Use of wild fish and other aquatic organisms as feed in aquaculture – a review of practices and implications in the Asia-Pacific

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SUMMARY

Global and Asian aquaculture have witnessed a ten-fold increase in production from 1980 to 2004. However, the relative percent contribution to production of each of the major commodities has remained almost unchanged. For example, the contribution of freshwater finfish has declined from 71 to 66 percent in Asia but has remained unchanged globally over the last 20 to 30 years. This fact has dictated trends in the use of fish as a feed for cultured stocks. The growth in the sector has gone hand in hand with an increasing dependence on fish as feed, either directly or indirectly. In a number of countries in the Asia-Pacific region, the aquaculture sector has surpassed the capture fisheries sector in its respective contributions to the gross domestic product (GDP). Aquaculture's increased contribution to national GDPs can be taken as a clear indication of the contribution of the sector to food security and poverty alleviation.

The use of finfish and other aquatic organisms as a feed source can be through direct utilization of whole or chopped raw fish in wet form, through fishmeal and fish oil in formulated feeds, and/or as live fish, although the latter is uncommon and the overall amounts used are relatively small. In the first two categories, the fish used are often termed "trash fish/low-value fish". Although attempts have been made to define this term, all definitions have a certain degree of ambiguity and/or subjectivity.

In this regional review, the amount of fish used as feed sources based on the above categories was estimated primarily from the production data, supported by assumptions on the inclusion levels of fishmeal in formulated feeds and observed feed conversion efficiencies for both formulated feeds and for stock fed trash fish/low-value fish directly. A scenario for the use of fish as feed was developed by starting from the levels of aquaculture production recorded in 2004 and assuming increases in production volumes of 10, 15 and 20 percent by 2010, respectively, for the three trajectories. In parallel, the pattern of wild fish use as feed was projected to change as fish and shrimp farmers increasingly replace farm-made feeds by incorporating trash fish/low-value fish with manufactured feeds that include fishmeal. Also, the fishmeal inclusion rates in manufactured feeds are falling slowly, and this has been incorporated into the projections.

The regional review also deals with the production of fishmeal using trash fish/low-value fish in the Asia-Pacific region. Regional fishmeal production as a whole is relatively low when compared with that of major fishmeal-producing countries such as Chile, Iceland and Norway, amounting to approximately 1 million tonnes per year. However, there is a trend towards increasing the use of fish industry waste, such as from the tuna canning industry in Thailand. The fishmeal produced in the region is priced considerably lower than globally traded fishmeal, but its quality is poorer. Total fishmeal use in Asian aquaculture in 2004 was estimated as 2 388 million tonnes, the highest proportion of this being used for crustacean aquaculture (1 418 million tonnes). Based on growth predictions (to year 2010) in the sector and improvements to feed quality and management, it is expected that the quantity of fishmeal used in Asian aquaculture will be slightly less than at present. An estimated 240 000 tonnes of fish oil is used in Asian aquaculture, principally in shrimp feeds.

Based on production estimates of commodities in 2004 that rely on trash fish/low-value fish as the main feed source, this regional review suggests that Asian aquaculture currently uses between 2 465 and 3 882 million tonnes, an amount that is predicted to decrease to between 1.890 and 2 795 million tonnes by 2010. The use of trash fish/low-value fish and fishmeal by the aquaculture sector has been repeatedly adjudicated as a non-sustainable practice, and globally the sector is seeking to reduce its dependence on fish as feed through improved feed management practices and development of better quality feeds and feed formulations using alternative ingredients. Over the next few years, decreases in the use of trash fish/low-value fish are also expected to be achieved through better conversion of raw materials into fishmeal and fish oil during the reduction processes.

The "way forward" in addressing the issue of the use of fish as feed in aquaculture in the Asia-Pacific region includes the need for a concerted regional research thrust to reduce the use of fish as feed sources in aquaculture, as has been achieved in the animal husbandry sector. Secondly, there is a need to increase farmer awareness on the use of trash fish as feed. This is achievable, considering the similar progress that has been made by the region's shrimp farming sector, which almost exclusively involves small-scale practitioners who are often clustered in a given locality.

The analysis also suggests that the use of trash fish/low-value fish in aquaculture may be compatible with improving food security and alleviating poverty. In Asia, trash fish/low-value fish is mostly landed in areas where there are other suitable fish commodities for human consumption. To make the trash fish/low-value fish suitable and available for human consumption would involve some degree of value-adding and transportation costs, which are likely to increase the price to beyond the means of the consumer, particularly in remote rural areas. Under such a scenario, the direct or indirect use of this perishable resource as a feed source to produce a consumable commodity appears to make economic sense and appears to be the most logical use for overall human benefit. In this manner, trash fish/low-value fish contributes to food security by increasing income generation opportunities and hence contributes to poverty alleviation. Another factor that needs to be taken into account is the large numbers of artisanal fishers who harvest this raw material. The continued use of trash fish/low-value fish, therefore, allows these fishers to maintain their livelihoods[1]. Admittedly, this is an area that warrants more detailed investigation, from resource use, livelihoods and economic viewpoints.

[1] The opinion expressed in this paragraph is of the authors and has not necessarily been endorsed by the editors.

1. INTRODUCTION

Aquaculture, an age-old tradition that commenced at least two millennia ago in Asia, has gradually transformed from an art form to a science over the last five to six decades. Aquaculture currently provides over 50 percent of all fish and seafood consumed globally (FAO, 2007). Asia has been in the forefront of most forms of aquaculture development and continues to lead the global production, with a contribution of 54.37 million tonnes in 2004 valued at nearly US$57 billon. In 2004, Asian aquaculture accounted for 91.5 and 80.8 percent of the global production and value, respectively.

As for any other primary production sector, aquaculture, globally or in Asia, cannot be expected to continue to grow almost exponentially. Indeed, a slowing of the growth rate has already been reported (FAO, 2007; De Silva and Hasan, 2007). The question, therefore, is whether Asian aquaculture can, at best, sustain the current growth rate, which over the last five years has averaged 6.8 percent per annum, or at worst, sustain the current level of production. Aquaculture will also need to limit any long-term impacts that it has on biodiversity and adjust to increasing demands on limited natural resources such as water, land and feed ingredients. Simultaneously, aquaculture needs to cater to increasing consumer demands for food safety, improved quality control standards, traceability and associated certification and ethical attributes (Singer and Mason, 2006), particularly in respect of exported aquaculture commodities. As Kutty (1997) pointed out, aquaculture's sustainability is no longer dependent only on economic viability but also on maintenance of environmental integrity.

Feeds and feeding and associated raw material procurement and usage are central to the success and sustainability of any animal farming system, and in this regard the aquaculture sector is no exception. However, aquaculture, a relatively new and emerging food production sector in many regions, is more often than not viewed in light of increasing concerns for and perceptions of environmental integrity, sustainability and prudent use of physical and biological resources. It has been reported that aquaculture development is unprogressive or at least wasteful in its dependence on fishmeal and fish oil (Box 1), two limited biological resources (Naylor *et al*., 1998, 2000), and its use of exotics or alien species (Naylor, Williams and Strong, 2001). However, these propositions have been strongly refuted by Hardy (2001) and Roth *et al.* (2002) and by De Silva *et al*. (2006), respectively. There is general agreement that the growth and sustainability of aquaculture will be significantly impacted by feed availability, efficacy of feed utilization, feeding practices and potential advances in feed manufacture, among others factors. These aspects are not secondary to those related to potential genetic improvements, development of culture technologies and improvements in disease prevention and control and hatchery techniques, all of which are essential for sustaining future aquaculture development.

This study reviews the status of use of trash fish/low-value fish, as well as other aquatic potential feed sources in aquaculture in the Asia-Pacific region and its possible impacts. In this context, an attempt is made to assess the availability of all types of feeds used in aquaculture in the Asia-Pacific region and evaluate the potential needs and constraints associated with feed types, availability and efficacy of utilization. This study is based on literature surveys, dedicated field studies in selected Asian nations and on two case studies dedicated to feeds and feeding in China and Viet Nam. In view of the diversity of the aquaculture practices in the Asia-Pacific region, and based on Food and Agriculture Organization of the United Nations (FAO) production data (FAO, 2007), an initial analysis was undertaken of the sector's production trends as they relate to culture environment, species/commodities cultured and the feed needs and usage.

BOX 1

Fishmeal and trash fish/low-value fish use in the Asia-Pacific region

Asia-Pacific aquaculture currently uses an estimated 2 388 thousand tonnes of fishmeal (equivalent to 10 271 thousand tonnes of raw material) and 2 465 thousand to 3 882 thousand tonnes of trash fish/low-value fish as a direct feed source. The low and high predictions for 2010, respectively, are on the order of 2 000 thousand and 2 191 thousand tonnes of fishmeal (equivalent to 8 386 thousand and 12 829 thousand, and/or 7 338 thousand and 11 225 thousand tonnes of raw material, based on expected improvements in efficiency of raw material to fishmeal conversion rates of 4.0 and 3.5) and 1 890 thousand to 2 795 thousand tonnes of trash fish/low-value fish as direct feed inputs. The estimates of trash fish use are based on production levels of cultured commodities that primarily use trash fish as the major feed source and differ significantly from some previously reported estimates. The estimates indicate that there would probably be a reduction in the amount of fish used as feed sources by the Asia-Pacific aquaculture sector in the ensuing years, even though overall aquaculture production will be higher. These reductions are likely to be brought about through better conversion efficiencies in the reduction industry processes, better feed management and also through a significant reduction of consumption by marine finfish farming through the increased use of formulated feeds.

Photos: Photographs show the use of fishmeal and trash fish/low-value fish in the Asia-Pacific aquaculture industry: A) pelleted feed prepared with fishmeal being the primary source of dietary protein; B) raw fish in farm-made moist feed; C) raw fish cut into pieces to facilitate better feeding.

A)

B)

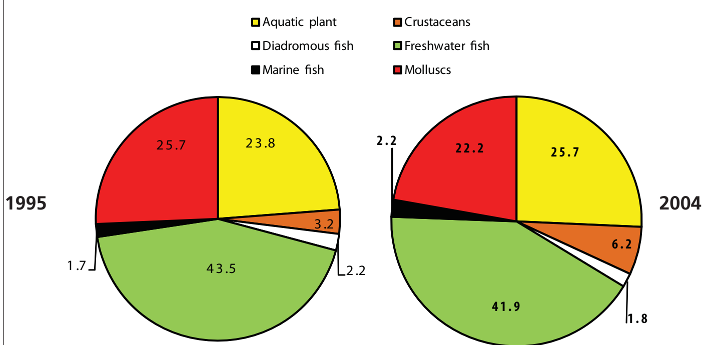
C)

2. MAJOR TRENDS IN ASIAN AQUACULTURE

Global and Asian aquaculture production has been and still is dominated by finfish (Figure 1). If seaweed culture is omitted from the calculations, finfish aquaculture accounted for 62.2 and 61.8 percent of Asian aquaculture production in 1995 and 2004, respectively. The relative contribution of each of the commodity groups has, however, remained almost unchanged over the last decade. The only significant variation recorded was a two-fold increase in the contribution of crustaceans to the total volume (Figure 1). Freshwater species contribute most to finfish production, while the relative proportions contributed by the three culture environments (freshwater, brackishwater and

FIGURE 1

The percent contribution to Asian aquaculture production (in volume) of different commodities, 1995-2004



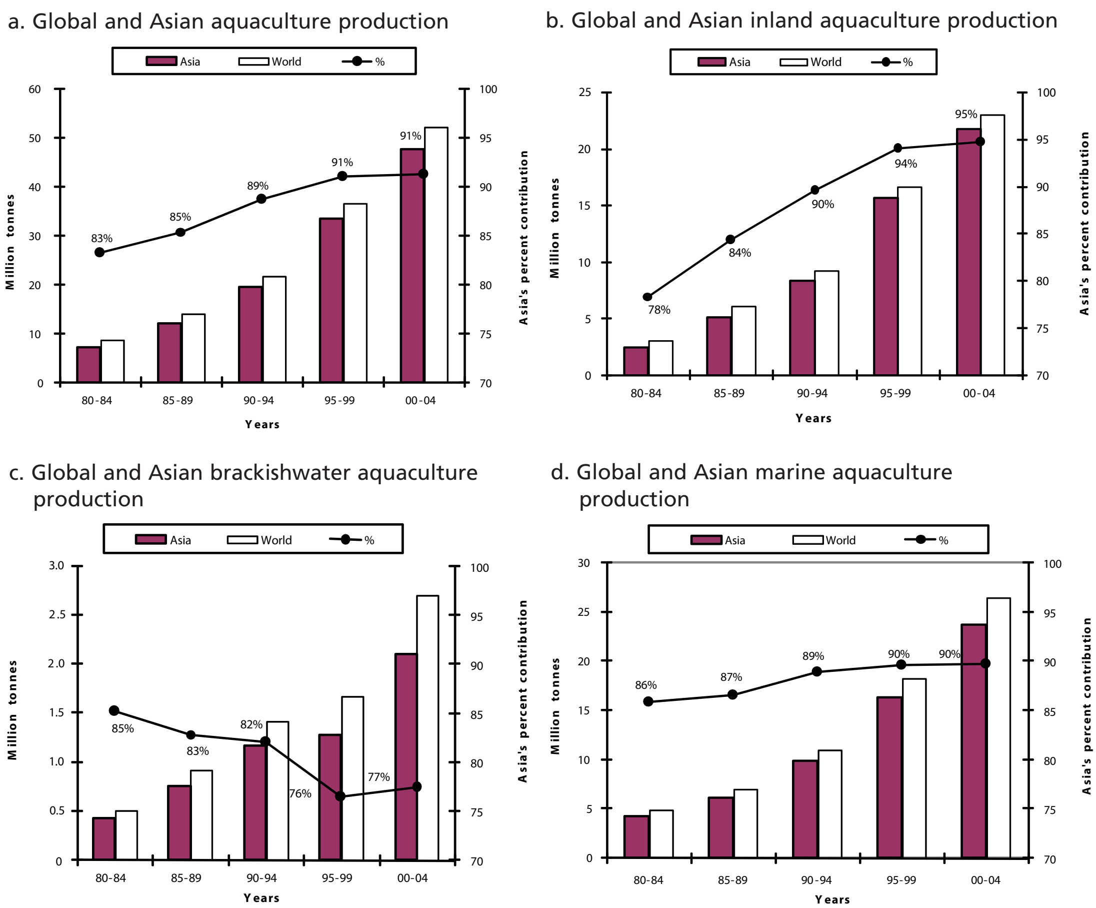
Source: FAO (2006a)

marine) have remained static. This implies that although major strides have been made in increasing the production volumes of the various commodities over the last two decades, the relative importance of each of these in the overall production scenario has remained unchanged.

