenous predatory species. It is because of this dependence that when governmental subsidies were withdrawn and there was no stocking, most of the reservoir fisheries collapsed.

Nguyen (2001) observed that the proportion of stocked species in the yields in nine reservoirs ranged from 38 to 99.8 percent, but in this instance the reservoirs considered varied in size from 5 to 22 000 ha. This analysis also used data from 1966 to 1973 for some reservoirs (Table 22). Despite this, it is important to note that even in a large reservoir such as ThacBa, the stocked species accounted for nearly 38 percent of the catch. Although the return of stocked fish was very high, the maximum yield recorded from this reservoir was rather low (20.4 kg/ha) when compared to reservoirs of comparable size elsewhere in Asia (Ngo and Le 2001). Nguyen (2001) demonstrated that the yield increased linearly in relation to

Table 22. Summary results on stocking and returns in selected reservoirs in Viet Nam (modified from Nguyen 2001)

Reservoir	Years of data	Area (ha)	SD (finger-lings/ha)	Maximum yield (kg/ha)	Stocked species		Self-recruiting species	
					(kg/ha)	(%)	(kg/ha)	(%)
SuoiHai	(1966-73)	960	667	63	54.4	87.1	8.1	13.0
VanTruc	(1969-73)	150	3 644	31	28.4	91.7	2.6	8.3
DongMo	(1972-75)	800	1 065	55	52.8	96.0	2.2	4.0
CamSon	(1971-72)	2 000	2 031	45	41.0	91.0	4.1	9.0
ThacBa	(1971-75)	22 000	217	20	7.8	38.2	12.6	61.8
EaKao	(1997-99)	210	3 641	734	604.0	82.3	130.0	17.7
EaKar	(1997-99)	141	4 884	454	453.0	99.8	0.4	0.1
YangRe	(1998-99)	56	4 686	584	501.0	85.8	83.0	14.2
Ho 31	(1997-98)	5.4	9 117	1 307	1 301.0	99.5	6.1	0.5

stocking density and that in individual reservoirs for which data were available for a number of years, the relationship was curvilinear.

In NuiCoc and SuoiHai reservoirs, the yield (Y – in kg)/stocking density (X – in millions of fingerlings) relationships were, respectively:

$$Y = 32.885\ln(X) - 124.41 \ (R^2 = 0.542), \text{ and}$$

$$Y = 28.28\ln(X) + 126.91 \ (R^2 = 0.855).$$

A detailed study on the stocking strategy in EaKao Reservoir (210 ha), which is intensively fished and well managed (Phan and De Silva 2000), showed that:

- the fish yield (y; kg/ha) in year n+1 was correlated to the amount stocked in year n (SD = number stocked/ha), the relationship being, $y = -0.0006SD^2 + 0.0969SD - 45.50$ ($R^2 = 0.86$);
- the total number of stocked fish (Y) caught was also related to stocking density in a similar manner; $Y = -0.06 \times 10^{-8} + 0.13SD - 67.04$ ($R^2 = 0.84$); and
- the stocking efficiency (Li 1988) in year n+1, was also similarly related to stocking density in year n.

Phan and De Silva (2000) demonstrated that the optimum stocking density (SD) for EaKao Reservoir was 2 800 fingerlings/ha and that a SD exceeding 3 200 fingerlings/ha results in a rapid decline in stocking efficiency.

Bui The Anh (RIA No. 1, Viet Nam, personal communication) found that in NuiCoc Reservoir the stocking density (SD) was significantly related to yield from year of stocking (y) to y+4 (Table 23). After the fourth year, the relationship was not statistically significant. Although the above analysis gives an approximate indication of the return from stocking, it is difficult to discern the contribution, for example to the yield in Y_{n+4} from the fingerlings stocked between years Y_{n+1} to Y_{n+3}. This would require relatively complicated mathematical modelling and additional data on growth rates, mortality etc. These results conform to the biological expectation that beyond a certain stocking density, the yield would begin to decrease, perhaps resulting from limitations in food resources.

Table 23. The statistical relationships between stocking density (number of fingerlings x 10 000) in year 0 (Yn) to year n+4 (Yn+4) to yield (kg/ha) in NuiCoc Reservoir (2 000 ha), northern Viet Nam. The analysis is based on stocking and catch data from 1978 to 2000

Statistical relationship	R^2
$Y_n = -0.00003SD^2 + 0.057SD + 14.29$	0.654
$Y_{n+1} = -0.00004SD^2 + 0.0666SD + 12.89$	0.756
$Y_{n+2} = -0.00004SD^2 + 0.0734SD + 11.06$	0.804
$Y_{n+3} = -0.00003SD^2 + 0.0622SD + 11.29$	0.691
$Y_{n+4} = -0.00006SD^2 + 0.0317SD + 13.20$	0.571

Information on the growth rates of stocked fish in Vietnamese reservoirs is scarce, and the only available data are those of Nguyen (2000) for five reservoirs. The growth rates of stocked fish (Chinese carps) such as bighead carp, silver carp and grass carp, did not have any relationship to the size of the reservoir. In the bigger reservoirs, stocked fish appeared to be caught even up to five years, the biggest being bighead carp at five years of age having a mean weight of 24 kg in ThacBa Reservoir (22 000 ha) (Table 24). In general, the growth of bighead carp was the best, particularly in the second year, when they often increased their weight by over 200 percent.

Nguyen (2001) also attempted to conduct an economic analysis and determine the cost-benefit ratio of stocking. This is one of the very few such studies of relatively large lacustrine waters done in the region. This analysis included small, medium and large-sized reservoirs; however, only the latter two are considered here. In the two reservoirs under consideration, the cost-benefit ratio was 5.38 and 7.75 for DongMo and SuoiHai reservoirs, respectively. Unfortunately this analysis did not include cost for infrastructure, fishing and other associated costs and therefore, the cost-benefit ratios are probably over-estimated.

Table 24. The yearly mean weight of stocked fingerlings in selected reservoirs in Viet Nam (modified from Nguyen 2000)

Species / Reservoir	Mean weight (kg)				
	Year 1	Year 2	Year 3	Year 4	Year 5
ThacBa (22 000 ha)					
Silver carp	1.20	2.40	4.30	6.50	7.80
Bighead carp	2.15	8.61	15.31	20.96	24.00
Grass carp	1.78	2.96	4.65	6.75	7.81
NuiCoc (2 010 ha)					
Silver carp	1.20	1.63	2.67	3.25	
Bighead carp	1.40	3.20	6.00	9.60	
Grass carp	0.10	1.20	1.70	2.80	
CamSon (2 300 ha)					
Silver carp	1.19	2.90			
Bighead carp	1.56	4.20	15.60		
SuoiHai (960 ha)					
Silver carp	0.77	1.71	2.73	3.44	4.20
Bighead carp	0.90	2.10	3.27	4.98	9.10
Grass carp	0.80	1.83	2.75	3.80	
EaKao (240 ha)					
Silver carp	0.54				
Bighead carp	0.70				

7. Recommendations for stock enhancement in large lacustrine waterbodies

7.1 Summary evaluation of current stock enhancement practices

It is quite apparent from the stock enhancement interventions adopted by different countries that they have not had a particularly strong biological basis and that there has been a general lack of critical evaluation. Stock enhancements have rarely been successful, except in the case of enhancement with species capable establishing breeding populations. The majority of successful enhancement interventions are almost entirely confined to medium-sized waterbodies, such as the EaKao Reservoir, Viet Nam. For Viet Nam, a substantial database is available and the reservoir fishery is almost totally dependent on stock enhancement; thus, a comparison of the data presented in Tables 22 and 25 is revealing. It is apparent that in most medium-sized reservoirs (Table 22), the stocked fish account for the great bulk of the catch. This is not the case in the two large reservoirs (Table 25), where the return of stocked fish ranges from 0.2 to 5.13 percent and averages only 4.4 percent.

Table 25. Summary data on economic returns of stocking in two reservoirs in Viet Nam (modified from Nguyen 2001)

Reservoir/species	Stocking		Recapture		Average weight (kg)	Harvest value ($x10^3$ VND)[1]
	No.	Cost ($x10^3$ VND)	No.	%		
DongMo						
Silver carp	777 500	11 429	14 306	1.84	1.5	29 334
Bighead carp	702 500	10 326	36 038	5.13	3.0	162 172
Mud carp	492 500	7 239	2 462	0.50	0.5	2 462
Grass carp	108 750	1 598	217	0.20	2.5	1 359
Cost-Benefit = Total harvest sales/cost of stocking = 5.38						
SuoiHai						
Silver carp	820 800	12 065	73 872	1.37	1.37	138 346
Bighead carp	471 360	6 928	22 483	1.47	1.47	49 576
Mud carp	430 080	6 322	39 997	0.42	0.42	33 597
Cost-Benefit = Total harvest sales/cost of stocking = 7.75						

[1] Price per kg at harvest in VND: silver carp – 13 670; bighead carp – 15 000; mud carp – 20 000; grass carp – 25 000; 12 500 VND = 1 US$ in 1998.