In this report, seaweeds and molluscs (except for Babylon snail and abalone) are not considered, as the culture of these commodities generally is not based on externally provided feeds. Figure 2 (a–d) depicts the changes in the global and total Asian freshwater, brackishwater and marine aquaculture production from 1980 to 2004 based on five-year averages, together with the percent Asian contribution in each of the cases. Asia clearly dominates all forms of aquaculture, contributing 91, 95, 77 and 90 percent to the total global, inland, brackishwater and marine aquaculture production, respectively, in 2004. It is also evident that throughout the recent history of the sector, when aquaculture began to gain prominence as an aquatic food provider to the global community, Asian aquaculture has been the largest contributor to production volume. Comparable trends (global and Asian) in the total cultured commodities and in each of the environments are evident for finfish (Figure 3a–c) and crustaceans (Figure 4a–c), the two groups of cultured commodities that are dependent on fish as a food source. In all of the above instances, Asia continues to dominate production. Moreover, China is the main aquaculture-producing nation (FAO, 2006b) and also dominates the global fish trade (Kurien, 2005).

FIGURE 2

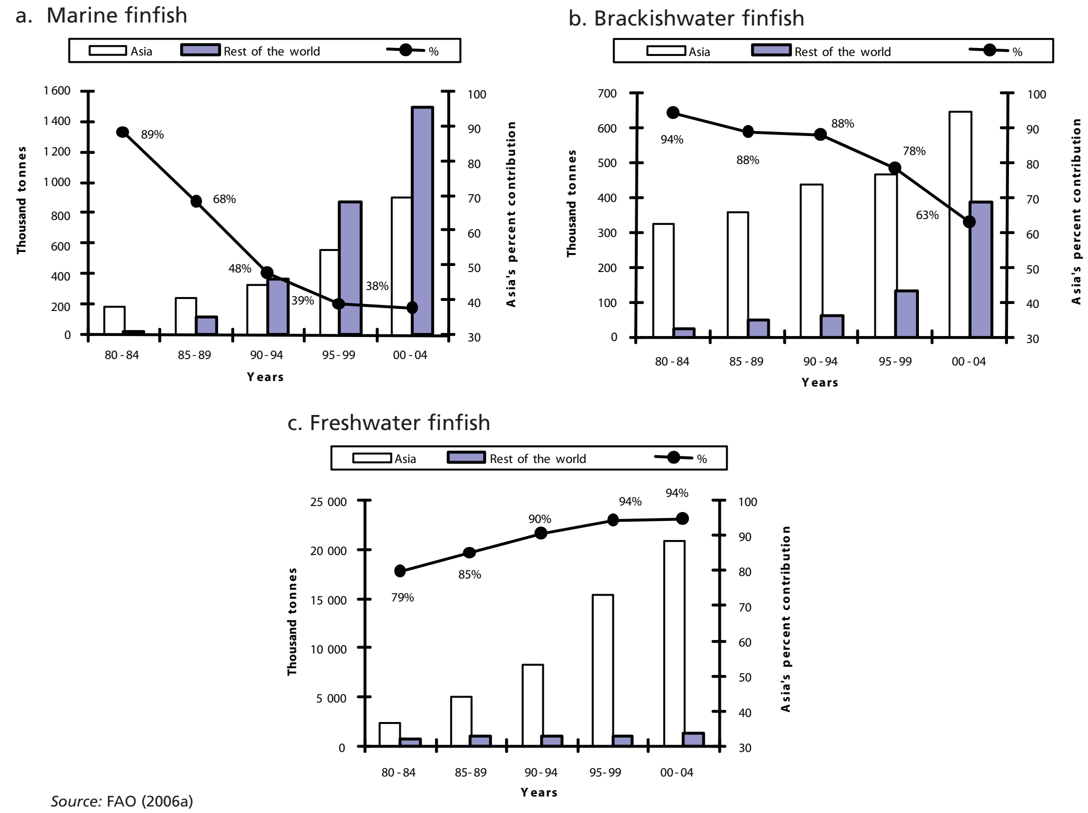
Total global and Asian aquaculture production (mean per year for five-year periods) and the percent contribution of Asian production to the total, 1980–2004



Source: FAO (2006a)

FIGURE 3

Total global and Asian cultured marine, brackishwater and freshwater finfish production (mean per year for five-year periods), 1980–2004

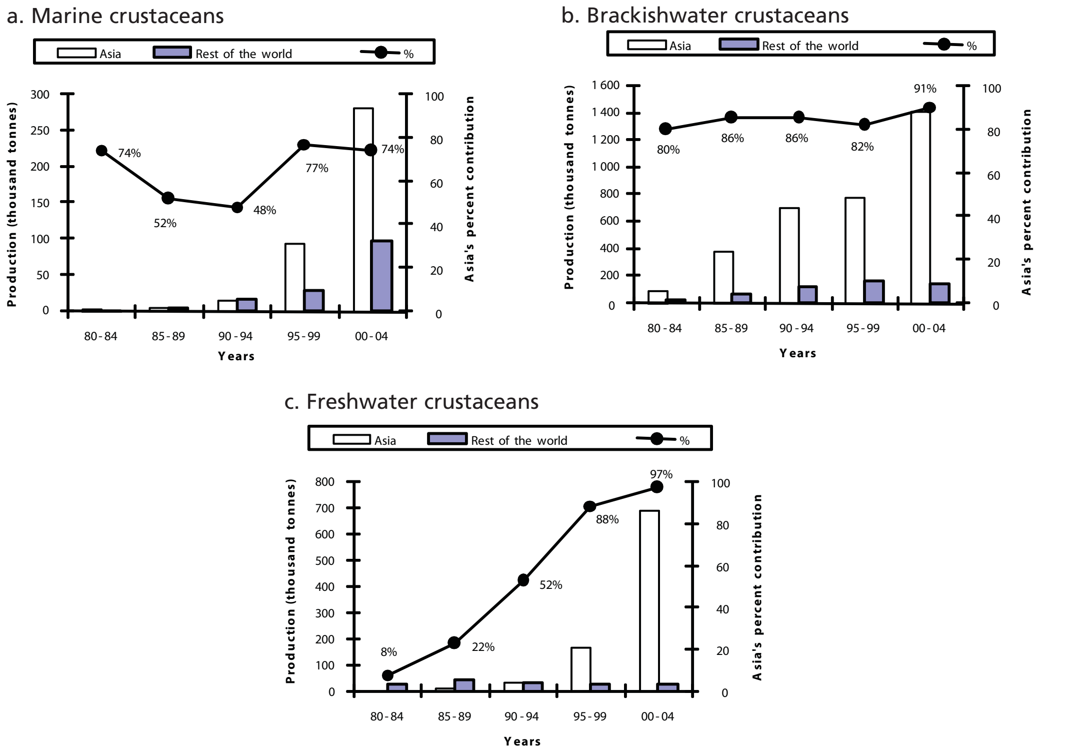


Source: FAO (2006a)

A further analysis of the data taking into account commodities and relevant species groups among finfish that are dependent on fish as food sources exemplifies the point made previously. In Figure 5, the contribution of such commodities to global and Asian aquaculture production (excluding seaweeds and molluscs) in 1980, 1990, 2000 and 2004 is depicted. Although there had been a ten-fold increase in global and Asian production of these commodities from 1980 to 2004, the percent contribution of each of the categories has remained almost unchanged. For example, the contribution of freshwater finfish declined from 71 to 66 percent in Asia, but remained unchanged globally. By contrast, Asian carnivorous finfish production in 2004 was 3 368 956 tonnes (967 348 tonnes from marine, 56 389 tonnes from brackishwater and 2 345 219 tonnes from freshwater aquaculture), while production in 1980 and 1990 were respectively and in order, 173 128 and 272 685 tonnes (marine), 2007 and 13 757 tonnes (brackishwater) and 169 550 and 437 496 tonnes (freshwater). Perhaps the greatest change is observed in crustacean production, which increased from 3 to 12 percent of total aquaculture production during the same period, both globally and in Asia. Another important change in the aquaculture sector (although perhaps less significant in the context of the total volume) is that crab production has increased to 200 000 tonnes per annum, surpassing captured production by almost five-fold.

The production figures *per se* may mask some of the major trends in the growth of the sector. In Figure 6a-d the mean yearly growth rates (percent per year) of finfish and crustacean aquaculture in different environments in Asia and the rest of the world, between 1980 and 2004 are depicted. It is evident that the growth rates in marine and brackishwater finfish aquaculture in Asia have increased somewhat, while the growth rate in freshwater finfish aquaculture has declined over the years, this trend also being

FIGURE 4
Total global and Asian cultured freshwater, brackishwater and marine crustacean production, expressed as the mean per year for five-year periods from 1980 to 2004



Source: FAO (2006a)

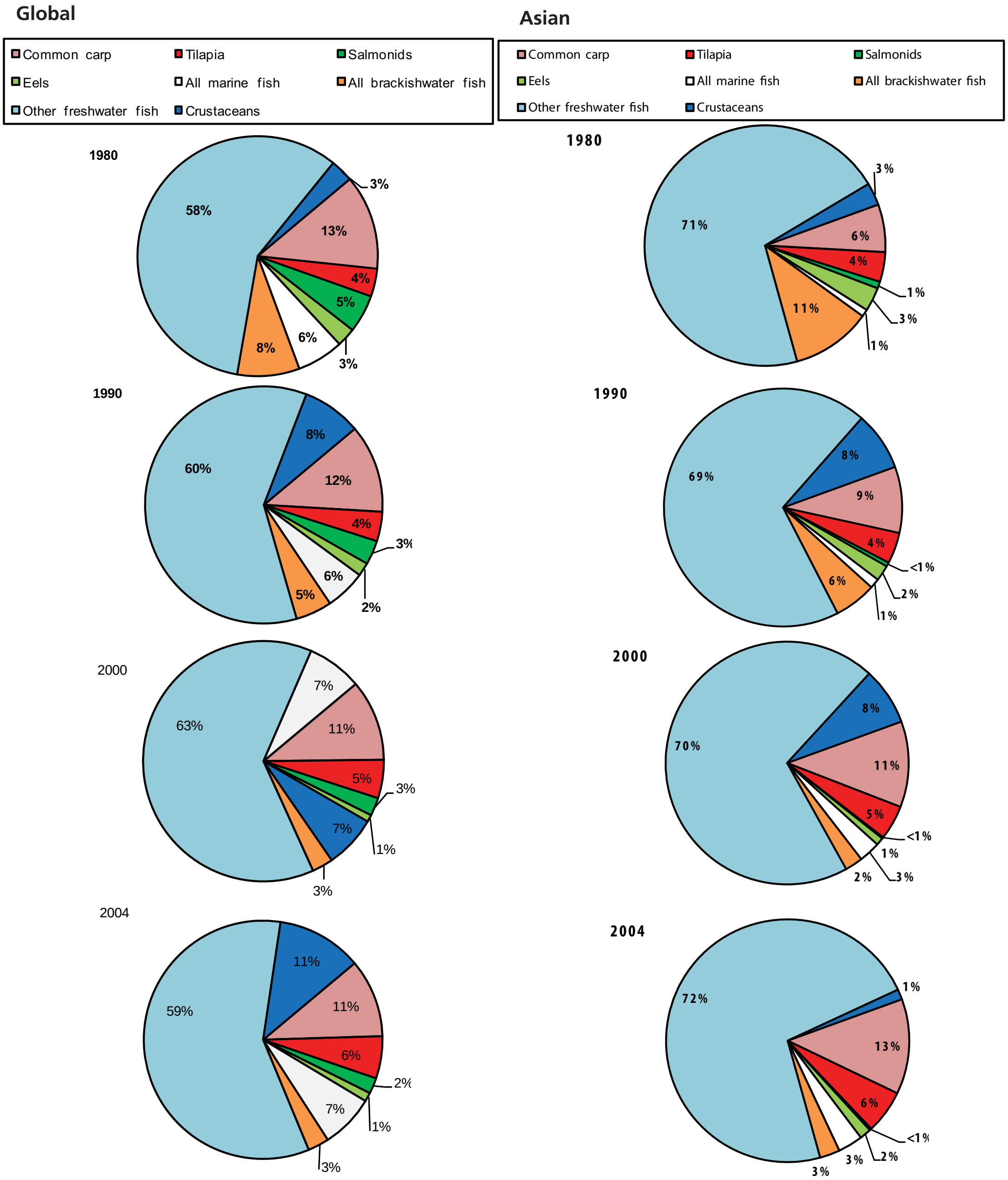
reflected in the sector globally. One possible reason for this trend could be the limitations on land and freshwater resources that prevent further expansion of inland aquaculture. Asia, the continent blessed with the greatest amount of freshwater resources, has the least per caput availability (Nguyen and De Silva, 2006). Another possible factor is water quality degradation that has arisen from anthropogenic developments in most watersheds in Asia, in particular, deforestation (Sodhi *et al*., 2004) and industrial effluent discharge, making water resources unsuitable for aquaculture. Although quantitative data are not readily available, frequent media portrayals of localized fish kills in cages are common, providing indirect evidence.

The growth rate of crustacean culture in the rest of the world has declined over the years, as opposed to that in Asia (Figure 6 b, d). It is also important to note that the relative increase was much lower in all instances in Asia, reflecting the fact that Asian aquaculture had reached considerably higher levels of production than the rest of the world prior to the 1980s (FAO, 2006b; De Silva and Hasan, 2007).

2.1 Trends in Chinese mariculture

The economic upsurge in China over the last 10–15 years has resulted in rising living standards and an increase in the proportion of the middle class, with higher disposable incomes. Consequently, this upsurge has impacted on the culinary habits of the Chinese population, leading to an increase in the consumption of high-value seafood species. This trend has been exacerbated by the perception that seafood offers better eating quality and certain health benefits. Driven by these factors, China is increasingly turning to the culture of high-value marine and freshwater fish. In the course of the expansion and intensification of aquaculture of such high-value species (which are

FIGURE 5
Percent changes in global and Asian finfish and crustacean aquaculture production. Freshwater finfish species that are generally fed formulated feed are indicated as separate entities



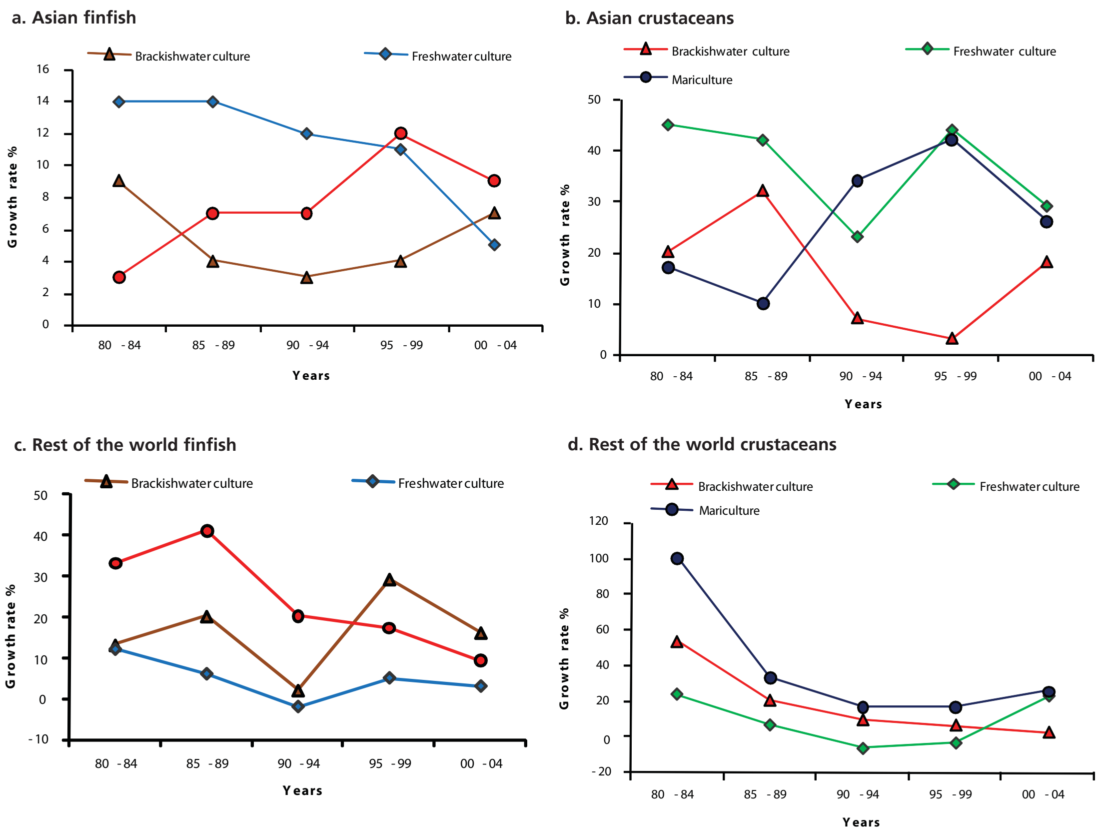
Source: FAO (2006a)

often carnivorous), the supply of aquaculture feeds with a high level and quality of protein emerges as an important factor.

However, the direct utilization of trash fish and low-value and small-sized live fish in growing high-value fish species is relatively new in Chinese aquaculture. It is often perceived that the direct use of large quantities of trash fish as feed by this sector has lead to adverse impacts on the environment and fishery resources, even though explicit scientific evidence is often lacking. In the past, there has been a lack of government policies to adequately guide the development of this type of aquaculture. As a result,

FIGURE 6

The rate of growth of finfish and crustacean aquaculture production in Asia as opposed to the rest of the world over a 25-year period, based on the mean of five-year blocks



Source: FAO (2006a)

some environmentally friendly and technically acceptable practices and techniques relating to the use of trash fish were not sufficiently extended among farms.

Mariculture and coastal aquaculture produced only about 50 000 tonnes of fish and shrimp in 1997, while using an estimated 100 000 tonnes of artificially formulated feeds. The sector has progressed much further since then and in 2005, the mariculture production of finfish and crustaceans, which is dependent on external feed inputs, reached nearly 1.5 million tonnes (Table 1), these practices being spread across an area of 76 680 and 310 742 ha (shrimp, 230 460 ha and crabs, etc., 80 282 ha), respectively.

The rapid growth of marine finfish and crustacean culture in China since the 1990s has been facilitated by the development of marine cage-culture technology (Halwart, Soto and Arthur, 2007), pen culture (Chen *et al*., 2007), land-based intensive culture techniques and facilities, and the transformation of low-yield coastal shrimp ponds into marine finfish farms. In addition, from the late 1990s, Chinese researchers achieved consecutive successes in the artificial propagation and nursing techniques for a significant number of marine finfish species with aquaculture potential, facilitating the growth of finfish farming in all coastal regions and thereby allowing mariculture to become an important aquaculture subsector in the country.

The national production of marine finfish from aquaculture in 2005 was about 660 000 tonnes (Table 1), and the geographical distribution of this production is summarized in Table 2. Overall, over 60 species/species groups are cultured, the main diversity occurring in southern China, in provinces and regions of the South China Sea coastal areas.

TABLE 1
Mariculture production in China, 2005

Group/Species	Production (tonnes)
Sea perch	87 994
Left-eyed flatfish	76 884
Large yellow croaker	69 641
Red drum	45 742
Breams	44 222
Groupers	38 915
Cobia	18 882
Fugu	18 802
Yellowtails	11 973
Right-eyed flatfish	5 676
Other fish species	240 197
Total finfish	**658 928**
Shrimp	
Pacific white shrimp	407 642
Giant tiger prawn	75 731
Fleshy prawn	49 901
Kuruma shrimp	41 090
Other shrimp species	49 794
Total shrimp	**624 158**
Crabs	
Swimming crab	79 068
Mud crab	111 423
Other crab species	13 805
Total crabs	**204 296**

Source: Xianjie (2008)

TABLE 2
The geographic distribution of cultured marine finfish production in China

Geographical region	Production (tonnes)	Species/species groups
Coastal areas of the Yellow and Bohai Seas	184 000	Flatfish (e.g. introduced turbot and sole)
Shandong province	120 000	Details not available
Liaoning province	47 000	
Fujian province*	150 000	Large yellow croaker (*Larimichthys crocea*), red drum (*Sciaenops ocellatus*), red seabream (*Pagrus major*), black porgy (*Acanthopagrus schlegelii schlegelii*)
Zhejiang province*	40 000	
Jiangsu province*	18 000	
Guangdong province**	223 000	Orange-spotted grouper (*Epinephelus coioides*), Hong Kong grouper (*E. akaara*), flathead mullet (*Mugil cephalus*), Japanese seaperch (*Lateolabrax japonicus*), barramundi (*Lates calcarifer*), (Amoy croaker (*Agyrosomus amoyensis*), *Nibea coibor, Pomadsys hasta*, red seabream, goldlined seabream (*Rhabdosargus sarba*), black porgy, red drum, cobia, (*Rachycentron canadum*), derbio (*Trachinotus ovatus*), four-eyed sleeper (*Bostrichthys sinensis*), *Takifugu obscurus*
Guangxi Autonomous Region**	25 000	
Hainan province**	20 000	

*Coastal provinces of eastern China.
** Provinces and regions of the South China Sea.
Source: Xianjie (2008)

There are three major types of marine finfish farming systems in China: indoor culture, pond culture and cage culture, and the culture techniques used in these systems are being refined continuously. The indoor culture of marine finfish is found mainly in Shandong and Liaoning provinces around the Yellow and Bohai seas in northern China. The major species groups cultured are flatfishes, breams and puffer.

Pond culture of marine finfish is spread along the coast of the East China Sea and the South China Sea (Table 2). Guangdong province is the largest producer, contributing 150 000 tonnes of marine finfish from pond culture. During the mid and late 1980s, Guangdong province pioneered the development of large areas of brackishwater ponds in the Pearl River Delta region, becoming the leader of marine finfish farming in estuarine and coastal areas of China. The major cultured species include Japanese seaperch (*Lateolabrax japonicus*), barramundi (Asian seabass) (*Lates calcarifer*), yellowfin seabream (*Acanthopagrus latus*), goldlined seabream (*Rhabdosargus sarba*), flathead mullet (*Mugil cephalus*), mangrove red snapper (*Lutjanus argentimaculatus*), derbio (*Trachinotus ovatus*), spotted scat (*Scatophagus argus*) and red drum (*Sciaenops ocellatus*).

Cage culture of marine finfish is widespread throughout China's coastal bays (Chen *et al.*, 2007; Halwart, Soto and Arthur, 2007) and is the major sea-farming method. The cultured species are very diverse but are mostly of higher market value. Major cultured species include groupers, flathead mullet, barramundi, sea bream, black porgy, red drum, cobia and puffer (Table 2). The annual output from cage culture is about 300 000 tonnes, out of which Fujian province produces 100 000–110 000 tonnes, Guangdong province produces 70 000–80 000 tonnes, and Zhejiang and Shandong provinces together produce 30 000–40 000 tonnes.

3. USE OF FEEDS IN AQUACULTURE

Aquaculture is an industry whose great diversity is reflected in the range of species cultured, singly and/or in combination, the culture environments (freshwater, brackishwater and marine), the intensity of culture practices, the nature of the containment systems utilized (ponds, cages, raceways, enclosed pens, recirculation systems, substrates (for e.g. net bags, ropes) used in seaweed and mollusc culture), and the socio-economic *milieu* in which the activities occur. All of the above are reflected in feeds and feeding. Fertilization as an indirect "feed" input into aquaculture is not dealt with in this report, and readers are referred to De Silva and Hasan (2007) for the details.

3.1 Importance of feeds in sustaining Asian aquaculture

De Silva and Hasan (2007) pointed out that the efficacy of feeds used in aquaculture has the potential to bring about major changes in culture practices, even in the case of small-scale rural aquaculture enterprises, which collectively make a significant contribution to the total production, economic value and social wellbeing of communities. In this regard, the fast-developing culture of pangasiid catfish, commonly referred to as sutchi catfish, striped catfish or tra catfish (*Pangasianodon hypophthalamus*), in the Mekong Delta is a good example. Feed costs have brought about a significant shift from pangasiid cage culture (once the dominate practice) to pond culture, as feeds account for only 78 percent of total costs in pond culture but for 90 percent when cages are used (Hung and Merican, 2006). Equally, changes in the market chains can bring about significant shifts in aquaculture practices (De Silva, 2008). One of the most notable recent changes, for example, is that of freshwater carp culture in Myanmar. In this instance, the recent opening of an export market to the Middle East and Europe (Aye *et al*., 2007) has triggered changes in the culture practices of the Indian major carp species, rohu (*Labeo rohita*) and catla (*Gibelion catla*). In these farming systems, a significant amount of formulated feeds is beginning to be utilized, as opposed to the culture practices of five years ago (Ng, Soe and Phone, 2007), which were conducted in a far less intensive manner. Most importantly, however, all evidence indicates that the export of these cultured species has not impacted on their availability and affordability to the local community. This has been achieved to some degree through a government policy that keeps Indian major carps cultured for exportation in production entities that are separate from those that produce the same fish for local consumption (Aye *et al*., 2007).

However, irrespective of the culture practice, the provision of food/nutrients to the cultured stock(s) is a crucial element in the farming activity. In general, the nature of the food availability, among other husbandry practices, will impact on the profitability and viability of the culture operations. An additional factor is the availability of ingredients at a suitable cost, either singly and/or in formulated feeds. In particular, the availability of fishmeal and fish oil at a reasonable price is fundamental to the long-term sustainability of the culture of marine carnivorous finfish species. In this regard, the availability and use of trash fish/low-value fish that forms the basis for the manufacture of feeds has become an issue of public concern and scientific debate (Naylor *et al*., 1998, 2000; Hardy, 2001; Roth *et al*., 2002).

Until recently, attention in respect of the "feeds-ingredients-protein sources-aquaculture" issue chain was mostly directed at fishmeal-related aspects. This is understandable, as until about the mid-1980s mariculture was still in its infancy, and aspects related to fish oil were essentially a non-issue. However, with the relatively rapid development of mariculture and the fact that currently 87 percent of the global fish oil production is used in aquaculture (Tacon, 2007), fish oil usage in aquaculture has become a burgeoning issue, and in most ways a more critical one than the use of fishmeal, as suggested in the early years of aquaculture development (Wijkstrom and New, 1989).

Much research effort has been expended to reduce fish oil use in aquaculture, particularly with respect to the culture of marine carnivorous species, which do not have the ability to synthesize highly unsaturated long-chain fatty acids, such as docosahexaenoic acid (22:6n-3) (DHA) and eicosapentaeonic acid (20:5n-3) (EPA), from the precursors α-linolenic acid (18:3n-3). Efforts to reduce the fish oil content in feeds have been directed, for example, to (a) replacing fish oils with vegetable oils and or blends that mimic the fish oil fatty acid profile (Regost *et al*., 2003; Izquierdo *et al*., 2003; Francis *et al*., 2007) and (b) using "finishing" or "washout" diets, where the stock is fed fish oil diets for a few weeks prior to harvesting, only when this change will enable the stock to achieve the desired flesh quality (Glencross, Hawkins and Vurnow, 2003; Jobling, 2004; Turchini, Francis and De Silva, 2007). These research efforts are complimented with those on new alternative lipid sources rich in long-chain polyunsaturated fatty acids, such as single cell oils or marine invertebrate oils, and/or the genetic manipulation of oilseed crops, to obtain terrestrial vegetable oils rich in EPA and DHA.

Although it is estimated that 87 percent of the total global fish oil production of 800 000 tonnes in 2006 (Jackson, 2007; Tacon, 2007) was used in aquaculture, a rational analysis of this usage (which has a bearing on the culture of marine carnivorous fish in Asia) has not been undertaken. The data from Jackson (2007) suggest that salmon and trout culture accounted for 390 000 and 120 000 tonnes, respectively, or nearly 65 percent of the global fish oil production. The fish species predominantly cultured in Asia (e.g. tilapias, carps, milkfish and eels) accounted for only a small proportion of the fish oil used in Asia (total of about 240 000 tonnes), the bulk being used by other marine finfish and shrimp. The envisaged increase in the use of fish oil in tilapia and carp feeds is surprising, as it is known that these species groups are capable of desaturation and elongation of base 18:3n-3 and 18:2n-6 fatty acids into longer and more unsaturated fatty acids (Kanazawa, Teshima and Ono, 1979; Kanazawa *et al.*, 1980), and as it is also known that these species require small amount of total dietary lipid in their diets. Therefore, it is surprising, as Jackson (2007) argued, that the use of fish oil in feeds for carps and tilapias will increase, while a marked reduction will occur for salmonids, all groups still witnessing an increased production, up to 2012. Apart from the indirect suggestion that tilapia and carp feeds may not need fish oil, there is minimal salmonid culture in Asia (salmonid production in 2004 was limited to only 22 324, 11 869 and 3 502 tonnes for Japan, China and the Republic of Korea, respectively). In essence, therefore, the direct use of fish oils in diets in Asian aquaculture amounts to less than 20 percent of global production, even though Asia accounts for more than 85 percent of total global aquaculture production. However, taking into consideration that the mariculture production of carnivorous finfish and shrimp is witnessing a marked growth, this scenario is bound to change.