In almost all the cases reviewed, the number of fish stocked appears to have been rather arbitrary and not based on any apparent scientific rationale. Similarly, the species combinations used may have been more of a reflection of availability, rather than specific knowledge. In mitigation of this, some stocking activities have sought to fill apparently vacant ecological niches. However, in large waterbodies the trophic relationships are extremely complex, and thus basing a stocking strategy on experiences from aquaculture ponds, in accordance with the polyculture principle in which a species is selected to fill a food niche, may not necessarily be the most suitable approach. This is apparent for a number of reasons:

- The water is typically much deeper than an aquaculture pond.
- Larger waterbodies have relatively low fertility and hence, phytoplankton productivity.
- There are influences of the catchments and climatic factors on productivity.

- The cycles of productivity are quite different.
- There are far more complex trophic relationships, due to the greater diversity of organisms.
- There is relative inaccessibility (seasonal or otherwise) to certain food sources resulting from physico-chemical stratifications.
- The nature of the fishery itself may prevent or minimize recruitment of the stocked species.

It is also apparent that for most enhancement strategies there was no attempt to correlate the amount stocked to the potential productivity of the particular waterbody. This ought to be the first step before determining the species composition of the seed stocked. There are now a number of tools available for fishery management to predict the total yield from a waterbody. The development and successful application of the Morpho Edaphic Index (MEI) for inland waterbodies in North America (Ryder 1965) was a starting point for this. Although primarily for natural lakes, MEI has been used for this purpose for tropical waterbodies (Henderson and Welcomme 1974).

Other fish-yield prediction indices have been developed, e.g. chlorophyll-a (Oglesby 1977) and shore-line development (Moreau and De Silva 1991). There has also been one prediction index using geographic information systems based on catchment land-use patterns. These appear to be a significant factor influencing reservoir productivity and hence fish yield (De Silva *et al*. 2001).

Such predictive models are increasingly used in managing individual fisheries, such as in Sri Lanka, through determining the number of operable crafts in a waterbody, a strategy that is expected to be increasingly adopted by other countries.

7.2 Developing a stock enhancement strategy for large inland waterbodies

Poorly planned attempts to stock large lacustrine waters yield very little rewards, except perhaps for the carnivorous, often naturally recruited, indigenous species already inhabiting these waterbodies, for whom the stocked fish provide an easy meal. Despite this, there is no reason to presuppose that well planned and well executed stock enhancement strategies will not yield positive results, even though such instances are very few and far apart (i.e. the occasional enhancement by species capable of establishing self-reproducing populations). The following sections contain suggestions regarding the process that could be followed in order to develop suitable stock enhancement strategies for large, inland, lacustrine waters in the Asian region.

7.2.1 Does the waterbody require a stock enhancement strategy?

Stock enhancement is not cheap, and a basic prerequisite for developing a strategy is to evaluate critically whether or not the waterbody requires any form of stock enhancement. As part of this evaluation, a number of questions must be addressed:

- What is the current yield and the species composition of the fishery?
- Is the fishery primarily dependent on indigenous and/or exotic species?
- Are the main constituent species of the fishery self-recruiting and does spawning occur in the waterbody or not?
- What is consumer acceptance of the main constituent species?

Having clear answers to these questions will indicate whether the waterbody needs regular stock enhancement.

7.2.2 What form should the enhancement take?

Should it be decided that stock enhancement is indeed warranted, the next decisions relate to the form of enhancement:

- Should the fishery be sustained through a regular stocking programme of non-self recruiting, but desirable species with ready consumer acceptability?
- Is it more appropriate to "reseed" depleted spawning populations of major species of the fishery (to sustain the existing self-recruiting fishery of either indigenous or exotic species)?
- Will the activity be financially sustainable?

There are only a limited number of large waterbodies (>600 ha) in Asia that depend on sustained stocking for their fisheries. Perhaps the main example of this is the reservoirs of Viet Nam. Prior to economic liberalization, stocking programmes in Vietnamese reservoirs were heavily subsidized by the central government, and all fishers and managers were on a monthly wage, irrespective of the fishery income. It has been previously pointed out that Viet Nam, in spite of its rich inland ichthyofauna, does not appear to have suitably adapted lacustrine species that could sustain relatively large and intense artisanal fisheries. The reasons for this are not immediately apparent, however. It may be that inland fishery developments in Viet Nam will have to continue to adopt a stock enhancement strategy, and details of such a strategy will have to be determined through trial and error coupled to sound scientific reasoning.

7.2.3 How to decide what to stock?

This is perhaps the most difficult question to answer, but addressing the following issues could ensure that the stocking activity achieves its objectives:

- Determine the potential fishery yield of the waterbody using an appropriate yield-predictive model.
  - If the actual fish yield is close to the predictive value, then stocking will not be effective and therefore it should not be undertaken. The principle in predictive yield models is that the model takes into consideration the overall productivity of the waterbody based on nutrient loading, using different parameters. The overall fish production depends on the natural food supply in the waterbody. If the existing populations are already sufficiently adequate to harness this food supply, increasing fish numbers through stocking will not be effective, and indeed there is the possibility for it to be counter-productive by diminishing growth.
  - If there is a significant gap between the actual and predicted yield, then enhancing fish stocks may be justified. Ideally, the stocks that should be enhanced are those that are the major constituents of the existing fishery, rather than through introduction of alien species. In addition, for practical purposes it is recommended that only one or two species be used for the enhancement.
- One of the most crucial aspects of stocking is to ensure that the stocked fish are of sufficiently large size. In Chinese culture-based fishery practices, where the predatory pressure is minimal, years of experience have shown that the most desirable size for stocking is above 13 cm in length (approximately 25 g fish). In large reservoirs, there is bound to be considerable predatory pressure and consequently, it will be appropriate to stock fingerlings larger than 13 cm in length.

- After the expected yield from the species to be stocked is estimated, the growth rate of each species in the fishery (or from comparable habitats) can be used to determine the time required for a suitably sized fingerling (typically more than 13 cm in length) to reach a target mean landing size (for example, 700 g).
- Using these data, it will be possible to determine the number that need to be stocked. Obviously, a reasonable allowance has to be permitted for potential mortality, which at the start of an enhancement initiative will be a very crude estimate, with time and experience this estimate can be improved and the stocking numbers adjusted accordingly.

7.3 Constraints to developing and sustaining stock enhancement strategies for large waterbodies

It quite clear from the analysis of enhancements for the individual countries covered in this review, that one of the main constraints to developing and sustaining stock enhancement initiatives in large waterbodies is the lack of economic viability. This lack of economic viability results from the poor planning of most programmes, including a general failure to use scientific criteria in their design. Even when enhancement initiatives are well designed based on the best scientific knowledge, a major practical constraint to developing sustained stock enhancement programmes is the availability of suitably sized fish for stocking (i.e. >13 cm). While the technical capacity exists in most Asian countries to produce large-sized fish for stocking, the culture area (i.e. aquaculture ponds) required and the costs to produce sufficient numbers for stocking constrains availability. In most countries in Asia, the fish fingerlings that are produced are typically channelled into aquaculture and culture-based fisheries (in smaller waterbodies). An additional issue is that most hatcheries are organized for the production of species used in aquaculture, and these are typically exotic species. The species selected for enhancing large waterbodies are quite often indigenous species that are capable of establishing breeding populations. There is, therefore, a significant gap between what is needed for the enhancement programme and what is available.

Quite probably, this situation is the reason why most enhancement initiatives in large waterbodies have been rather ad hoc and ill planned. They are hampered by inadequate supplies of the right species and in some cases, merely serve as a secondary use for “left-over” seed stock that cannot be used for aquaculture or culture-based fisheries.

Fisheries in large waterbodies in Asia are open access, with a few rare exceptions (e.g. Ayunha Reservoir (3 700 ha) in Phu Yen Province, central Viet Nam). This inevitably means that any stock enhancement strategy has to be undertaken by the relevant state agencies for the public good and cannot be expected to be an income-generating enterprise or even to break even. Examples of state investment in interventions of this nature (i.e. those in which the state does not directly benefit) are increasingly rare in the agricultural sector. Earlier in this review, it was mentioned that state-funded stocking of large waterbodies was in operation in Viet Nam until the economic liberalization of the late 1980s, when the stock enhancement programme had to be suspended. Thailand continues to stock its large waterbodies, with a clear understanding that this is for the general benefit of the open-access fishers who continue to rely on these resources. Where this activity persists, it can be said that the decisions on the quantity of fish stocked and the species used are probably more aligned to the available budget than to the actual requirements for intervention. It has been mentioned that many stock enhancement interventions are not particularly well designed, and that almost all of them are not adequately evaluated. This limits the ability to determine critically whether the stock enhancement activity is actually producing any real benefit or whether it is more of an exhibition of the state supporting poor fishers.