The fact that most Asian mariculture is dependent on the use of trash fish/low-value fish entails a minimal demand on global fish oil supplies *per se*. However, with the envisaged changes away from the direct use of trash fish/low-value fish in Asian mariculture, the demand for fish oil in feeds used in this sector is likely to increase.

3.2 Basic feed types

The feed types used in Asian aquaculture are closely related to the intensity of the culture practices and to the species cultured. It is commonly accepted that all aquaculture practices can be categorized as extensive, semi-intensive or intensive. From a feed input/utilization viewpoint, extensive culture practices will not use any external feed input and the stock will obtain all its nutritional needs from the natural foods produced within the system, while in semi-intensive systems, the stock will be provided with supplementary feeds that are not nutritionally complete, and finally, in intensive systems, the stock will depend entirely on external feed inputs that have to be nutritionally complete. These practices are a continuum and it is, at times, difficult to draw a line between intensive and semi-intensive aquaculture. At the lower end of the spectrum, in semi-intensive aquaculture, feed inputs can be single ingredients (such as rice bran) or simple mixes of feed ingredients. At the opposite end of the spectrum will be a more or less nutritionally complete mixture of ingredients that are "cooked" in some form and fed to the stock as a semi-moist dough (Figure 7), as a crude pellet or even as a moist mixture. Farm-made feeds fall into this category.

In contrast is the feeding of whole, chopped or minced trash fish/low-value fish in Asian aquaculture (Box 1). In some cases, low-value fish are prepared in the form of fish meat and fed to high-value cultured species such as groupers. Trash fish/low-value fish are used as the only food source for most cultured marine finfish species (such as groupers, Epinephalidae), as well as mud crabs (*Scylla* spp.), lobsters (*Panulirus* spp.)

FIGURE 7

Sequence of photographs depicting farm-made feed practice on an integrated farm in Myanmar (species cultured: catfishes)

a. Raw ingredient (rice bran)

b. Cooking utensils used to make a dough consisting of poultry waste and rice bran. Poultry waste is generally obtained from the poultry pens

c. Fish feeding by placing feed in containers that are hung in the ponds

BOX 2

Catfish farming in Thailand

Hybrid catfish (*Clarias macrocephalus* x *C. gariepinnus*), the most important freshwater fish cultured in Thailand, accounted for a production of 189 940 and 130 784 tonnes in 2004 and 2005, respectively. However, over the last few years the farmgate price of catfish has declined, which is also reflected in the decreased total production. In an effort to be more cost effective, catfish farmers have adopted new strategies, the foremost of which is a change of ingredients used in farm-made feed, whereby they have shifted from the use of trash fish to wastes from the poultry processing industry. The farm-made feeds use 8 parts of poultry waste (skeletal frames with bits of flesh), 1.5 parts of lard from the cattle slaughter industry and 0.5 parts of salt. The feeds are readily accepted by the stock, and the farmers believe that the production returns have not changed. The cost of feed has been reduced by approximately 30 percent. Of course the nutritional basis behind this change remains unexplained, a situation comparable with that previously described by Wood *et al.* (1992) for shrimp farming in Andhra Pradesh, India, where the traditional farm-made feeds performed far better than feeds formulated on the strict nutritional requirements of the cultured stock. This change among catfish farmers in Thailand has resulted in a significant reduction in the dependence of freshwater finfish culture on trash fish, with apparently no change in consumer acceptability of the product.

Photos: Feed preparation, feeding of cultured fish and voraciously feeding catfish

and Babylon snail (*Babylonia areolata*), providing all the nutritional requirements of the cultured stock. These cultured species are all relatively high-valued and are cultured primarily for export and the local, up-market, restaurant trade. The culture practices used for these commodities would normally fall within the realm of intensive culture, and it is thus an exception to the rule that these stocks obtain their nutrition from a single ingredient.

The other main category of feeds used in aquaculture is formulated feeds. Formulated feeds can be divided into two basic types, viz. "farm-made" or "home-made" feeds and commercial feeds. For the former, the formulations are based on locally available ingredients and, in general, are not strictly in accordance with the nutrient requirements of the cultured stock(s). These feeds, as the name implies, are made on farm (in accordance to the specifications provided by the farmers) or by small enterprises that are locally based and cater to a restricted farming community(ies). These feeds are made in small quantities, at most a week's supply at a time, based on needs and demand. Bearing in mind that the great bulk of Asian aquaculture, in particular inland finfish culture, is semi-intensive, these feed types are an important entity in the chain of events, and will undoubtedly impact on the long-term sustainability of Asian aquaculture.

BOX 3

Snakehead culture

Snakeheads are difficult to wean on to pellet feed, and hence the industry continues to depend upon moist feeds that include about 70–80 percent trash fish. However, a number of small hatcheries are now beginning to wean the wild-caught snakehead fry on to pellet feed, initially feeding a mixture of pellet feed and minced trash fish and gradually reducing the latter. The fish can be completely weaned on to a dry diet in 10 to 12 days. An increasing number of grow-out farms are beginning to obtain weaned fingerlings, and in a few years, it can be expected that snakehead farming in Thailand will be transformed almost completely, as was seabass farming.

Photos: Feed bag covers and the hatchery set up used for weaning snakehead

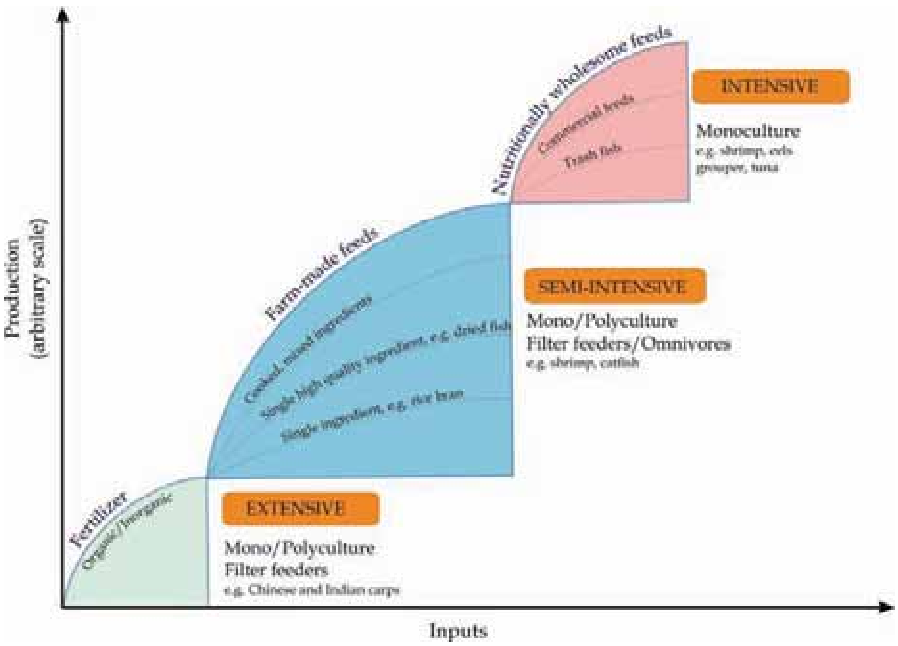


The use of farm-made feeds based on trash fish/low-value fish and/or other animal protein sources (mainly processing waste from poultry) is still a common practice in freshwater and marine carnivorous finfish culture and crab and lobster fattening in Asia. However, in some instances there are trends to change from the use of farm-made feeds to commercial feeds, the most notable of these being in catfish farming in the Mekong Delta, a sector that has witnessed an explosive growth in the last decade and was estimated to have had a production volume of over 1 million tonnes in 2007 (Phoung and Oanh, 2009). The snakehead and catfish farming sector in Thailand is predominantly based on farm-made feeds (see Boxes 2 and 3), but these feeds are predominantly based on the use of poultry processing wastes and in such feeds the amount of ingredients originating from aquatic organisms is often negligible, with exceptions such as in pangasiid culture in Viet Nam (see Section 5.2).

In contrast to "farm made" feeds, commercially manufactured feeds are produced in large quantities in central manufacturing plants and are purported to be in accordance with the dietary requirements of individual species. Rarely, more generalized feeds that are reckoned to be useable and effective for a whole range of cultured finfish are also available in the market. In Asian aquaculture, some of the commonly found feed types are those for tilapias, shrimp, eels, seabass and catfishes. Often such feeds differ marginally in their specifications for different stages of the grow-out cycle of each of the species, and of course, between species. It is not uncommon that in intensive culture systems, the feed costs often account for more than 50 percent of the recurring costs of an operation.

In general, there is very limited quality control of commercial feeds in the region, perhaps with the exception of countries such as Thailand (personal observation). This as an area where investigation is needed, especially in view of the proliferation of small-scale feed mills in the region and the ever-increasing product certification requirements of importing nations. With an exception of a study carried out in Bangladesh (Kader, Hossain and Hasan, 2005), such investigations on feed quality are rather uncommon and have to be intensified and, where appropriate, more stringent regulations introduced with respect to types of feed ingredients and their quality. A schematic representation of the efficacy of the broad feed types on the growth of cultured stocks is shown in Figure 8.

FIGURE 8
A conceptual representation of the effectiveness of fertilizers and different feed types on production



Source: De Silva and Hasan (2007)

3.3 Ingredients used

The ingredients utilized in fishfeed production vary widely depending on the feed type, the cultured stock(s) and the farmers' financial limitations. Basically, they range from agricultural and animal industry by-products to fishmeal and fish oil, among others. A detailed account of the availability of commonly used ingredients and the type of usage in Asian aquaculture, particularly of agricultural by-products, has been presented elsewhere (Tacon, 1987; Hertrampf and Pascual, 2000; De Silva and Hasan, 2007; Hasan *et al*., 2007).

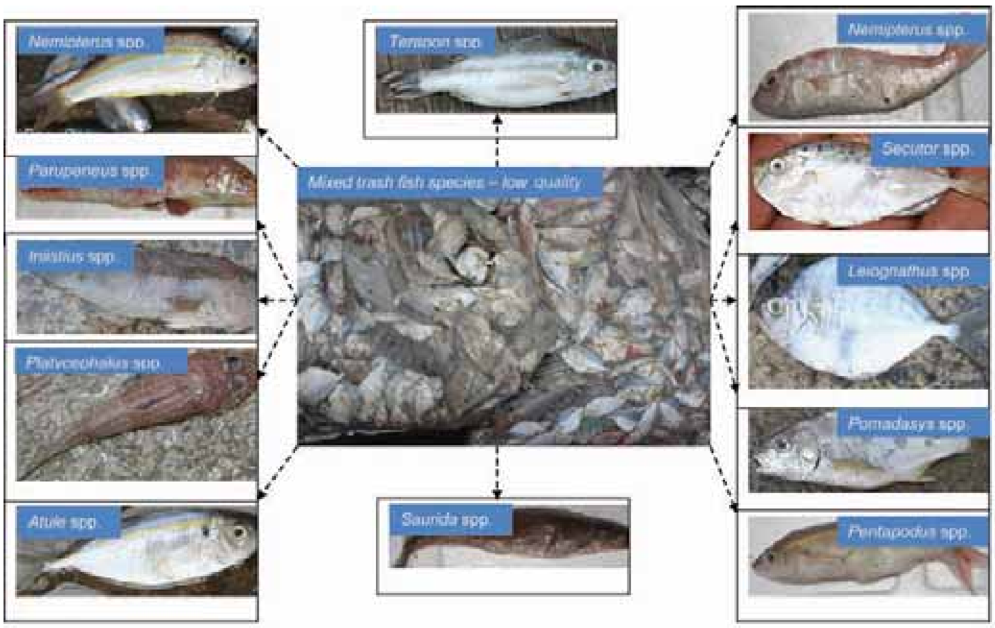
3.4 Use of fish and other aquatic products in aquaculture

Fish used directly and/or reduced into a form such as fishmeal or fish oil to feed cultured stocks are referred to as trash fish/low-value fish. Recently it has been pointed out that the use of the term "trash fish" is misleading and that a better term would be "low-value fish", which has been defined as *"fish that are generally of relatively low economic value and typically small sized; they can be used for human consumption or as animal feeds (both fish and livestock); they may be used directly in both aquaculture to feed other fish or processed into fishmeal/oil for incorporation into formulated diets; the same is true for human food, where the fish may be consumed directly, or further processed often using traditional methods of processing small fish"* (Sugiyama, Staples and Funge-Smith, 2004). Trash fish/low-value fish have also been defined as: *"Fish that have a low commercial value by virtue of their low quality, small size or low consumer* *preference. They are either used for human consumption (often processed or preserved) or used for livestock/fish, either directly or through reduction to fishmeal/oil"* (Funge-Smith, Lindebo and Staples, 2005).

From an Asian regional viewpoint, based on use in aquaculture, the following categorization is considered appropriate:

- *Trash fish* are generally a mix of species of varying sizes, have minimum commercial value and often are not suitable for human consumption. They often originate from bycatches. When landed, the fish normally appear mushy and have an unpleasant odour (Figure 9). In certain instances, even fish that are suitable for human consumption may become less desirable due to poor capture techniques or poor handling and are thus used for feeding cultured stocks.
- *Low-value fish* normally consist of a single species (such as scad, trevally anchovies or sardines). The quality is relatively good and they may be suitable for human consumption; the flesh is firm and there is no unpleasant odour. These fish originate from targeted fisheries whose catch is aimed for human consumption (Figure 10). However, as their price is low, some farmers who raise higher-value species commonly use these fish as feed for their cultured stock. Also, some fish farmers actively fish in local waters to obtain this resource for feeding their cultured stocks, which practice they believe is cost-effective.

FIGURE 9
Mixed trash fish/low-value fish used in Asian aquaculture and species representations



The methods of capture of trash fish/low-value fish, the price ranges of the produce and its usage in selected Asian countries are discussed by Funge-Smith, Lindebo and Staples (2005). Fish species considered as trash fish/low-value fish vary from country to country, and the price also varies with usage in a given country. Importantly, not all trash fish/low-value fish are destined for use as animal feed in one form or another. A qualitative assessment by Funge-Smith, Lindebo and Staples (2005) indicated that in countries such as Bangladesh, India and the Philippines, and to a lesser extent in Thailand and China, a significant proportion is used for human consumption in fresh, dried and other processed forms. Also in Viet Nam, trash fish/low-value fish are often used for processing into fish sauce, and in some countries such as Cambodia and Viet Nam, these fish undergo "household" processing into a "fish powder" that is used predominantly for poultry feeds at the cottage level (De Silva, 2008).

FIGURE 10
Types of trash fish/low-value fish of single species caught and used in Asian aquaculture

4. USE OF FISHMEAL AND FISH OIL IN ASIAN AQUACULTURE

The preference for the use of fishmeal and fish oil in all forms of diets for cultured stocks is based on their favourable amino acid and fatty acid profiles, respectively, which provide all of these essential nutrients. These products are easily digested by aquatic animals and also provide unknown growth factors, some essential micronutrients and highly unsaturated fatty acids, all of which cannot be synthesized *de novo* in adequate quantities by most cultured stocks, particularly marine finfish.

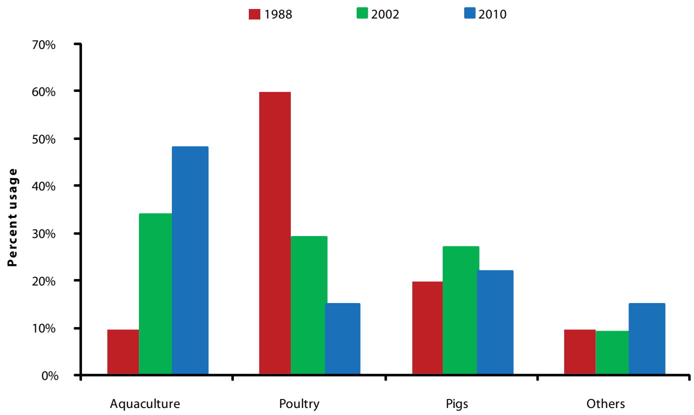
Fishmeal and fish oil are manufactured from trash fish/low-value fish put through a "reduction process". The raw material used in industrial reduction processes is also referred to as "forage fish". Globally, the main species used on a large scale to manufacture fishmeal and fish oil are small pelagic species such as anchovetta (*Engraulis ringens*), sand eels (*Ammodytes* spp.), Atlantic menhaden (*Brevoortia tyrannus*), capelin (Family Osmeridae, e.g. *Mallotus* spp.), Atlantic herring (*Clupea harengus harengus*), Chilean jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*). On average, 4–5 kg of wet fish will yield 1 kg of fishmeal and 100 g of fish oil (FAO, 1986; De Silva and Anderson, 1995). However, in Asia, as will be discussed later, fishmeal manufacture is based on a species mix, and seafood industry waste is also being increasingly used. In addition, there is a trend to utilize processing waste from cultured fish such as pangasiid catfish in Viet Nam and rohu in Myanmar to extract fish oil and also as a protein source in feeds.

4.1 Historical aspects of the use of fishmeal and fish oil in aquaculture

Prior to the third quarter of the last century, aquaculture was not seen as a major fish-food production sector, the harvest from the oceans was thought to be inexhaustible, and fishmeal and fish oil use in aquaculture was negligible. Most of the global production of these commodities was used by the terrestrial animal husbandry sector. However, with the growth of the aquaculture sector, particularly salmonid culture in the Northern Hemisphere, the demand for fishmeal and fish oil began to increase. The first warning signs were given by Wijkstrom and New (1989) and New (1991, 1997), who suggested that the growth of the aquaculture industry could be limited by the availability of fishmeal.

Over the last 30 years, aquaculture production has grown from 8.52 million tonnes valued at US$12 billion in 1984 to 54.37 million tonnes valued at US$57 billion in 2004, an average annual rate of increase of 6.8 percent (FAO, 2007). As this growth was accompanied by the increased production of carnivorous finfish (such as salmonids) and shrimp, there was a concurrent and very significant increase in fishmeal (Figure 11) and fish oil usage in aquaculture. If this trend continues, aquaculture will become the major user of these commodities (Tacon, 2004), whose production has levelled off but whose prices continue to increase (Jackson, 2006; FAO, 2007). Indeed, the price of fishmeal doubled between 2004 and 2006, rising to almost US$1 600 per tonne, freight on board (FOB) (INFOFISH, 2006).

FIGURE 11
Changes in the proportion of fishmeal usage by different sectors over the years, including a projection for 2010



Source: Pike and Barlow (2002)

As shown in Figure 11, fishmeal usage in poultry farming has declined very significantly, while its use in the pig farming sector has remained static. This is not due to decreased production of poultry and pigs, but is a result of the replacement of fishmeal in the feeds used by these sectors with other ingredients and of improvements in feed utilization efficacy. Admittedly, the protein requirements of poultry and pigs are lower than that of fish (McDonald *et al.*, 2002), which tend to utilize proteins to meet basic metabolic energy requirements (De Silva and Anderson, 1995). Genetic improvements of poultry and pigs, a result of concerted and well-planned research outcomes, have also contributed to better feed utilization, while there have been only limited improvements of aquaculture species in this regard (Gjedrem, 1997). The questions, therefore, arise as to whether the aquaculture sector can achieve likewise results, and if so when, and if not, why, and what are the limiting factors and the pivotal constraints?

In aquaculture, unlike in poultry and pig farming, the number of species cultured is quite high (FAO, 2006b). For example, in the Asia-Pacific region 204 species belonging to 86 families are cultured, while on a global level 336 species belonging to 245 families are farmed. Each cultured species has unique nutrient requirements, and many species must be provided with externally derived food, particularly those reared under intensive culture practices, which often have to be provided with specially formulated feeds that conform to their specific nutrient requirements.

The major increases in aquaculture production have occurred through the rearing of omnivorous fish species and filter-feeding molluscs, while carnivorous fish production, although significant, still only accounts for less than 20 percent of total production. For certain cultured carnivorous species, particularly the salmonids, the fishmeal content of the diets has been significantly reduced without loss of performance and flesh quality or an increase in negative environmental effects. This achievement has occurred in a progressive fashion with the increased understanding of the physiology of the animal and its application through appropriate feed formulations (Åsgård *et al.*, 1999; Hardy, 2000). In the case of salmonids, the renowned "protein sparing effect", the physiological capability to "spare" dietary protein by lipids (De Silva and Anderson, 1995), which is a common trait in coldwater species (Beamish and Medland, 1986), has enabled a gross reduction in the fishmeal (protein) content of the feeds and resulted in the indirect benefit of such diets being more environmentally friendly in that much less nitrogen and phosphorous are discharged into the environment (Hardy, 2000). However, the metabolism differs among finfish species, particularly with respect to traits such as "protein sparing" capability. In general, the protein sparing capabilities of cultured tropical species are not that significant. Therefore, from a feed formulation viewpoint, the prospect of using this physiological trait to reduce the amount of fishmeal in the diets of tropical finfish is relatively remote. These traits, together with the generally poor uptake of research findings by feed manufacturers (De Silva and Davy, 1992; De Silva and Hasan, 2007), have delayed achieving reduction of fishmeal and fish oil use in aquaculture.

There are lessons to be learned from Japan, where large-scale mariculture originated based entirely on using trash fish/low-value fish as the feed source (Watanabe, Davy and Nose, 1989). The development of formulated feeds took a certain length of time, a major breakthrough being the development of a soft-dry diet with high palatability for Japanese amberjack (*Seriola quinqueradiata*). This breakthrough revolutionized feed development for marine cage farming and literally removed its dependence on the direct use of trash fish/low-value fish (Watanabe, Davy and Nose, 1989). Of course, feed formulations and feed manufacturing technology for finfish have now progressed much further (Box 4). Currently, much research effort is being expended on feed formulation for emerging marine cage-farming species in the Asian tropics such as grouper and cobia (Rimmer, McBride and Williams, 2004).

4.2 Fishmeal and fish oil production in Asia

Fishmeal and fish oil are world-traded commodities, with the production dominated by Chile, Iceland, Norway and Peru, all countries that have access to and exploit large single-species stocks such as the anchovetta, sand eel and Atlantic menhaden. Although

BOX 4

Research trends in finfish nutrition

Over the years, the most extensive research on finfish nutrition has been the study of fishmeal replacement in feeds. This research has involved almost all species of cultured finfish and a wide range of potential ingredients ranging from agricultural by-products to single-cell proteins to animal industry by-products. Most recently, the use of krill species (*Euphausia* spp.) as a potential substitute for fishmeal (Olsen *et al*., 2006; Suontama *et al*., 2007) has received considerable attention. However, it should be noted that a reduction in krill populations has been observed (Atkinson *et al*., 2004), possibly as a result of global warming. Moreover, the use of krill may do little more than shift the problem of sustainability from finfish stocks to krill.

fishmeal and fish oil production has increased over the years and has somewhat steadied in the last three years, these commodities are often subjected to unpredictable availability and wide price fluctuations due to the influence of climatic changes such as the El Niño events (Jackson, 2006). For example, the fishmeal price increased from approximately US$600 to US$1 600 per tonne from 2003 to January 2006 (INFOFISH, 2006), while the price of a commodity such as soybean meal, for example, remained almost static over the same period (GLOBEFISH, 2005).

Fishmeal production in Asia is dominated by Thailand, China and Japan (Table 3). Chinese production has shown a decline since 2000 (Figure 12) and was only 306 000 tonnes in 2004. Globally, only Japan, Thailand, China, Taiwan POC, Indonesia and Viet Nam are included among the top 16 producers, importers and consumers of fishmeal (IFFO, 2005). It is noteworthy that, other than Japan and China (which produced 68 000 and 13 000 tonnes, respectively, in 2004), Asian countries are not significant fish oil producers.

TABLE 3
Fishmeal production in the Asia-Pacific region

Country	Year	Production (tonnes)	No. of plants	Imports (tonnes)
China[a]	2005	300 000	na*	1 580 000
Taiwan Province of China[b]	2005	16 100[J]	na	220 976
India (Karnataka)[c]	1990 to 2003	8 000–10 000	18	34 000[d]
Myanmar[e]	2005	12 610	14	na
Japan[f]	2004	195 000	na	402 000
Republic of Korea[g]	2005	45 000	na	na
Thailand[h]	2004	403 000	95	4 800
Viet Nam[i]	2004	80 000	15–20	82 000
Total		**1 061 710**		**2 323 776**

*na: not available
Source: [a]Tang (2006); [b]S-Y. Shiau (National Taiwan Ocean University, personal communication, 2007); [c]IMM Ltd. (2003); [d]Chandrapal (2005); [e]Lay (2006); [f]IFFO (2005); [g]US Department of Agriculture (http://www.indexmundi.com/en/commodities/agricultural/meal-fish/2005.html); [h]IFFO (2005); DOF (2006); H. Kongkeo (NACA, personal communication, 2007); [i]Edwards, Le and Allan (2004); Dao, Dang and Nguyen (2005); [J]FAO (2007)

Over the over the last few years, Asian production of fishmeal (notably in the three nations that rank within the top 16 globally) has not increased significantly, while consumption has decreased by about 200 000 tonnes over the period 1999 to 2004 (Figure 12). However, in Viet Nam, which is an emerging aquaculture nation, fishmeal consumption has increased to 82 000 tonnes from almost zero in 1999. By contrast, importations by Thailand have decreased from 10 080 tonnes in 2004 to 4 800 tonnes in 2006 (H. Kongkeo, NACA, personal communication, 2006). Increased domestic fishmeal production is probably the main reason for the decline in imports to Thailand. It is also claimed that there has been a gradual improvement in the quality of the fishmeal produced in Thailand, particularly in those plants owned and/or managed by Charoen Pokphand, one of the world's leading animal feed producers (Gill, 2003).

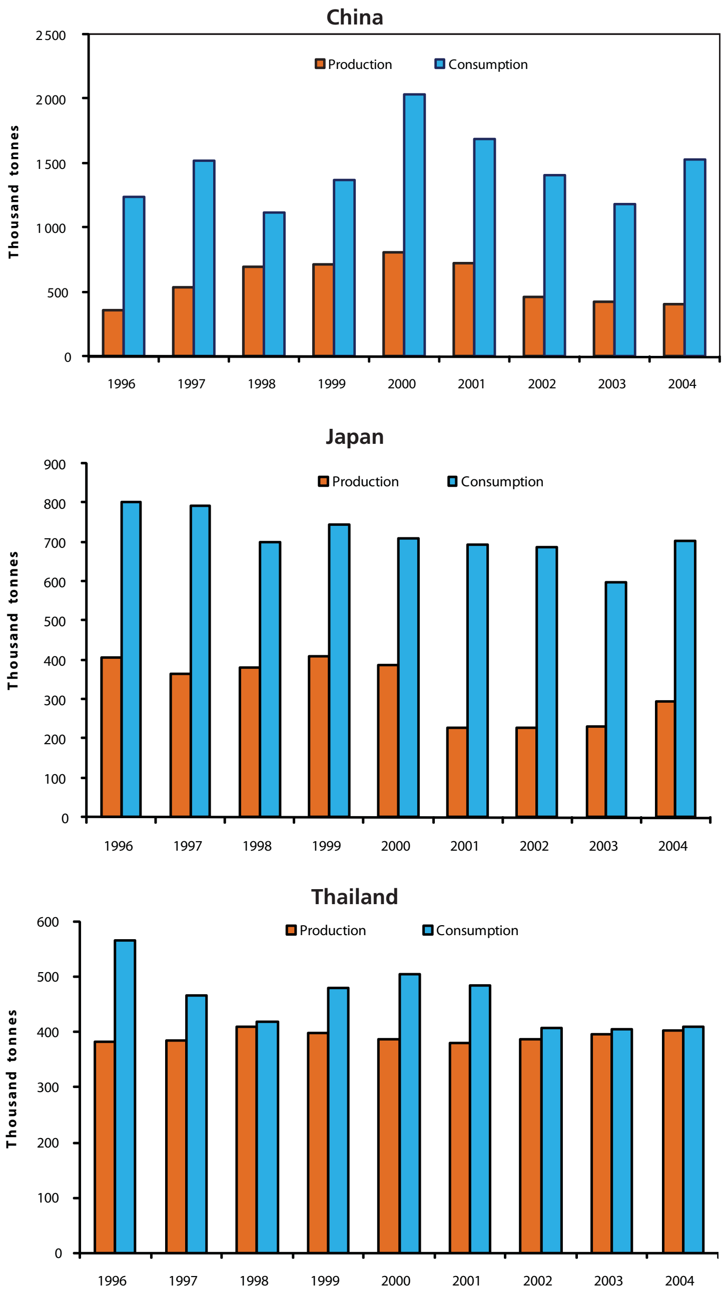
In Viet Nam, it is purported that there is a specialized fleet for catching trash fish, and a total of 300 000 to 600 000 tonnes of trash fish/low-value fish is landed, of which about 280 000 tonnes are used by the fishmeal plants, a conversion rate of 3.5 (Dao, Dang and Nguyen, 2005). By contrast Edwards, Le and Allan (2004) estimated the trash-fish landings in Viet Nam to be 933 183 tonnes in 2001, valued at Vietnamese dong (VND)1 390 416 million (US$99 315 428) (Table 4).