If the goal of the enhancement is to develop a sustainable fishery, then some form of cost-recovery mechanism is required, coupled to some form of fishery management. In most cases, this would be realized as access limitations through licensing or the establishment of a “fishers group”. Costs are recovered through realistic license fees or levies imposed on landings, the income being used to support the cost of seed for stocking and the management activities of the fishery. Such systems are rather difficult to implement in large waterbodies, since individual landings are dispersed around the fishery and cannot be effectively taxed. The cost of monitoring fishing boats is also high, and the large area to patrol makes illegal fishing quite possible, especially at night.

There is a more fundamental underlying problem and this is that fishers may be more willing to pay for an enhancement if they believe that it has an impact. The difficulty is in demonstrating that the stock enhancement activity is actually having an impact. Stocking with indigenous species (which then form self-recruiting populations) creates the problem that it is difficult to determine whether the fish captured is one that has been enhanced or whether it is naturally occurring. After the stocked fish become broodstock, this issue becomes irrelevant.

Stocking with exotic species is one way of demonstrating the effect of an enhancement activity. To the authors’ knowledge, this has taken place in at least one country in the region because the state agency undertaking the enhancement wanted the fishermen to be aware that the fish they were catching were the result of the agency’s stock enhancement activities. This is an example where the objective of the enhancement is directed primarily at building a relationship between fishers and state agencies in order to justify licensing and/or levies placed on the fishery.

The large reservoirs of Viet Nam are an example where co-management mechanisms have been established with access restriction and cost recovery mechanisms. Again, in this situation there is still little evidence that the stocking activity is cost effective.

The nursing of fingerlings for release to the fishery by fisher groups or individuals is one method to make fishers more accountable for the costs of stocking. In this case, the nursed fingerlings are paid for by the fisher groups. This, therefore, requires that the fishers using a waterbody are sufficiently organized to be able to levy fees on members to pay for the stocking. The land required for nursing in ponds is considerable, and therefore, the nursing of fingerlings in netcages has been suggested as a viable strategy in large inland waterbodies in Sri Lanka and Viet Nam (details are presented in Section 8.3). Local nursing takes advantage of locally available labour and relies on locally sourced materials. Nursing activities also provide opportunities for womenfolk of fisher households to be involved in the management of husbandry-related activities, for example, in the preparation of feeds, ingredients for which are sourced, at least partially, by fishers from the waterbody itself. There are probably more examples of this type of activity where the fish are not actually released, but are retained and fed in cages until harvested for sale. This cage aquaculture is relatively common on large waterbodies, but requires an investment level beyond the reach of many of the poor fishers who are reliant on the open-access fisheries of large waterbodies.

In most of Asia, large waterbodies are typically under the purview of several different administrative bodies such as irrigation and agriculture authorities, hydroelectric generation bodies and occasionally, forestry or national park authorities. They are rarely, if ever, under the management of fisheries authorities. The stocking of fingerlings in large waterbodies is rarely coordinated with water release schedules nor are suitable structures installed near sluices to prevent the loss of stocked seed. Lack of coordination between stocking events and water release, especially in the immediate post-stocking period before the seed finds its most suitable location within a waterbody, can often result in loss of stocked seed. In smaller waterbodies, there are conflicts between water use for irrigation and retaining the minimum amount of water necessary to support fish or a fishery. In very small irrigation reservoirs, it is not unusual for almost complete drainage to occur. This can lead to conflicts between fisheries groups and groups that rely on water for dry-season irrigation. Unfortunately, except the study of Jhingran (1992), this issue has not been studied in detail anywhere in the world, and it essentially remains an unknown entity that affects the returns from all stock enhancement programmes. Jhingran (1992) reported a nearly 300 percent increase in fish production in three reservoirs in India as a result of coordination between water release and stocking, and provision of devices to prevent fingerling escape from the spillway.

8. Stock-enhancement in small and medium-sized inland waterbodies

The area of small waterbodies (those with water area <400 ha) in the region is estimated to be 66 710 052 ha (FAO 1999). The great majority of these waterbodies are man-made, except perhaps the oxbow lakes (locally known as baors) in Bangladesh. These waterbodies are typically constructed for irrigation purposes, supplying water for downstream agricultural activities such as rice-paddy cultivation and often depend on relatively small catchments for water. The management of these small waterbodies usually comes under the purview of a government authority such as Agrarian Services (Sri Lanka) and/or a division (e.g. Irrigation Department) of the agricultural services (e.g. Thailand, Lao PDR etc.). Day to day management of the water resources is carried out by the competent government agency, often in collaboration with government-approved farmer organizations comprised primarily of the downstream farming communities. Such organizations have various names and can be collectively referred to as “water user groups”. Perhaps one of the few exceptions in the region are the leased floodplain fisheries in Myanmar, where large areas of the floodplain are effectively almost perennial waterbodies and can be quite large (up to about 600 ha). These waterbodies fall under the purview of the fisheries authorities of the government and the local authority, which determines the leasing arrangements. In PR China, each waterbody is managed by a Reservoir Bureau, with subcomponents for catchment, downstream and fishery management. In Viet Nam, small waterbodies come under the purview of the provincial government authorities, such as the agriculture and rural development departments of the provincial government. These waterbodies are leased to individuals or groups of individuals for varying periods of time, for conducting fishery activities.

Small waterbodies have very different characteristics to those considered in the previous section, and the major differences are listed in Table 26. The natural fish recruitment and production of small waterbodies are usually is too low to support any substantial fishery. Because of its small size, the waterbody has few habitats that cannot be easily fished, and thus while the productivity of the waterbody might be quite good, the natural fish population is quite vulnerable to over-fishing. Fisheries development in small waterbodies is therefore usually done in conjunction with a regular stock enhancement programme.

Small waterbodies also tend to be managed by individuals and/or organized groups of individuals who determine access and fishing effort and in some cases, implement some form of stock enhancement. These groups also tend to have some form of direct or indirect ownership of the stocked fish that may or may not have some form of official recognition. This range of features is quite different to the situation found in the open-access fisheries of large waterbodies, and they are, in fact, features more akin to the definition of aquaculture. These forms of management practice are commonly referred to as “culture-based fisheries” (FAO 1997, De Silva 2003) or “aquaculture-based fisheries” (Lorenzen 2003).[5]

The scope for fisheries development in small waterbodies (i.e. culture-based fisheries development) is widely recognized (Welcomme and Bartley 1998; De Silva 2000, 2003; Lorenzen *et al*. 2001) to have one of the highest potentials to increase foodfish production in Asia in the near future. Such developments have added benefits to most communities, and foremost of these are:

- providing an affordable source of fresh animal protein;
- contributing significantly to rural household and farmer income;

[5] This review will use the former terminology of “culture-based fisheries” throughout.

Table 26. A comparison of the principal, general characteristics of small and large inland waterbodies

Small waterbodies	Large waterbodies
• Almost always man-made and single purpose; generally for minor irrigation	• Natural (lakes) and man-made; the latter single- and/or multi-purpose
• Often located in small catchments; dams simple, simple engineering of sluices and spill ways; often tend to dry-up for some part in the year; rarely any dead-storage	• Catchments relatively large and very diverse; dams, when present, are elaborate; sophisticated engineering of sluices and spillways when present; rarely dries up; always will have a dead storage area
• Shallow and productive	• Deep to moderately deep; biologically less productive
• Often sheltered; shoreline relatively regular; littoral area gradually sloping	• Embayments, coves etc. always present; shore line irregular; littoral areas generally more steep
• Sufficiently small to be able to manipulate natural productivity	• Almost impossible to manipulate natural productivity
• Very limited naturally recruited fish stocks; naturally recruited stocks tend to be small-sized species; often insufficient to support any artisanal fishery	• Could have large self-recruiting populations supporting artisanal fisheries; production variable from year to year and influenced by fishing mortality
• Fisheries generally have to be developed and sustained through regular stocking	• Stocking may enhance fish production

- encouraging multiple and non-consumptive use of a primary resource – water, with little foreseeable negative influence(s) on the traditional use of the resource by the community;
- creating synergies that result from a communal activity, with relatively undefinable and unquantifiable but often positive influences on the immediate community;
- being relatively less resource intensive and needing little capital expenditure as compared to most forms of aquaculture; and
- opening up of new opportunities for some sectors of the community as a direct result of culture-based fishery development.