In Viet Nam, the commercial landings of trash fish/low-value fish vary depending on the locality, season, species composition and demand. The price is very variable and is linked to usage (also see Funge-Smith, Lindebo and Staples, 2005). Trash fish/low-value fish used for fishmeal production, fish powder production and direct feeding for cultured fish stocks range in price from VND700 to 1 800, VND500 to 800, and VND 2 000 to 2 500 per kg, respectively (US$1=VND14 500), conceivably reflecting the quality of the trash fish.

In some countries, fishmeal manufacturing also tends to use aquatic food industry waste products. However, the quantities utilized are difficult to obtain, and estimates are restricted to countries that have a major aquatic food industry sector, such as the tuna canning sector in Thailand. In Thailand, the total tonnage used for fishmeal production ranged from 388 987 to 769 361 tonnes from 1997 to 2004, and in 2004 it was 671 641 tonnes (DOF, 2006). The latter amounted to 43.2 percent of the raw material used in the production of 423 866 tonnes of fishmeal in Thailand in 2004.

In India, the coastal state of Karnataka is a major center for fishmeal production (IMM Ltd., 2003), the number of fishmeal plants having increased from two in 1975 to 18 in 1998. However, operations are very seasonal, depending on the availability of the main raw material (oil sardines, *Amblygaster* spp.), both locally and from other states such as Gujarat and Mahashatra. The fishmeal produced is very variable in quality (IMM Ltd., 2003), the average protein content being only about 40 percent. The current market price of the fishmeal produced ranges from Indian rupee (INR)5 000 to

FIGURE 12
Fishmeal production and consumption in three Asian countries (China, Japan and Thailand) that are ranked among the top 16 globally in both these respects



Source: IFFO (2005)

8 000 per tonne (US$1=INR43), considerably lower than the world market price. At present, only about three fishmeal plants are in full operation.

The demand for animal protein feed sources in China is soaring due to the rapid development of aquaculture and the husbandry of other animals. At present, there is an estimated annual supply shortage of 10 million tonnes of animal protein feed material and of 30 million tonnes of ingredients for providing energy. Animal protein sources for aquaculture feed mainly depend on fishmeal, but China produces less

TABLE 4
Estimations of trash fish/low-value fish production in the Asia-Pacific region

Country	Low-value/trash fish (tonnes)	% of total catch	Dominant gear (%)	Year of estimation
Bangladesh	71 000	17	Gillnets (48)	2001–2002
			Set bags (42)	
China	5 316 000	38	Trawl	2001
India	271 000	10–20	Trawl	2003
Philippines	78 000	4	Trawl (41), Danish seine (22) purse-seine (12)	2003
Thailand	765 000	31	Trawl (95)	1999
Viet Nam	933 183	36	Trawl	2001

Source: Funge-Smith, Lindebo and Staples (2005)

than 0.5 million tonnes of fishmeal per annum. In 2004, 1.6 million tonnes of fishmeal were imported into mainland China, accounting for 20 percent of the world's total fishmeal production or more than 25 percent of its traded volume. Fishmeal accounts for 45 percent of the total importation of fisheries products by China. These figures demonstrate the Chinese feed industry's pressing need for animal protein. In China, locally produced fishmeal is of low grade and low price because of the lack of raw materials and the use of poor and out-dated processing technology. China still relies heavily on the importation of quality fishmeal for the manufacture of feeds for marine shrimp and soft-shell turtles.

4.2.1 Localized (non-industrial) fishmeal production

Apart from major fishmeal manufacturing plants, in some Asian countries (e.g. Indonesia, India and Viet Nam) local, small-scale fishmeal plants and fish drying and powdering operations are often located near major landing sites. The produce of these plants caters mostly to the local animal husbandry sector, primarily poultry farming (also see Funge-Smith, Lindebo and Staples, 2005) and to a lesser extent, the aquaculture sector, for inclusion in farm-made feeds.

Locally prepared fishmeal (in essence, a fish powder) is typically manufactured manually in small-scale operations by drying and powdering trash fish/low-value fish. In Viet Nam, the raw material used for fish powder is of poorer grade, as indicated by the price, than that used in fishmeal production and/or for direct feeding to aquaculture stocks. The quantity of fish powder produced is estimated at 185 000 tonnes per year (Edwards, Le and Allan, 2004; Dao, Dang and Nguyen, 2005). In addition, in Viet Nam there are significant quantities of low-value fish of freshwater origin, primarily fished during the flood season in the Mekong Delta, that are sun dried and used for direct human consumption, for making fish sauce and as a substitute for fishmeal (powdered on site) in farm-made feeds in catfish culture (De Silva, 2008).

There is a paucity of data on fishmeal production in India, even though it is the world's second most important aquaculture-producing nation; however, it is common knowledge that production of fish powder in the traditional manner supersedes the industrial production of fishmeal. As early as 1995, Ali *et al*. (1995) estimated that the marine protein sources available for reduction amounted to 335 191 tonnes by dry weight, and consisted of finfish, crustaceans such as mantis shrimp (*Squilla* spp.), cephalopods and molluscs. Ali *et al*. (1995) also acknowledged that the fishmeal produced was of low quality, being mostly pulverized dried fish. Currently, the price of trash fish/low-value fish appears to range from INR2 to 10 per kg (US$1=INR43).

4.2.2 Cost of production of fishmeal

Details on the cost and use of raw material in fishmeal production are not easily accessible. However, some details on fishmeal production that are available for Thailand are summarized in Table 5. The conversion rate of the raw material over the years was consistent, averaging 3.85 over the eight-year period. The cost of Thai fishmeal in 2004 was US$590 per tonne (US$1=Thai baht (THB) 38), considerably less than the average world market price. Assuming that all three types of raw material (Table 5) used in fishmeal production in Thailand result in similar conversion efficiency (CE), in 2004, 771 723 tonnes of trash fish/low-value fish would have produced 207 694 tonnes of fishmeal. The average price of trash fish for fishmeal plants was US$121.5 per tonne of fishmeal produced, accounting for only 20.6 percent of the raw material cost of production of a tonne of fishmeal.

By contrast, in Viet Nam, based on an average price of trash fish/low-value fish used for fishmeal production of VND1 300 per kg and a conversion rate of 3.5, the total cost of the raw material needed to produce a tonne of fishmeal was approximately US$314.

TABLE 5
Summary of fishmeal production in Thailand

Year	Raw materials used (tonnes)			Fishmeal	
	Trash fish	Others	Processing waste	Tonnes	Conversion efficiency (CE)
1997	799 814	45 756	670 187	378 940	3.99
1998	758 465	53 841	511 581	342 438	3.87
1999	755 382	57 464	388 987	309 248	3.89
2000	725 489	62 675	358 927	299 073	3.83
2001	722 109	56 363	659 259	378 352	3.80
2002	679 640	59 908	768 096	391 583	3.85
2003	695 999	63 668	769 361	392 312	3.89
2004	771 723	112 586	671 641	423 866	3.67

Source: DOF (2006a)

Sinh (2007) reported that fishmeal plants in the Mekong Delta bought about 29 916 tonnes/year of trash fish/low-value fish, of which 63.3 percent was from wholesalers and/or other companies, 20 percent was directly from fishers and the remainder was from collectors. The average price of trash fish/low-value fish bought by the fishmeal plants was VND2 800 per kg (±100). The average production of fishmeal was 7 479 tonnes/year and the average selling price was VND13 000 per kg (±500). The average marketing costs were VND284 per kg of this raw material, which provided an average marketing profit of VND166 per kg of raw material. It was reported that 80.6 percent of the fishmeal produced was channelled to feed processing plants, 26.7 percent was distributed through a network of wholesalers and the remainder was exported.

4.2.3 Quality of fishmeal produced in the Asia-Pacific region

The quality of fishmeal is crucial to diet formulation and is affected by the species composition of the raw material, its freshness, the season, the presence of any foreign material (e.g. sand and contaminants) and of course, the reduction techniques employed. In essence, the quality of a fishmeal is partially determined by its protein level (higher the better) and ash content (lower the better). A comparison of the proximate composition of fishmeal of different origins is given in Table 6. It is seen that Asian fishmeal has considerably lower fat content and a very high proportion of ash, both traits that are less desired for formulation of fish feeds. It should be noted that although most fishmeal plants in Asia do not extract fish oil, the fishmeal produced has a significantly lower fat content compared to American and European fishmeals. The use of low-quality fishmeal will result in reduced performance of the cultured stock and also increased feed requirements, which increase the requirement for raw material – trash fish/low-value fish.

With an envisaged increase in the capacity of the reduction industry for fishmeal production in the Asian region, it is imperative that quality control methods be put in place and the efficacy of production improved.

TABLE 6
Typical proximate analysis of selected fishmeal of different origin

Region	% Protein	% Fat	% Ash	% Moisture
South America	65.0	9.0	16.0	10.0
Europe	72.7	9.1	10.1	8.1
United States of America	62.6	10.1	19.2	8.1
Europe/Asia	65.0	5.0	20.0	10.0

Source: Adapted from Pike (2005)

4.3 The use of trash fish/low-value fish for fishmeal production and the potential for direct human consumption

The raw material (much of which is trash fish/low-value fish) used for fishmeal production in Asia is generally in poor physical condition, often literally "mashed", and frequently not suitable for human consumption. While there are no quantitative data available, qualitative data can be derived by visual inspection (the photos in Figure 9 show the physical condition of the fish). These raw materials are landed at sites that have alternative supplies of fish of better quality, with a wide range of species of different sizes and at a range of prices that cater to a broad spectrum of socio-economic groups. If such raw materials were to be transported long distances to areas where availability of fish is significantly less, the quality would further deteriorate. Moreover, the transportation costs would be such that potential prices would not be commensurate to the product quality, and consequently there would be rather limited consumer demand.

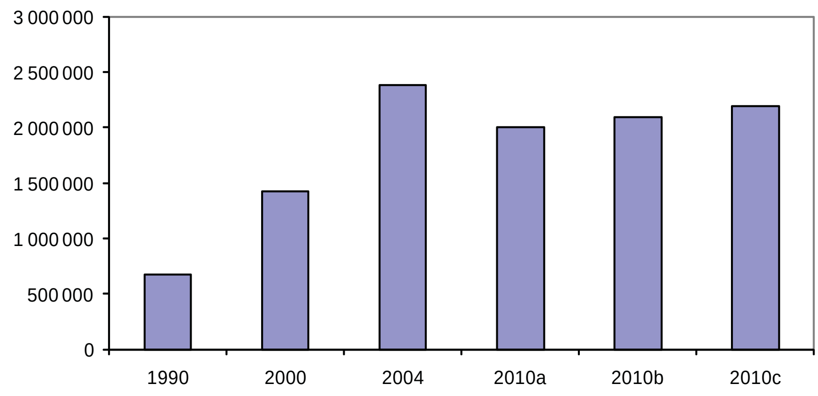
The question "if the raw material used is not reduced, can it be made available to potential consumers in a reasonable state, and at an acceptable price?" is not as simple or straight forward as it is often made out to be (see Funge-Smith, Lindebo and Staples, 2005; FAO, 2007). Although no direct estimates are available, in all probability the costs of transportation and preservation (icing/refrigeration/freezing) far exceed its "real value".

A parallel can be drawn with the very seasonal "dai"[2] fishery of the Cambodian sector of the Mekong River. The overall production from the Mekong fisheries is estimated to be about 1.5 million tonnes (Coates, 2002; Sverdrup-Jensen, 2002). The dai fishery operates for about six to eight weeks, and the bulk of the catch is small migrating species, mostly cyprinids and pangasiids, with yields ranging from 7 000 to 18 000 tonnes per year (Sverdrup-Jensen, 2002). The bulk of the catch is probably too large in volume and too low in value to be transported into neighbouring countries for direct consumption, and hence value-adding has been a traditional best use of the raw material. These value-added products are used for direct human consumption, and their production is related to cultural traits that have evolved in parallel over many hundreds of years.

By contrast, in Asia, value-adding for marine species has been mostly confined drying and to a very small extent, converting into salted fish and fish sauce, the latter particularly in Viet Nam (Phan, 2007). In all these instances, the fish used are of relatively high quality and suitable for human consumption, either fresh or reduced.

[2] The "dai" or "bagnet" fishery is the seasonal capture fishery based on the yearly crop of small fish species migrating out of flooded areas around the Great Lake and Tonle Sap River to the Mekong River.

FIGURE 13
The estimated fishmeal use in compounded feeds in Asian aquaculture



Source: Data from Table 8

Although fishmeal production in Asia is still relatively small, it is growing, albeit slowly. The fact that a nation such as Myanmar produced nearly 12 000 tonnes of fishmeal is of importance to the region, and in this instance the raw material used is considered to be unsuitable for direct consumption. There are 14 reduction plants for this purpose employing over 300 persons (Lay, 2006). The financial gains from this additional employment may well exceed the equivalent food security value of this resource if the fish were used for direct human consumption. In all of the above instances, a potential waste is eliminated and employment is created, indirectly contributing to poverty alleviation and food security (Aye *et al*., 2007).

Asia is the world's major aquaculture producer, and given the current trend towards increased production of species that require feeds with relatively high protein content (i.e. fishmeal) and the relatively limited fishmeal and fish oil production in Asia, Asian aquaculture development is bound to be impacted by global trends.

In Tables 7 and 8, three projections for the growth of Asian aquaculture and the corresponding use of fishmeal by the sector are made based on production increases of 10, 15 and 20 percent from the level in 2004, a corresponding increase in the use of compounded feeds for certain groups, a decrease in the amount of fishmeal used in the feeds and improvements in conversion efficiencies. The latter two criteria are admittedly subjective, but the improvements expected are based on those achieved over the last

TABLE 7
Asian aquaculture production (tonnes) for groups of species farmed on fish feeds that include fishmeal

Species group	1990	2000	2004	Projected 2004–2010 increase in production		
				(10%)	(15%)	(20%)
Crustaceans	618 178	1 644 365	3 338 706	3 672 577	3 839 512	4 006 447
Marine/diadromous fish	964 115	1 586 385	2 158 865	2 374 752	2 482 695	2 590 638
Milkfish	399 554	429 622	514 656	566 122	591 854	617 587
Others*	564 561	1 156 763	1 644 209	1 808 630	1 890 840	1 973 051
Freshwater fish	6 277 800	18 342 611	22 431 118	24 674 229	25 795 785	26 917 341
Anguillidae	163 505	218 035	238 508	262 359	274 284	286 210
Catfishes	74 791	136 388	270 101	297 111	310 616	324 121
Cichlidae	285 561	953 202	1 398 723	1 538 595	1 608 531	1 678 468

*Include all other cultured marine species.
Source: FAO (2006a)

TABLE 8
Estimated amounts of fishmeal used in Asian fish feeds

Species group	Criteria used 1990–2004			Estimated fishmeal usage (tonnes)*****		
	Feed usage (%)**	Fishmeal (%)***	CE****	1990	2000	2004
Crustaceans	100	25	1.7	262 727	698 855	1 418 951
Marine fish*	50	45	1.5	190 542	390 461	554 920
Milkfish	100	12	1.6	76 713	82 488	98 813
Anguillidae	100	50	1.4	114 200	152 625	166 956
Catfishes	80	3	1.4	3 140	5 727	11 344
Cichlidae	85	7	1.4	27 985	97 783	137 074
			Total	**675 307**	**1 427 939**	**2 388 058**
Estimates for 2010				**Estimated fishmeal usage (tonnes)**		
Species group	**Feed usage (%)**	**Fishmeal (%)**	**CE**	**10%********	**15%**	**20%**
Crustaceans	100	20	1.5	1 101 773	1 151 853	1 202 934
Marine fish	70	40	1.3	658 341	688 265	718 190
Milkfish	100	5	1.4	39 628	41 934	43 231
Anguillidae	100	40	1.2	125 933	129 257	137 381
Catfishes	80	4	1.3	7 724	8 076	8 427
Cichlidae	90	4	1.2	66 467	77 176	80 566
			Total	**1 999 866**	**2 096 561**	**2 190 729**

*All marine species as per Table 7.
**Production based on formulated feeds.
***Percent content of fishmeal in feed.
**** CE = conversion efficiency (kg of dry feed required to produce 1.0 kg of fresh fish).
*****Fishmeal use estimated using the production figure of Table 7.
******Increase in production, in percent, for the period 2004–2010.
Source: Fishmeal use in feeds for species groups are based on averages derived from the literature and also used by De Silva and Hasan (2007)

ten years in feeds used in Asian aquaculture and are believed to be attainable through better formulations and improved feed management. Accordingly, in spite of envisaged increases in production, by 2010 the quantity of fishmeal used in compounded feeds in Asian aquaculture is expected to decrease, in terms of percent inclusion in feeds, from the current levels (Figure 13).

In the present analysis, fishmeal usage in the Asia-Pacific region was estimated at 1.427 millon and 2.388 millon tonnes in the years 2000 and 2004, respectively[3]. In this context, the estimates of the present study for fishmeal use in aquaculture appear to be more realistic. More recently, Merican (2006) estimated the feed requirement for shrimp and freshwater fish culture in six Asian countries (Indonesia, India, Malaysia, the Philippines, Thailand and Viet Nam) in 2005 at 2.385 millon tonnes. Assuming the mean protein content to be 65 percent and that 35 percent of the protein is from fishmeal, the total fishmeal requirement is 542 547 tonnes.

4.4 Fishmeal requirements for compounded feeds in Asian aquaculture

Estimates for raw material are computed based on the fishmeal requirements of Asian aquaculture. In this computation, the conversion rate of the raw material (essentially trash fish/low-value fish) is adjusted based on the envisaged increased efficiencies in conversion (details are given in Table 9). Based on the estimates presented in Table 9, by 2010 the raw material required for fish feeds using fishmeal in aquaculture will be at least 6.999 million tonnes and at most 8.762 million tonnes. Considering that in 2004 nearly 10 million tonnes of raw material were required to sustain Asian aquaculture production, the scenario is an optimistic one.

3 Sugiyama, Staples and Funge-Smith (2004) estimated the fishmeal usage in Asia and the Pacific to be 3 726 591 tonnes in 2001. However, it is unclear whether this amount referred to use in aquaculture or the total use.

From a global perspective, the above lower estimate approximates the use of 30 to 33 percent of the raw material used in fishmeal manufacture in Asian aquaculture. However, given that Asian fishmeal manufacturing increasingly tends to use by-products from the fish food industry, it may be that the dependence on trash fish/low-value fish for fishmeal production could decrease further.

A case in point is the example of Myanmar, a newly emerging aquaculture nation where there are 14 fish reduction plants and 28 fish-feed production plants of varying capacity dedicated to producing aquafeeds. Three of these fish-feed plants have their own fishmeal production plants supplying their fishmeal requirements. The aquafeed industry caters to both the shrimp and carp farming sectors. One feed plant that produces 200 tonnes/day of fish feed employed 104 persons (Htoo Thit Fish Feed Plant, personal communication, 2007). Another enterprise, Ayeyarwardy Fisheries Ltd., which specializes in catfish cage culture and the export of fillets, has its own fishmeal plant with a production capacity of 1 tonne/day and employs 18 persons; its output, in turn, is used for fish-feed production (70 tonnes/day), employing 36 persons. The raw material for fishmeal production comes solely from the catfish processing, which in turn employs 400 persons, and the feed is solely used for its own catfish production. As noted earlier, additional data similar to that given above are needed to objectively assess the debate on the use of trash fish/low-value fish in Asian aquaculture.

TABLE 9
Estimated use of fishmeal and raw materials in Asian aquaculture, 1990-2010

Year*	Fishmeal (tonnes)	CE1**	CE2	Raw material (tonnes)	
				CE1	CE2
1990	675 307	5	–	3 376 535	–
2000	1 427 939	4.5	–	6 425 725	–
2004	2 388 058	4.3	–	10 270 894	–
2010[a]	1 999 866	4	3.5	7 999 464	6 999 531
2010[b]	2 096 561	4	3.5	8 386 244	7 337 963
2010[c]	2 190 729	4	3.5	8 762 916	7 667 551

*Three estimates (denoted by the superscripts a, b and c) for use of fishmeal have been derived for 2010. They are based on a projected production increase from 2004 to 2010 of 10, 15 and 20 percent.
**Two estimates of conversion efficiency (CE1 and CE2) were used to calculate 2010 projections of fishmeal use. CE = conversion efficiency of raw material to fishmeal (kg of raw material required to produce 1 kg of fishmeal).
Source: Data from Table 8

5. DIRECT USE OF FISH AS FEED IN ASIAN AQUACULTURE

Although trash fish/low-value fish are used for the feeding of finfish cultured in fresh-, -brackish- and marine waters, as well as for the rearing of crustaceans (such as mud crabs and lobsters) and a few molluscs, the highest usage is in marine finfish culture. Allan (2004) suggested that globally about 5 million tonnes of trash fish/low-value fish are used directly (i.e. as raw ingredients not previously reduced to fishmeal) as feed in aquaculture. D'Abramo, May and Deng (2002) estimated that in 2001 about 4 million tonnes were produced and used in China alone. As the epicenter of all forms of aquaculture, the Asia-Pacific region undoubtedly accounts for the greatest usage of trash fish as a direct feed source. Funge-Smith, Lindebo and Staples, (2005) estimated that while 9.8 million tonnes of trash fish/low-value fish are produced in the Asia-Pacific region, only a part of this volume is being directed for use in animal feeds. It is likely that a significant proportion of the remainder is processed into products such as fish sauce. For example, Edwards, Le and Allan (2004) estimated that the current production of fish sauce in Viet Nam is 80 million litres and is expected to double in ten years.

Fish fed to cultured stocks can be divided into three broad categories:

- Fish landed mostly by small-scale artisanal fishers, usually comprised of a single species at any one time, and which may be suitable for human consumption (Figure 10). This category includes slightly larger-sized fish with firmer flesh and can be and is consumed by local populations. This category is often used in the culture of crabs and molluscs (such as Babylon snail), often filleted or chopped into suitably sized pieces.
- Fish that are evidently not suitable for human consumption, mostly caught by trawlers and often equivalent to the grade of low-value fish used in fishmeal production. The species that fall into this category vary from region to region. In general, the species included in this category are small-sized, often crushed and literally "mushy" (Figure 9).
- Fish of relatively high quality that are used to feed large-sized broodstock (often individuals of over 10 kg) of some cultured marine species such as grouper. This category includes horse mackerel, large oil sardines, etc., and is small in total quantity.

5.1 Use of trash fish/low-value fish in brackishwater and marine aquaculture in Asia

5.1.1 Current use of trash fish/low-value fish in brackishwater and marine finfish aquaculture in Asia and future projections

The very significant increase in marine and brackishwater finfish production in Asia over the last ten years, amounting to an average yearly increase of 9.6 percent, has increased the demand for trash fish as the major food source for cultured brackishwater and marine finfish stocks. These cultured stocks include a range of species belonging to at least eight major families, the family/species group that currently accounts for the highest demand for trash fish species being the groupers (Table 10). In the region, fish is used as feed directly in mariculture in China, Indonesia, Malaysia, Thailand and Viet Nam, and in the farming operations for southern bluefin tuna (*Thunnus maccoyii*) in southern Australia.

Estimates of trash fish/low-value fish usage in aquaculture are available only for Australia and Viet Nam. In the case of Viet Nam, trash fish/low-value fish use in inland and coastal aquaculture ranged from 64 800 to 180 000 tonnes and from 71 820 to 143 640 tonnes, respectively, and the total amount used in aquaculture in Viet Nam was between 176 420 and 323 440 tonnes (Edwards, Le and Allan, 2004). The latter figures amount to approximately 22 percent of all trash fish/low-value fish production in Viet Nam. The bulk of trash fish/low-value fish is used for the production of fish sauce (Dao, Dang and Nguyen, 2005).

Australian southern bluefin tuna fattening, which is based on the on-growing of wild-caught juveniles, is totally dependent on trash fish/low-value fish as the feed source. In 2003, 5 409 tonnes of wild-caught tuna (of average weight 15 to 30 kg) were fattened in cages to produce 9 102 tonnes (processed weight), over a period of three to five months. The tuna were fed solely on pilchard and mackerel, and their farmgate value was Australian dollar (AUD)$266 million (US$1=AUD$0.75) (Primary Industries and Resources SA, undated; EconSearch Pty Ltd., 2004). The approximate increase in fattened weight of 4 000 tonnes required 50 000 to 60 000 tonnes of imported trash fish/low-value fish (Allan, 2004), giving a CE that is, at best, 12.5.

The computations given in Table 11 on the use of trash fish/low-value fish in Asian finfish aquaculture are based on production figures for the major cultured groups over a ten-year period (1995–2004) and at two levels of CE, 6 and 10 based on the best and the average conversion efficiencies observed in practices in Asian countries. Orachunwong, Thammasart and Lohawatanakiul (2006) estimated the conversion efficiencies when trash fish/low-value fish are used in mariculture to range from 8 to 15.

TABLE 10

Changes in total production (thousand tonnes) of cultured marine finfish species in Asia-Pacific from 1995 to 2004 and the estimated trash fish/low-value fish used (ETFU) (% use) for each species at conversion efficiencies of 6 and 10*

Species	% use	1995			1996			1997			1998			1999		
		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU	
			6	10		6	10		6	10		6	10		6	10
Barramundi	40	10	24	40	14	33	54	13	30	50	16	39	65	19	45	74
Amberjack, mackerel, etc.	0	178	0	0	152	0	0	145	0	0	154	0	0	148	0	0
Flatfishes	0	14	0	0	17	0	0	35	0	0	30	0	0	29	0	0
Cobia	30	0	0	0	0	0	0	0	0	0	1	2	3	1	1	2
Seabass	10	4	2	4	6	3	6	6	4	6	9	5	9	13	8	13
Seabream	10	86	52	86	91	54	91	97	58	97	101	61	101	107	64	107
Snappers	50	3	8	13	3	10	16	2	6	11	2	6	10	2	6	10
Groupers	80	5	24	40	5	26	43	6	28	47	6	28	47	9	41	68
Other marine finfishes	50	162	484	809	199	597	996	285	856	1 426	339	1 018	1 695	367	1 100	1 834
Total		**462**	**594**	**992**	**487**	**723**	**1 206**	**589**	**982**	**1 637**	**658**	**1 159**	**1 930**	**695**	**1 265**	**2 108**

*Fish used as feed in "tuna fattening" in Australia are not included.
Source: FAO (2006a)

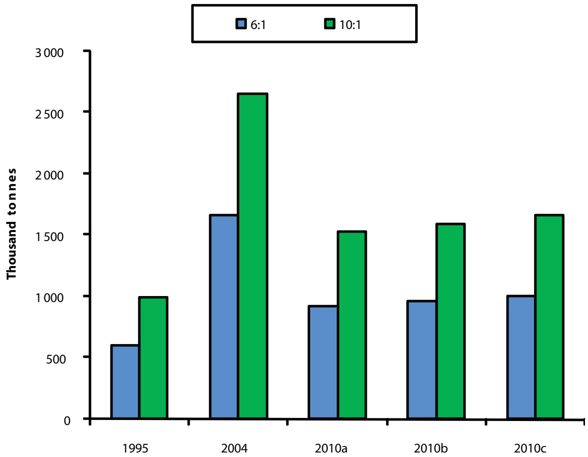
TABLE 10 *continued*

Species	% use	2000			2001			2002			2003			2004		
		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU		Prod.	ETFU	
			6	10		6	10		6	10		6	10		6	10
Barramundi	40	17	42	69	23	56	93	22	52	87	24	57	95	25	60	99
Amberjack, mackerel, etc.	0	144	0	0	160	0	0	170	0	0	176	0	0	169	0	0
Flatfishes	0	21	0	0	23	0	0	30	0	0	82	0	0	103	0	0
Cobia	30	3	5	8	3	6	10	2	4	7	21	37	62	20	37	61
Seabass	10	19	11	19	17	10	17	17	10	17	104	62	104	110	66	110
Seabream	10	107	64	107	95	57	95	95	57	95	162	97	162	165	99	165
Snappers	50	4	11	18	3	8	14	2	7	11	3	10	16	4	13	22
Groupers	80	10	46	77	13	62	103	23	108	180	53	253	422	58	278	464
Other marine finfishes	50	456	1 367	2 278	525	1 575	2 624	601	1 802	3 003	351	1 055	1 758	370	1 110	1 849
Total		**781**	**1 546**	**2 576**	**862**	**1 774**	**2 956**	**962**	**2 040**	**3 400**	**976**	**1 571**	**2 619**	**1 024**	**1 663**	**2 770**

Source: FAO (2006a)

FIGURE 14

Changes in the estimated trash/low-value fish usage in marine and brackishwater finfish culture in Asia at two conversion efficiencies of 6:1 and 10:1



Note: a, b and c denote three estimates for use of fishmeal for 2010. They are based on a projected production increase from 2004 to 2010 of 10, 15 and 20 percent

Source: The 2010 values are based on increases in production (based on information extracted from Tables 9 and 11)

Estimates of projected needs for trash fish/low-value fish in 2010, based on increases of 10, 15 and 20 percent over the production levels obtained in 2004, with corresponding decreases in the proportion of each major group of finfish fed on trash fish/low-value fish and a marginal improvement in conversion rates resulting from better feed management, are given in Table 11 and Figure 14. The projected increases in production are retained at rather conservative levels for a number of reasons. The main growth phase in the mariculture sector is believed to have already occurred, and most suitable areas for small-scale farming (which is the norm in Asia) are mostly saturated already. In addition, advances in seed production technology have not progressed as expected, with, for example, a survival rate for grouper species of only 10 to 15 percent at best (Rimmer, McBride and Williams, 2004). Finally, the ethical aspects of using trash fish/low-value fish for fish feed instead of directly for human food are likely to remain a bone of contention and possibly a limiting factor for aquaculture. In this context, it is important to point out that offshore cage culture of carnivorous fish has not expanded significantly in Asia over the last decade or more, even though it has been suggested as a potential growth area. Although plausible reasons for this trend have been dealt elsewhere, one factor that is often not taken into account is the relative unsuitability of the hydrographical conditions in most offshore areas in Asia (De Silva, Phillips and Mohan, 2007). Figure 14 portrays a projection of the use of trash fish/low-value fish as fish feed in the year 2010. The amount used will be significantly lower than that reported for 2004, a situation similar to that expected for the use of fishmeal in Asian aquaculture.