Fishery development in small inland waterbodies shares many common features of pond aquaculture:

- the environment is relatively easy to manipulate;
- the waterbody can be prepared so that almost all the stock is what was seeded (through removal of “wild fish” prior to stocking);
- seed stock can be based on potential consumer acceptability and marketability;
- all stock is harvestable, and partial or staggered harvesting can be carried out to suit market demands; and
- the natural productivity can be enhanced through fertilization (if commercially viable).

In general, the greatest difference between pond culture and culture-based fisheries is that the latter is a secondary user of the water resource and rarely needs supplementary feed input (with the possible exception of grass when grass carp is stocked), relying instead on natural productivity and/or fertilization.

8.1 Stock enhancement and/or culture-based fisheries in Asia

Considering the diverse opportunities and potential within the Asian region, it is perhaps surprising that, with the exception of PR China, culture-based fisheries have only received attention in most countries in the last 20 years. The possible reasons for this are that:

- Pressure on aquatic food resources began to occur only two to three decades ago.
- Culture-based fisheries were dependent on limited wild sources of seed stocks and were in competition with aquaculture for that supply.
- Artificial propagation of stocked species has only recently become a widely available technique.
- Waterbodies suitable for culture-based fisheries were under the purview of non-fisheries related state authorities.
- Farming communities who used the water resource had little interest or skill in culture-based fisheries.
- A relatively recent realization at the policy level, of the potential of culture-based fisheries has led to the consequent provision of relevant state mechanisms to support development, including the introduction of required legislative changes, provision of institutional structures etc.

Most developing countries in Asia that have suitable water resources now acknowledge the potential of culture-based fisheries to contribute significantly to foodfish supplies, particularly among the rural poor. The latter group is the immediate beneficiary of such activities by virtue of the fact that most of the water resources suitable for culture-based fisheries are invariably located in rural areas.

There has been quite a significant amount of research targeted at culture-based fisheries in Asia over the past two decades (see, for example, Thyaparan 1982; Lorenzen 1995, 2003; Middendorp *et al*. 1996; Lorenzen *et al*. 1998; Nguyen *et al*. 2001; De Silva 2003), and this review will not cover individual country practices (Plates 19, 20, 21). The common features of culture-based fisheries are that they tend to be communal activities and are mostly village based. The yield from culture-based fisheries far exceeds that from other larger, inland waterbodies (Middendorp *et al*. 1996, Lorenzen *et al*. 1998, Nguyen *et al*. 2001), and in certain instances, even that from semi-intensive pondfish culture. Perhaps the greatest strides in culture-based fisheries have been made in PR China, where the yield increased from about 50 000 to 1 million tonnes in the period 1980–1997, with a concurrent increase in yield from about 80 to 763 kg/ha/yr (Song 1999).

Li (1988, 1992) and Li and Xu (1995) described the culture-based fishery practices in PR China, where over a number of years of trial and error, general guidelines for maximizing production from culture-based fisheries have been empirically determined. Foremost among these is the stocking size and preparation of the waterbody prior to stocking. In China, the average stocking size is 27 g (12-14 cm seed), and in small and medium-sized waterbodies, predators are removed prior to stocking. A more recent development in culture-based fisheries is to retain, depending on the nature of the waterbody and the prevailing prices, high-valued, small predatory species such as clearhead icefish *(Protosalanx hyalocranius)* and indeed, such species may be introduced to increase the value of the yield (Liu and Yongchuan 1998). The Chinese culture-based fishery is based on using standard species combinations and stocking densities that are calculated from the productivity of each reservoir (Table 27). Another notable factor contributing to the relatively high yields is that fishery activities were taken into account during the planning stages of Chinese reservoir construction. This included designs that minimize the number of escapees and facilitate harvesting.

Plate 19. Aspects of culture-based fisheries in oxbow lakes in Bangladesh (photos by Dr. M. Hassan). (A) A general view of an oxbow lake. (B) Oxbow lake fishing community gathering. (C) Fishing in operation and (D) the harvest.

Plate 20. Aspects of culture-based fishery practices in Sri Lanka; (A) Community meetings of farmers held regularly to plan activities. (B) Stocking. (C) Partial harvesting. (D) Sorting the harvest.

Plate 21. Aspects of culture-based fishery practices in Viet Nam: (A) Weighing of fingerlings. (B) Acclimation of fingerlings before release. (C) Partial harvesting in progress. (D) A woman farmer lessee with some of the harvest ready for the market.

Table 27. Data depicting the relationship of stocking combinations and mean yield to reservoir trophic status and size, in culture-based fisheries in PR China (modified from De Silva 2003; original data based on Li and Xi 1995)

Size (ha)/ Trophic status	SD (fish/ha)	Stocked proportion (%)			Yield (kg/ha/yr)
		Bh, Sc[1]	Gc, Wf	Cc, Mc	
Small (<70)	3 000-7 500				750-3 000
Eutrophic		45	40	15	
Hypotrophic		35	30	35	
Oligotrophic		10-15	10-15	70-85	
Medium (70-670)	1 500-3 000				45-750
Eutrophic		45	40	15	
Hypotrophic		50	30	20	
Oligotrophic		40	20	40	

[1] Bh – bighead carp, Sc – silver carp, Gc – grass carp, Wf – wuchang fish; Cc – Common carp, Mc – mud carp.

Based on an estimated area of 66 710 052 ha of small waterbodies in the Asian region (FAO 1999), De Silva (2003) predicted that even if only 15 percent of the total area was under culture-based fisheries using the best practices of the Chinese, this would translate into a potential fish yield of 2.5 million tonnes/yr. This may not be an unrealistic estimation in view of the increasing emphasis by governments on culture-based fisheries development in the region and the accompanying changes that are being introduced to improve institutional structures to make them a success. As the management of culture-based fishery activities is mostly at the community level, their success depends, to a significant extent, on having the appropriate and functional village institutional structures in place (Lorenzen *et al*. 1998).

8.2 Constraints to culture-based fishery development

As indicated earlier, with the exception of PR China, culture-based fisheries is a relatively new development in many Asian countries. This means that the technical, management and socio-economic aspects are still in a process of development. It is possible to identify a number of common constraints that affect most countries that must be addressed if culture-based fisheries are to be developed to any significant degree.

8.2.1 Species combinations and stocking ratios

One of the main constraints in optimizing yields from culture-based fisheries in most countries is the lack of knowledge on the most appropriate species combinations that should be used. Use of ad hoc species combinations and stocking densities can lead to reduction in yield, as well as the production of under-sized fish, resulting in low economic return. The waterbodies suitable for culture-based fishery activities differ widely in their morphology, catchment features and hydrological regimes and consequently, in their biological productivity. The final yield from a waterbody will depend not only on the species stocked and their size at stocking, but also on the biological productivity of the waterbody, which determines the food availability to the stocked seed, and hence their growth and well being. The success seen in PR China is based on the adoption of stocking strategies that have been worked out to suit the productivity of each waterbody (Table 27). A comparable method based on Secchi depth has been developed for oxbow lake fisheries in Bangladesh (Hasan *et al*. 1999).

The final strategy is based on the relationship of productivity (Y = fish yield in kg/ha) to stocking density (SD = number/ha) and Secchi depth (X = cm), which are:

$$Y = 811 - 3.18\,X, \text{ and}$$

$$Y = 15.88 + 0.184SD.$$

Examples of stocking densities and related species combinations for two oxbow lakes of different productivity suggested by this model are given in Table 28.

The empirical models used in Bangladesh and PR China provide an opportunity for the improved planning of enhancement activities that would not only lead to a cost saving on seed stock, but also to increases in fish yield.

Table 28. The suggested stocking ratio for culture-based fisheries in two oxbow lakes of different productivity (based on Secchi depth). Compiled from data from Hasan *et al.* (1999)

Fish species	Number stocked	Ratio	Fish species	Number stocked	Ratio
Secchi depth 100 cm; stocking density 5 000/ha			**Secchi depth 180 cm; stocking density 3 000/ha**		
Silver carp	1500	6	Silver carp	450	3
Catla	500	2	Catla	300	2
Grass carp	500	2	Grass carp	450	3
Rohu	1250	5	Rohu	750	5
Mrigal	500	2	Mrigal	450	3
Common carp	750	3	Common carp	600	4

8.2.2 Seed supplies

Problems of seed supplies are not restricted to quantity and quality. Culture-based fisheries are often a secondary activity that is typically conducted in small non-perennial waterbodies. The timing of the supply of seed for stocking is crucial, and availability has to coincide with the filling of these waterbodies with the onset of rains. De Silva (1988) pointed out that the failure of the culture-based fishery development programme in Sri Lanka in the early 1980s was primarily due to the lack of availability of suitably sized fish at the correct time. The problem tends to be further exacerbated in most countries, as the main species used in the programmes (Chinese and Indian major carps) are often artificially propagated only once a year, typically at the onset of the monsoon season. This means that the fingerlings are too small to stock, and by the time they have been nursed, the water in small, non-perennial waterbodies is already depleted. The spawning of Chinese and Indian carps several months prior to the rainy season is possible, as well as multiple spawnings; however, this is more complicated and would not become mainstream practice unless there was high demand.

8.2.3 Management structures/institutions

Successful culture-based fisheries are dependent upon functional management structures, and these require a supporting institutional environment.

In Bangladesh, for example, the culture-based fisheries are in oxbow lakes that are under the purview of the Department of Fisheries and are managed by the stakeholders, a system that is referred to as a common property regime (CPR). Apu *et al*. (1999) observed that such a CPR can be sustained only through fostering cooperation among stakeholders (fishers), by providing incentives, maintaining equity, and ensuring democratic rotation of leadership and the monitoring all operations by the fishers themselves. These authors also observed that long-term security of tenure of the fishing rights for the CPR, as well as the long-term tenure of individual fishers in the CPR, were important determinants of sustainability.

Felsing *et al*. (2003) pointed out that in India, the current institutional context provides only limited incentive or support for aquaculture initiatives appropriate for resource-poor farmers, such as culture-based fisheries in non-perennial waterbodies in rural areas. These authors noted that the governmental emphasis is on capital intensive aquaculture technologies suitable for wealthier farmers, and that this emphasis has a bearing on the availability of credit, waterbody usage etc. They concluded that existing policies would hamper culture-based fisheries development or at least fail to provide the necessary momentum needed for the practices to flourish.

In Sri Lanka, the waterbodies used for culture-based fisheries are already under the management of the Village Cultivation/Farmers' Committee (VCC) (drawn from among the downstream farming community), under the overall purview of the Department of Agrarian Services. Government bodies associated with fisheries development have no authority over these waterbodies. Culture-based fisheries in small, non-perennial waterbodies could therefore be developed only through the involvement of interested parties of the VCC, functioning as a Fishery Subcommittee of the VCC, thereby ensuring harmony among the major users of the water resource. Pushpalatha (2001) discussed the importance of the involvement of the farming community in culture-based fishery development and the need to train the farmers in the practices *per se* prior to investing in development.

8.2.4 Harvesting and marketing

The main harvesting period for most culture-based fisheries in the region is dictated primarily by the water regime in these non-perennial waterbodies, harvesting being done as the waterbody dries up. In general, this means that in a given area there will be simultaneous harvesting in many such waterbodies, often leading to an excess supply within a very short time frame and leading to a reduction in farm-gate price. The situation is further exacerbated because the great bulk of culture-based fisheries in the region are conducted in rural areas of low population density, where marketing channels are often not well developed. In most countries in Asia, with the possible exception of PR China, culture-based fishery activities are taken up by traditional agricultural farmers, as a subsidiary activity, and it is important that these activities result in a net economic gain to maintain farmer interest and hence, long-term viability. Therefore, the need to address the above issue is crucial.

There is very little information available on post-harvest technology for the species commonly used in culture-based fisheries, as well as on consumer acceptability of such products. Perhaps this is an area that warrants further investigation. Development of simple processing techniques such as sun drying of suitable species may be one avenue of ensuring a reasonable return to the producers.

Another plausible solution to preventing an over supply of fish in a given area may be to introduce staggered harvesting as the dry season approaches. Such an approach could be advantageous in two ways: firstly, by preventing an over supply within a narrow time frame and secondly, by increasing yields as a consequence of removal of the larger cohorts from the population. However, this strategy requires training of the communities involved on methods of partial harvesting, i.e. techniques for using a selective gear such as gillnets, ready access to such gear, and the rationale for adopting such a strategy. Adoption of this strategy should be preceded by relevant research, as information in this regard is not presently available.

8.3 Fingerling production for stock enhancement

The availability of fingerlings of appropriate size and species remains one of the major constraints to all forms of stock enhancement practices in most Asian countries. In most countries, often the priority is to fulfil the fingerling requirements for intensive aquaculture operations, and consequently and more often than not, the requirements for stock enhancement practices fall behind. It is also difficult to separate the availability of supplies for stock enhancement from that for aquaculture *per se*. Indeed, the problems of availability of seed stock and its quality have not received the attention that they rightly deserve from governments and researchers.

Technically, artificial propagation of the bulk of the species used in stock enhancement practices in Asia has been successful. Perhaps one of the improvements needed is to develop techniques for routine multiple spawnings in a year, ensuring a year-round supply of seed stock. Only the year-round availability of seed stock will ensure that most waterbodies, particularly the non-perennial ones, can be stocked at the proper time, so that the whole culture period can be effectively used by the stock. As previously discussed, one of the reasons for the failure of the culture-based fisheries programme in Sri Lanka in the 1980s was incorrect timing between seed availability and the filling of waterbodies (De Silva 1988).

In most Asian countries, backyard hatcheries are common, particularly for the propagation of Chinese and Indian major carps. These backyard hatcheries generally produce only fry, which are not suited for stock enhancement purposes, unless grown to advanced fingerling stages (Plate 22). Backyard hatcheries are generally effective, not capital intensive and are managed by at most, two persons. In Orissa, India, for example, community-based carp hatcheries are successfully run by village women (Radheyshyam 2001). These community-based hatcheries enable poor women who do not have pond resources to be engaged in fish-related activities, providing them with additional household income. Such hatcheries tend to contribute significantly to rural aquaculture development and indirectly, to poverty alleviation in rural communities.

Plate 22. (A) A backyard hatchery in southern Nepal, and (B) in Dak Lak Province, central Viet Nam (also see Plate 12).

Fry production is often separated from fry to fingerling rearing, and this is the bottleneck for most stock enhancement and extensive aquaculture. In the authors' view, one of the most effective fry to fingerling rearing systems is found in Viet Nam. Here the fry produced in hatcheries are often reared to advanced fry stages in concrete tanks in the hatchery complex itself, and the rearing of advanced fry to fingerlings is carried out in earthen ponds owned by fingerling producers (Plate 23), who may be many hundreds of kilometres away from the former sites. This division of labour offers many advantages – higher rate of survival to fingerling stage, better distribution of income, the spread of aquaculture-related activities into a wider area of the country and easier access to fingerlings for aquaculture and stock enhancement purposes. In addition, it also contributes to income generation in rural areas.

Sen *et al*. (undated), in one of a few such studies in the region, studied fingerling production systems in three provinces in Viet Nam (Hoa Binh, Thai Nguyen and Yen Bai). These authors recognized four categories of fingerling production/rearing/nursing systems:

- hatchery-based nursing systems;
- full or part-time private pond-based nursing systems near hatcheries or main centers;
- part-time private nurseries in remote areas; and
- part-time cage culture.

These authors observed that the demand for smaller-sized fingerlings (6 cm) occurred around April-May, that for medium-sized fingerlings for cage and paddyfield stocking around May-August and finally, that for the largest fingerlings (12 cm), for stock enhancement in reservoirs, in September-November. Sen *et al*. (undated) conducted a preliminary economic analysis of the different production/nursing systems (Table 29), and found that there was a large variation in net income among farmers using a particular practice, as well as between practices. These individual variations were attributed to differences in the number of production cycles, survival rates, species cultured, farmer knowledge, pond management practices and time spend on other economic activities.

Plate 23. Fry to fingerling rearing facilities in concrete ponds and in outdoor earthen ponds in Viet Nam

The use of cages in fry to fingerling rearing is becoming increasingly popular in some countries, particularly those having large numbers of perennial waterbodies (Plate 24), such as Sri Lanka (Ariyaratne 2001, Pushpalatha 2001) and Viet Nam (Bui and Nguyen 2001). Generally, the initial investment and labour costs in cage fry to fingerling nursing are much higher than those for comparable activities on land. However, these costs can be balanced through the relatively high profitability of the former. Ariyaratne (2001) suggested that feed costs in cage nursing can be reduced by harvesting small fish species such as minor cyprinids from the perennial waterbodies where cage-culture operations occur (De Silva and Sirisena 1989). Minor cyprinids are not used for human consumption, but for preparing low-cost, farm-made feeds (Plate 25) of relatively high protein content by sun drying, powdering and mixing with other agricultural by-products.

Unfortunately, fry to fingerling rearing has received only marginal attention from researchers and governments in Asia. In many countries, the processes have evolved and adapted as a result of rural entrepreneurship, rather than through governmental encouragement and backing. The dearth of well planned studies comparing different fry to fingerling rearing systems in Asia is also bound to retard development and adoption of these practices as an alternative livelihood in rural areas, in spite of the scope and the demand for expansion and the products.

Table 29. A summary of the preliminary economic returns from different fingerling production/rearing systems in Viet Nam (based on data from *Sen et al.* undated)

Type of practice	Net income (VND/m^{-2})[1]	
	Mean	Range
Hatchery based	1 372	975-2 039
Full/part-time, pond-based	6 735	1 372-19 024
Part-time, remote areas	3 388	2 400-4 376
Cage rearing	234 757	7 268-723 915

[1] 1 US$ = 14 500 VND.

Plate 24. Cages for the culture of fry in a perennial water body

Plate 25. Cage operator family preparing a farm-made feed using minor cyprinid species (not used for human consumption) caught in the perennial water body, dried and powdered and used as a replacement for fish meal

9. Biodiversity issues in relation to stock enhancement in inland waters

Relatively un-regulated tropical rivers and their floodplains support a high biodiversity, rivalling that of the most diverse marine systems. This is due, in part, to extreme ecosystem complexity. Such rivers traditionally support very important, but often under-valued, fisheries (Coates *et al.* 2003).

Although surface freshwaters account for only a very small proportion of all waters on earth (see Figure 6), they are estimated to contain 2.4 percent of all known living species, and per unit area, are slightly richer in species than is the land (3.0 vs 2.7), and about ten times richer than are the oceans (3.0 vs 0.2) (McAllister 1999). They also account for a relatively richer ichthyofauna, an estimated 41 percent of the approximately 25 000 species of fish occurring in freshwaters. On the negative side, 20 to 35 percent of freshwater fish species are thought to be either threatened or extinct, and 43 percent of crocodilians and 59 percent of freshwater mammals are threatened (McAllister 1999). An analysis of fishes under threat in the 1996 International Union for the Conservation of Nature (IUCN) Red List indicated that species that depend on freshwater at any stage of their lifecycle are 10 times more likely to be threatened than marine and brackishwater species (Froese and Torres 1999). These authors, who confined themselves to only those species listed in FishBase (Froese and Pauley 2005), observed that 547 of the 637 threatened species (nearly 85 percent) had a link to freshwater. All these facts show the need to consider the impacts of stock enhancement on biodiversity if fisheries in inland waters in developing countries are to be sustainable.

There seems to be a common perception that, apart from recent developments such as dam building and a general deterioration of the quality of natural waters, the deliberate and/or accidental introduction of species has had a significant affect on biodiversity. However, De Silva *et al*. (2004), in reference to tilapias, which have had a major impact on fisheries and aquaculture in the Asia-Pacific region, concluded that there is no objective evidence to show that these introductions have significantly affected biodiversity in the region. Indeed, these authors went on to demonstrate that most of the evidence that has been brought forth previously has been misinterpreted and misconstrued.

Most stock enhancement practices in Asia, except perhaps in PR China and India, tend to use exotic species, mostly Indian and Chinese carps, which are known to grow fast and reach large sizes. There has not been a concerted attempt to assess the influences of these species on biodiversity in any nation, except for the preliminary study by Hossain *et al*. (1999) on stock enhancement in beels in Bangladesh described in Section 9.1. Even more disconcerting is that translocations of some of the above species within national boundaries are a common practice. More often than not, such translocations are not considered as “introductions”, and any affects they may have on biodiversity receive little or no attention.

9.1 Biodiversity issues associated with floodplain fisheries stock enhancement

Floodplain waterbodies are neither riverine nor lacustrine, exhibiting features of both of these categories at some stage of their annual watercycle. The importance of floodplains as nursery, breeding and feeding grounds for many riverine fish species has been well documented. It is within this context that human interventions through physical changes to the floodplains and/or biological modifications such as through stock enhancement and introductions and transfers can impact biodiversity.

In the floodplain examples cited in the previous sections, stock enhancement activities have almost without exception involved exotic species, e.g. the use of Chinese carps and Java barb in Bangladesh and tilapia in Myanmar. Appropriate assessment of the biodiversity of floodplain fisheries is problematic, as they do not always have a permanent/resident fauna and the cyclical effects of flooding mean that this fauna changes according to the effects of inundation. To assess changes in biodiversity under such conditions is difficult, and to attribute the impacts of stock enhancement to any of these changes is even more problematic.

Hossain *et al.* (1999) conducted a study in three floodplain beel fisheries in Bangladesh from 1992 to 1995 that involved catches for 23 gear types (11 of which were selective). In this study, 41 species belonging 19 families (Table 30) were recorded (not taking into account species groups and two species for which the family status was not clear). Most importantly, only six species (including stocked species) were common to all three fisheries, clearly indicating the diversity of the fish fauna of the different floodplains. The authors used the Shannon-Weaver Index as a measure of diversity and concluded that (Table 31):

- in one beel (BSKB), fish diversity increased during the study period;
- the diversity index for all three beels varied from year to year;
- the stocked species dominated (by number) in the catches only once and in one beel only;
- the diversity index in two of the beels (Chanda and Halti beels) declined on termination of stocking with carp fingerlings; and
- overall, fish diversity declined significantly in one beel, remained unchanged in another and showed a small increase in the other beel.

In general, it is accepted that fish biodiversity of rivers and their associated wetlands is under severe threat. Welcomme (2000) suggested that perhaps the current threats make them the most endangered ecosystems on earth. Although the extent of stock enhancement of floodplain fisheries, and in particular, the use of exotic species for their enhancement, is not widespread in Asia, we know very little of the influence of this practice on biodiversity.

As the fragility of river and associated wetland ecosystems is increasingly perturbed through direct and indirect human intervention, the threat to the biodiversity of these systems is likely to increase. Stock enhancement offers opportunities for sustaining the productivity of some waterbodies – particularly those waterbodies whose fisheries have been impacted by environmental modifications or man-made structures such as reservoirs. This must be balanced against potential negative effects on biodiversity in other waterbodies that are still in a relatively unperturbed state and which still provide fisheries services through natural, unenhanced recruitment processes.

The study of Hossain *et al.* (1999) is perhaps the only attempt in Asia to discern a relationship between stock enhancement and fish faunal biodiversity, and it brings to focus the complexity of the problem and the serious lack of information relating to the issues concerned. With the current state of knowledge, it would be difficult, if not impossible, to draw general guidelines for future developments of stock-enhanced fisheries of floodplains. Indeed, the only way this would become possible is through the commissioning of some relatively long-term studies on some of the significant floodplain fisheries of the region where stock enhancement is currently (or intended to be) undertaken.

9.2 Biodiversity issues related to stock enhancement in large lacustrine waters

The impoundment of rivers and streams brings about a reduction in biodiversity of the fish species of the impounded waters. This is due to the changes in flow regimes, barriers to spawning migrations, stratifications and altered trophic interactions. A recent study by Li (2001) on four representative reservoirs in PR China clearly showed a reduction in fish species biodiversity resulting from reservoir impoundment (Table 32). Another feature of impoundment is that, with the decrease in diversity, a few fish families tend to dominate the ichthyofauna. For example, in Danjiangkou Reservoir

Table 30. Fish species recorded from three floodplain, stock-enhanced fisheries in Bangladesh. Based on data from Hossain *et al.* (1999); only data on identifications to the specific level are included

Family	Species	CB[2]	HB	BSKB
Anabantidae	*Anabas testudineus*			++
Aplocheilidae	*Aplocheilus panchax*		+	
Badidae	*Badis badis*			+
Bagridae	*Mystus cavasius*		+	+
	M. tengara			++
	M. vittatus	++[3]	++	
	Sperata aor	+		+
Belontidae	*Xenetodon cancila*	++		
Channidae	*Channa marulius*		+	+
	C. punctata	++	++	++
	C. striata		+	++
Cobitidae	*Botia dario*		+	
	Lepidocephalichthys guntea	+		+
Clupeidae	*Corica soborna*	+	++	
	Gudusia chapra	+	++	+
	Tenualosa ilisha		+	
Cyprinidae	*Amblypharyngodon mola*			+
	Barbonymus gonionotus[1]		+	
	Catla catla		+	
	Cirrhinus cirrhosus			++
	Ctenopharyngodon idellus[1]		+	+
	Cyprinus carpio[1]	++		
	Labeo ariza	+	+	+
	L. gonius	+	+	
	L. rohita			++
	Hypophthalmichthys molitrix[1]	+		+
	Rasbora daniconius	+	+	
Gobiidae	*Glossogobius giuris*		++	
Heteropneustidae	*Heteropneustes fossilis*	++		++
Mastacembelidae	*Macrognathus aculeatus*		+	+
	M. pancalus			
Mugilidae	*Rhinomugil corsula*		++	+
Nandidae	*Nandus nandus*	++	+	+
Notopteridae	*Chitala chitala*	+	+	+
	Notopterus notopterus		+	
Schilbeidae	*Ailia coila*			+
	Clupisoma garua	+	+	
	Pseudeutropius atherinoides			+
	Silonia silondia		+	
Siluridae	*Ompok pabda*			+
Sisordidae	*Bagarius bagarius*	+	+	+

[1] introduced species.
[2] CB – Chanda Beel, 10 870 ha; HB – Halti Beel, 16 770 ha; BSKB Beel, 26 040 ha.
[3] ++ recorded among top five species at least once; + recorded at least once.

Table 31. Summary results of the Shannon-Weaver Index on fish species diversity, in different years, including (A) and excluding (B) stocked species, of the three floodplain beels (modified after Hossain *et al.* 1999)[1]

SWI:	Chanda Beel				Halti Beel				BSKB Beel			
Year:	'92	'93	'94	'95	'92	'93	'94	'95	'92	'93	'94	'95
Species	43	41	43	37	43	45	37	44	29	35	35	43
A	4.13	4.27	5.96	na[2]	4.27	3.94	na	na	3.5	3.66	3.53	4.14
B	3.69	3.55	5.96	4.05	3.98	3.41	3.41	2.72	2.49	2.82	2.89	3.30

[1] Note the number of species includes some species groups and hence, the discrepancy from Table 30.

[2] na = not available.

Table 32. Selected features of four reservoirs and the status of the fish fauna in comparison to the original river and the principal river system (modified from Li 2001)

Feature	Danjiangkou	Xinanjiang	Chanhshouhu	Hongmen
Original river	Hanshui	Xinanjiang	Longqi	Ganjiang
Principal basin	Yantze	Qiantangjiang	Yantze	Yantze
Year of impoundment	1967	1959	1955	1960
Size (ha)	62 000	53 333	4 470	6 900
Mean depth (m)	20.0	30.4	10.0	7.3
No. of fish species				
– Reservoir	67	83	40	69
– Original river	75	102	20	na[1]
– Principal basin	340	220	340	340

[1] na = not available.

members of the family Cyprinidae account for 64.2 percent of all the species, whereas in the original river they accounted for only 44.2 percent. Similarly, only 12 families occur in the reservoir as opposed to 49 in the original river (Li 2001).

Comparable reductions in the biodiversity of the ichthyofauna have been demonstrated in other countries. For example, in Hoa Binh Reservoir in northern Viet Nam, only 21 species have been recorded, whereas the river basin is purported to have 108 species (Ngo and Le 2001).

The loss of biodiversity in reservoirs cannot be avoided; it is an inevitable consequence of change from a riverine to a lacustrine habitat and the dam acting as a barrier to upstream movement of species. Conversely, it has been clearly shown that reservoirs have enabled increases in aquatic reptilian fauna and in fish-eating birds. Reservoirs are man-made habitats, and the more important question is whether the construction of a reservoir has resulted in a loss of biodiversity in the river that has been dammed and/or the principal river system of which the river is a part. The study of the effects of water management structures on river fisheries has been largely ignored during the initial environmental impact assessments, and it has only more recently been acknowledged that there have been wide ranging changes in the fisheries that were part of the systems affected.

More recent constructions have attempted to assess the effect of impoundments, but these have largely targeted the economic impact and/or overall production rather than the wider issue of species diversity. There is still a very poor understanding of how to balance the impacts of water management structures on fisheries and local livelihoods against the more wildly perceived benefits of income from electricity generation and irrigation. The reduction of the issues to gross economic returns often fails to capture relevant issues relating to people and their homes and the critical issue of long-term sustainability. A good example of this is the inappropriate application of aquaculture as mitigation for lost fishing livelihoods.

It is worth mentioning at this point that (typically cage) aquaculture is occasionally suggested as a means of offsetting the impacts on fisheries caused by dam closure or other changes to inland fisheries. The assumption is that the fishers can merely shift their activity to aquaculture. This simplistic approach is critically flawed for the following reasons:

- The aquaculture operation may often be geographically remote from the original fishing location (i.e. the loss of river fishing and requirement to move activities into the headpond behind a dam).
- The cost of the cages for aquaculture limits the ability of the great majority of fishers to change over to this activity.
- Fish in cages must be permanently guarded against theft, requiring a time investment that may have previously been used for other income generating/livelihood activities (this is rarely taken into economic calculations of the viability of aquaculture).
- The technical complexity of aquaculture is something that must be learned, making the activity highly risk prone in its early years.
- The establishment of aquaculture in a reservoir where there is a fishery means that marketing of the aquaculture product is in direct competition with the fish from the fishery, which may be lower priced or have a higher consumer preference (the result is that the aquaculture product may be more difficult to market profitably).

What is more relevant to the present study, however, is to assess whether stock enhancement in large inland waterbodies has been or is responsible for directly or indirectly influencing biodiversity. With the exception of PR China and Thailand, it can be generalized that the species used for stock enhancement of large waterbodies are almost always exotics. The issue then becomes more complex, as there are the double effects of the introduction of exotic species coupled to their effects on the existing species. This makes it very difficult to demonstrate cause and effect.

Perhaps the most controversial issue has been the introduction of exotic tilapias, most notably into Lake Lanao in the Philippines and their purported adverse affects on native cyprinids. Another example was the near extinction of a small endemic goby (the “sinarapan”, *Mistichthys luzonensis)* in Lake Buhi, which is also suggested to be the result of the introduction of tilapia. De Silva *et al*. (2004) critically examined the available evidence on both cases and concluded that the exotic tilapia was not a primary factor in the decline of these indigenous species. This is evidenced by the fact that, with better management of the fishery activities in Lake Buhi, “sinarapan” is staging a recovery. More recently, Guerrero (1999) considered the influence of tilapias on the biodiversity of finfish in lakes and reservoirs in the Philippines and concluded that there had not been any adverse affects on the endemic fish fauna.

In Indonesia, the decline of the indigenous cyprinid *Lissochilus* spp., considered to have cultural importance, in Lake Toba, was attributed to the introduction of *Oreochromis mossambicus* to the lake (Baluyut 1999), although supporting evidence for this observation is not available.

Perhaps the primary reason that most stocked species (particularly the Chinese and Indian major carps) do not tend to influence the biodiversity of large inland, lacustrine waterbodies is that they are generally unable to reproduce in such waters and thereby form large populations that would compete for common resources. The accidental introduction of silver carp into Gobindasagar Reservoir (16 867 ha), Himachal Pradesh, is reported to have resulted in a marked decline in the fishery for indigenous major carps and other indigenous species and a concurrent dominance of silver carp, followed by grass carp and common carp. The contribution to the fishery from the latter group increased to 87.4 percent in 1989 from a meagre 14.2 percent in 1974–1975 (Sugunan 1995).

During this change, the importance of indigenous species, in particular *Labeo dero*, *L. dyocheilus*, *L. bata*, *L. ariza* and *Barbodes sarana* drastically declined, not necessarily a reduction in biodiversity *per se*, but a change that could lead to such a status in the future.

The exception to this is the tilapia, which readily establishes in large waterbodies and forms large self-sustaining populations. The case may be clearer for natural waterbodies; however, it is difficult to resolve the issue for large man-made waterbodies. In this case, it is necessary to determine the extent to which the tilapia is exploiting vacant niches within the artificial waterbody and the extent to which it is directly displacing indigenous species that may otherwise have established following the creation of the waterbody.

9.3 Biodiversity issues in culture-based fisheries

Except perhaps for the oxbow lakes in Bangladesh, all culture-based fisheries in the region are conducted in quasi-natural habitats. These are most commonly man-made waterbodies, some ancient and some relatively recent. Needless to say, these habitats are colonized to varying degrees by indigenous flora and fauna. However, the fish populations are not generally sufficiently large to support subsistence or artisanal fisheries on their own, and hence the secondary use of the waters for culture-based fisheries. From the earlier sections and previous reviews on the subject (De Silva 2003, Lorenzen 2003), it is evident that one other characteristic feature of these fisheries, with the exception of PR China, is that the practices depend either wholly or partially on exotic species. For example, the culture-based fisheries of Sri Lanka, Thailand and Viet Nam and to a lesser extent, India and Bangladesh, are based almost entirely on exotic species (Indian and Chinese major carps, common carp etc.).

As enhancement activities are most frequently conducted in quasi-natural waters, the apparent negative impacts on the biodiversity of the 'indigenous' flora and fauna of such waters cannot be strictly considered to be invasive as the environment has been artificially created. Indeed, the interactions and potential competition between exotic and native species in small waterbodies in the region have been barely studied. In one such study, in Sri Lanka, Wijeyaratne and Perera (2001) concluded that although some exotic and indigenous species shared common food resources, because of the nature of these food resources and their great abundance, there was no foreseeable competition *per se* between the two groups. This conclusion is supported by the study of Piet (1996).

Conversely, negative effects of culture-based fisheries could arise from exotic escapees invading the natural habitats of indigenous species, but there is no evidence yet that this has occurred. Since exotic species have been used for both fisheries enhancement and also aquaculture, it will be difficult, if not impossible to determine the specific effect of an enhancement activity. Despite this uncertainty, it is still important is to ensure that no new exotics are introduced for culture-based fisheries development *per se* and to make do with those species that are currently available. Additionally, it is preferable to explore the possibility of using other indigenous species, although economic considerations such as yield reductions that may result from this will have a strong influence on decisions.

There is an urgent need to address biodiversity issues in Asian waters, particularly in relation to fish species usage in stock enhancement practices. Not only are the direct affects of such practices important, but also their affects on the genetic diversity of the enhanced species brought about through generations of inbreeding. Unlike in aquaculture operations where there are deliberate efforts to prevent escapees of species with reduced genetic diversity, stock enhancement activities deliberately introduce hatchery-bred stocks (which may have similarly narrow genetic diversity to aquaculture stocks) to open environments where there is a greater probability of mixing with wild stocks, thereby increasing risks to the biodiversity of natural systems.

10. Socio-economic issues related to stock enhancement in inland waters

It is evident from the preceding sections that all forms of stock enhancement in the Asian region have one purpose: to increase the foodfish supplies, thereby contributing to human nutrition, providing additional employment opportunities, and in the long term, contributing significantly to poverty alleviation. It is also important to note that the great bulk of stock enhancement practices in Asia occur in rural areas, by design rather than choice, because the waterbodies used for this purpose happen to be located in rural areas.

One of the major features of larger waterbodies in Asia is that they are often common-property, open-access resource waters. This could be one reason that stock enhancement in large, lacustrine waters, in most Asian countries, such as lakes and reservoirs, has not yielded the expected results. Floodplain stock enhancements, which are designed to enhance fisheries benefits in a more equitable manner, have been undertaken in Bangladesh and Myanmar. However, it must be recognized that despite the effort to deliver benefits to the fishing community as a whole, social traditions and hierarchies are still prevalent and often an integral part and parcel of the societal structure, thus benefits may not be distributed evenly and may still be captured by an elite group.

As previously discussed, the success of most stock enhancement practices is highly dependent upon community participation. Different practices bring together different communities. Enhancement in beels in Bangladesh succeeds when coherent groups of traditional fishers are formed, whereas culture-based fisheries depend on mobilizing farmer groups into adopting a somewhat alien practice that will generate synergies and community well being for individual and community benefit. In all instances, some intervention is needed, at least at the initial stages, that will finally culminate in sustainable practices managed and owned by the relevant community/stakeholders. The successful stock enhancement practices that are prevalent in the region are perhaps good examples of the purposeful secondary use of a primary resource – water – for the community well being, whose benefits are expected to filter down to other such activities as the practices mature.

Of course there is also a down side to stock enhancement. In the main, this pertains to stock enhancement of large lacustrine waters, which are usually a common-property resource. All evidence indicates, with perhaps the single exception of stocking giant river prawn in Thai reservoirs, that the returns are not cost-effective. Indeed, the most devastating affect on inland fisheries, resulting in a complete collapse of the inland fishery in large lacustrine waters, occurred in Viet Nam when the subsidized stock enhancement programme was withdrawn by the government as a consequence of economic liberalization that commenced in the mid-1980s. Asian countries need to reconsider strategies in respect of stock enhancement of such waters. It may be that the size of fingerlings at enhancement needs to be significantly increased if a economically viable return is to be obtained, or it may be that countries are better advised to use the stocking material for other purposes, such as rationalizing stock enhancement programmes in smaller waterbodies that are more suitable for culture-based fisheries development, and so on. Most importantly, stock enhancement practices should not be used for the sole purpose of political gain, as is often the case.

In contrast to large lacustrine waters, stock enhancement in floodplain and culture-based fisheries has shown to be cost effective, economically viable and sustainable in the long term. It needs to be pointed out however, that the number of socio-economic studies on stock enhancement practices in Asia is few. There is an urgent need for such studies to ensure improvement and sustainability of these practices, and to effect a greater mobilization of the communities. A sizeable array of studies in individual countries will also enable a better comparison of performances among countries and a realization of technologies and extension work that should be put in place in order to achieve better results.

It has also been shown in the previous sections that the success of stock enhancement practices depends largely on the availability of suitable institutional structures, aptly demonstrated for Bangladesh (Toufique 1999), Sri Lanka (Pushpalatha 2001) and Thailand (Lorenzen *et al*. 1998). In Viet Nam, where culture-based fisheries are in a relatively early stage of development, the average tenure of a lease ranges from three to six years, but varies both between and within provinces. More often than not, farmer lessees find the lease period too short, and the uncertainty has, on occasion, inhibited development. However, with the current commitment of the Government of Viet Nam to develop inland fisheries, it is expected that more uniform lease regulations will be brought forward. Such problems are not unique to Viet Nam. For example, in Sri Lanka the non-perennial, small waterbodies used for culture-based fisheries development are under the purview of the Department of Agrarian Services, which delegates its authority for water management purposes to Farmer Committees that essentially consist of downstream users. However, under the Agrarian Services Act fisheries development/activities are prohibited in such waters, suggesting that there is an urgent need to change the statute to encourage downstream farmers to take up fishery activities. The most important change that is needed in all Asian countries is a change in public perception – that fishery activity in a waterbody does not negatively affect downstream activity and/or use of the waterbody for daily household needs.

11. Conclusions

Inland fisheries contribute about ten percent to the global fish production and Asia is the leading producer of inland fish, accounting for over 80 percent of the total. Until recently, the inland fisheries sector had taken back stage in fisheries development plans, particularly so given the emphasis being placed on aquaculture development throughout the world, Asia being no exception. Aquaculture development in most Asian countries is beginning to face major problems in respect of primary and secondary resource availability, as well as environmental concerns and related public perception. As a result, inland fishery development is seen as a non-invasive, less resource intensive mode of increasing foodfish supplies, particularly to the rural poor. Consequently, inland fisheries in Asia has begun to re-emerge, gaining the attention from governments, development authorities and the general public that they richly deserve.

Inland fisheries in Asia are mostly rural, artisanal activities, catering to rural masses and providing an affordable source of animal protein, employment opportunities and household income. Stock enhancement is an integral component of most inland fisheries. With recent advances in artificial propagation techniques for fast-growing and desirable fish species and the consequent increased availability of seed stock, such activities are beginning to affect inland fishery production in most Asian countries. Indeed, new avenues of production such as culture-based fisheries are being increasingly adopted and are seen as a way forward in most countries. Inland fishery activities also have a distinct advantage, in that their development is less resource intensive than is aquaculture, for example. Furthermore, they are generally more environmentally non-invasive.

Apart from a few possible exceptions, stock enhancement in all inland waters has not been successful, and this is particularly the case for large lacustrine waterbodies and for rivers. The economic viability of stock enhancement of such waterbodies has not been demonstrated in any Asian nation, their fisheries being dependent on naturally recruited stocks, perhaps requiring only occasional replenishment of broodstock. The most successful stock enhancements in Asia are in the floodplain beels and oxbow lakes in Bangladesh, where the use of small waterbodies that are not capable of supporting fisheries has led to culture-based fisheries where stock and recapture rates are very high. Culture-based fisheries development, however, requires major institutional changes. These are now being addressed by the respective governments in the region, and thus culture-based fisheries are generally considered to have the greatest potential for further development. Added advantages of culture-based fisheries are that they are considerably less resource intensive, and by and large, are community-based activities that can generate synergies that are advantageous to the community. The main problem facing their development is the possibility of over production and glutting of the market. This results because harvesting is mostly based on the hydrological regimes of the waterbodies in a given region, occurring when the water levels are receding. This problem, however, is not insurmountable and can be addressed through the introduction of planned, staggered harvesting, inter-community cooperation and improved marketing channels.

Stock enhancement in inland waters will continue to be influenced by fingerling availability. In general, although the volume of fry production of sought-after fish species is thought to be adequate, there is a bottleneck in fingerling availability. This again is mostly felt in the culture-based fishery programmes in which fingerling availability has to coincide with the filling of small waterbodies, which tend to be, by and large, rain fed. In the case of floodplain enhancement, the problem is less compounded because flooding and the spawning of preferred species often coincide.

One of the major concerns of stock enhancement in inland waters is its possible effects on biodiversity. This is for two reasons: firstly, most countries depend wholly or partially on exotic species for stock enhancement, and secondly, freshwater fishes are known to be among the most threatened of vertebrates. Thus, major studies should undertaken to evaluate the current situation, so that remedial steps can be taken, if needed, without causing a major impact upon some of the stock enhancement practices that are gaining momentum.

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