5.1.2 Trash fish/low-value fish use in finfish mariculture in Indonesia, Peninsular Malaysia, Viet Nam and China[4]

Indonesia

In Indonesia, four locations (i.e. Lampung, Situbondo, Bali Island, and Batam) were surveyed and conversion efficiencies of trash fish and commercial feed for various marine species are presented in Table 12. Most marine fish farms in the Lampung area produce grouper species. Trash fish/low-value fish use accounts for about 70 percent of the total feed inputs in these farms. The cost of trash fish averages about 40 percent of the total operating costs, ranging from 25 to 65 percent. The farmers' perception is that trash fish are cheaper and easy to obtain, and that stocks perform better than when commercial feeds are given. Trash fish are also the main food source used in barramundi (Asian seabass) as well as grouper farming in Situbondo. The daily trash fish/low-value fish usage for a 15-pond (5 000 m^2) production system is around 150 kg/pond/day for fish weighing more than 500 g. The estimated CE for seabass in ponds is around 6.0, while CE for groupers varies between 7.2 and 8.4. In Batam, trash

[4] This section is based on the findings of Sim (2006) except that of China. Information of China have been extracted from Xianjie (2008)

TABLE 11

Estimated production (thousand tonnes) of cultured marine finfish species in Asia-Pacific for 2010 based on 10, 15 and 20 percent increments and the corresponding prediction on the estimated trash fish/low-value fish usage (ETFU) for each species group at conversion efficiency of 6 and 10*

Species	Trash fish/low-value fish usage (%)		Estimated production and corresponding TF/LV fish use in 2004			Predicted production (at 10, 15 and 20% increments) and corresponding increase in TF/LV fish use in 2010								
	Estimated usage in 2004	Predicted usage in 2010	Production	ETFU		+10%	ETFU		+15%	ETFU		+20%	ETFU	
				6	10		6	10		6	10		6	10
Barramundi	40	20	25	60	99	27	33	55	29	34	57	30	36	60
Amberjack, mackerel, etc	0	0	169	0	0	186	0	0	194	0	0	202	0	0
Flatfishes	0	0	103	0	0	113	0	0	118	0	0	123	0	0
Cobia	30	15	20	37	61	23	20	34	24	21	35	25	22	37
Seabasses	10	5	110	66	110	121	36	61	127	38	63	132	40	66
Seabream	10	5	165	99	165	181	54	91	190	57	95	198	59	99
Snappers	50	25	4	13	22	5	7	12	5	7	12	5	8	13
Groupers	80	40	58	278	464	64	153	255	67	160	267	70	167	278
Other marine finfish species	50	25	370	1 110	1 849	407	610	1 017	426	639	1 063	444	666	1 110
Total			**1 024**	**1 663**	**2 770**	**1 127**	**913**	**1 525**	**1 180**	**956**	**1 592**	**1 229**	**998**	**1 663**

*The production obtained in "tuna fattening" is not included.

Source: Estimated use of trash fish/low-value fish and fish production for 2004 were adapted from Table 10.

TABLE 12
Conversion efficiencies (CE) for marine finfish aquaculture using trash fish/low-value fish and pellet feeds in selected locations in Asia (for comparison, Australian tuna fattening is also included)

Location	Species	Food conversion efficiency	
		Trash fish	Commercial feed
Lampung, Indonesia	Groupers	10.0–12.0	2.0-2.7
Situbondo, Indonesia	Groupers	7.2–8.4	n/a
	Barramundi	6.0	1.5
Bali Island, Indonesia	Humpback grouper	8–10	1.5–2.0
	Brown-marbled grouper	8–10	2.0–2.5
	Coral trout	8–10	1.7–2.5
	Yellowfin tuna (*Thunnus albacares*)	7.0–9.0	n/a
Batam, Indonesia	Groupers	8.0–15.0	n/a
Kukup, Johor, Malaysia	Groupers	10.0–12.0	n/a
	Other carnivorous marine finfish*	n/a	3.0–4.0
South Australia	Southern bluefin tuna	12.5–15.0	n/a

n/a: not available.
*Some farms using farm-made feed with CE of 4.
Source: Sim (2006), Allan (2004)

fish are rather limited and expensive, so many farmers use farm-made feeds, and most of these farms use fingerlings that have been weaned onto such feeds at an early stage. In Bali Island, trash fish are used for grouper (humpback and brown-marbled grouper and coral trout) with CE varying between 8 and 10.

Peninsular Malaysia
In Malaysia, trash fish/low-value fish account for about 30 percent of the total feed usage in marine farming (Kukup, Johor) of groupers (*Epinephelus* spp.), snappers (*Lutjanus* spp.), snubnose pompano (*Trachinotus blochii*), threadfins (mainly fourfinger threadfin, *Eleutheronema tetradactylum*), cobia (*Rachycentron canadum*), trevally (mainly giant trevally (*Caranx ignobilis*) and golden trevally (*Gnathanodon speciosus*)) and barramundi (*Lates calcarifer*). Feed cost generally amounts to about 60 percent of the total operational costs, and trash fish/low-value fish account for about 20–30 percent of the latter.

BOX 5
Mariculture in central Viet Nam
In central Viet Nam, where there is intense mariculture activity in certain areas, the marine fish farms tend to act cooperatively with regard to trash fish purchases and prefeeding preparation as an effective means of saving costs and labour.

Photos: Raw trash fish used in grouper culture and their preparation for feeding to stock

TABLE 13
Trash fish usage in some marine finfish farms in Indonesia, Malaysia and Viet Nam

Region	No. of farms	Trash fish usage		Trash fish cost (% recurring)	
		Quantity (kg/day)	No. of farms	% cost	No. of farms*
Indonesia	20	10–20	2	<20	2
		21–50	8	20–30	4
		100–150	5	31–40	1
		Unknown	5	41–50	5
				51–60	2
				61–70	2
				>70	1
				Unknown	3
Malaysia	2	Unknown	2	20–30	2
Viet Nam (north)	53	5–20	3	<20	2
		10–20	5	20–30	1
		10–25	4	31–40	3
		20–30	6	41–50	20
		20–40	5	51–60	17
		20–50	4	61–70	2
		Unknown	26	Unknown	8
Viet Nam (central)	62	17 –38 **	62	31–40	30
				51–60	20
				61–70	12

*Expressed in percentage in the case of Viet Nam (north).
**There was considerable variation among farms based on the species cultured. Average use ranged from 17 to 38 kg/day, while in some farms, trash fish use of 80 to 200 kg/day was recorded
Source: Sim (2006)

Viet Nam

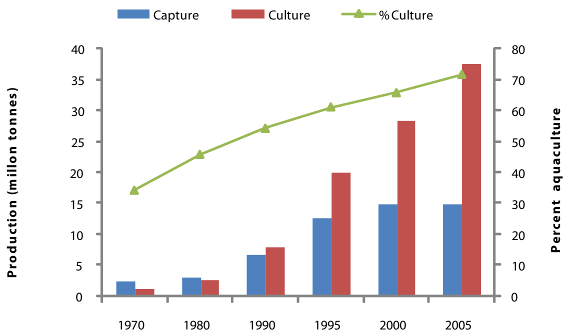
The case study in Viet Nam involved the survey of a total of 68 and 62 small-scale mariculture farms in the north and central regions, respectively (Table 13). In the north, 53 of the 68 farms surveyed used trash fish/low-value fish as the main food source for the stock, while in the central region all farms except those culturing penaeid shrimp fed trash fish/low-value fish. Trash fish/low-value fish usage ranged from 2 to 65 kg per day, and for most farms the feed cost accounted for 41 to 61 percent of the cost of production (for approximately 73 percent of farmers; Table 13). The main species cultured are brown-spotted grouper (*Epinephelus chlorostigma*), cobia, barramundi, snapper and mud crab. In general, the farmers believed that the use of trash fish/low-value fish was cheaper and that the stock performed better.

In central Viet Nam, the survey covered the districts of Van Ninh and Cam Ranh of Khanh Hoa province, and Son Tra district of NhaTrang City (details are given in Phan, 2007). Fish farming in these areas includes the culture of shrimp, marine finfish (mainly groupers and barramundi, and to a lesser extent, Japanese amberjack), lobster (*Panulirus ornatus* and *P. homarus*) and Babylon snail (Box 5). All the cultured stocks except shrimp are fed only trash fish, which are generally considered to be of a quality unsuited for direct human consumption, with the exception of *Stolephorus* spp., which is relatively high-priced among trash fish/low-value fish. In most instances, the trash fish/low-value fish are purchased daily, either directly at the landing sites or from middlemen, there being a well-established market chain for this commodity in areas where mariculture occurs.

China

China has a vast sea area with relatively rich fishery resources, and the fisheries sector has grown since the 1980s. However, with increasing fishing pressure, marine fishery resources have declined sharply, and fish production from aquaculture now exceeds production from capture fisheries, contributing increasingly to the national gross domestic product (GDP) (Figure 15). The catch of high-valued marine fish has dropped gradually, while the catch of medium-valued fish now accounts for 57–59 percent of the country's total marine capture fishery production. Only 30 percent of these less-valued fish are channelled into the food processing industry, and the remainder are mostly used as trash fish/low-value fish for marine finfish culture.

FIGURE 15
Trends in capture fisheries and aquaculture production in China and the percent contribution of aquaculture to the total production, 1970–2005



Source: Data from FAO (2006a)

In recent years, the increased development of mariculture in China, particularly the farming of higher-valued finfish, has resulted in a growing demand for feeds. Most of the cultured marine finfish feed high in the food chain and hence require a higher amount of protein in their feeds. In addition, trash fish/low-value fish remains indispensable for the culture of broodstock of many fish species. For many finfish species that are cultured using pellet feeds, "feedfish" or trash fish/low-value fish are still used during final conditioning to improve appearance and meat quality (such as reducing the fat content in the flesh of large yellow croaker fed with pellet feeds) for better market acceptance and higher price.

This demand places heavy pressure on trash fish/low-value fish supplies and on fishery resources. Farmers still use trash fish/low-value fish because of their relatively low cost, better attraction to the cultured stock and the superior appearance and flesh quality of the final product. Concurrently with the growing demands from aquaculture to feed carnivorous species, the market demand for low-value fish for direct human consumption and for the value-adding processing industry is growing too. This exacerbation of demands on this resource is of increasing concern to all users and primary stakeholders.

In China, trash fish/low-value fish are obtained mostly from trawl fisheries, supplemented by artisanal gillnet fisheries, which operate along most of the coastline. The species composition and availability of the trash fish/low-value fish vary depending on locality, as shown in Table 14.

Trash fish are used in indoor culture, pond culture and cage culture. The annual production in indoor culture is about 100 000 tonnes. Among the marine finfish

TABLE 14
The main trash fish/low-value species of marine origin and their availability in China

Region	Species and availability
Yellow and Bohai Seas	Japanese anchovy *(Engraulis japonicus)* (August–October), common hairfin anchovy (*Setipinna tenuifilis*) (year round)
East China Sea	Bombay-duck (*Harpadon nehereus*) (April–January), *S. tenuifilis* (year round), Commerson's anchovy (*Stolephorus commersonii*) (summer, fall), skinnycheek lanternfish (*Benthosema pterotum*) (year round), *E. japonicus*/*Engraulis* spp. (autumn, winter), Ammodytidae (year round), yellow croaker (*Larimichthys polyactis*) (April–May, August–September)
South China Sea	Japanese sardinella (*Sardinella zunasi*), *S. commersonii*, chub mackerel (*Scomber japonicus*), large hairtail (*Trichiurus lepturus*), Japanese scad (*Decapterus maruadsi*), Japanese jack mackerel (*Trachurus japonicus*), toothpony (*Gazza minuta*), Konoshiro gizzard shad (*Konosirus punctatus*),Kammal thrissa (*Thrissa kammalensis*), hardyhead silverside (*Atherinomorus lacunosus*), Gunther's lizard fish (*Synodus kaianus*),keeled mullet (*Liza carinata*), bald glassy (*Ambassis gymnocephalus*), brownback trevally (*Carangoides praeustus*), *Equulites rivulatus*, orangefin ponyfish (*Photopectoralis bindus*), deep pugnose ponyfish (*Secutor ruconius*), shortnose ponyfish (*Leiognathus. brevirostris*), whipfin silverbiddy (*Gerres filmentosus*), longtail silverbiddy (*G. longristris*), Japanese silverbiddy (*G. japonicus*), moonfish (*Mene maculata*) (year round except June–August, when a closed season is imposed)

Source: Xianjie (2008)

species cultured, artificially formulated feeds for flatfish and breams are relatively well developed. The use of pellet feeds is rather common in indoor marine finfish culture, formulated feeds accounting for more than 90 percent of the feed consumed. Less than 10 percent of the feed used consists of trash fish or farm-made feeds that include trash fish as a major ingredient. Overall, the indoor culture of marine finfish consumes 90 000 to 100 000 tonnes of trash fish annually.

Pond culture of marine finfish occurs primarily in Fujian, Zhejiang and Jiangsu provinces, with an estimated annual yield of about 250 000 tonnes. In coastal pond culture, which is often in the inter-tidal zone, about 20 percent of the pond area is under extensive culture with very limited feeding. About 50 percent of the ponds culturing bream and other perciform fish use formulated feeds. Most other pond-cultured species depend on trash fish/low-value fish as feed or on farm-made feeds containing trash fish/low-value fish as a major ingredient. Trash fish consumption in marine finfish pond culture is estimated at 750 000 to 800 000 tonnes per year.

The current annual output from cage culture is about 300 000 tonnes. A local survey showed that the use of pellet feeds for cage culture in Zhejiang and Shandong provinces is proportionally higher than in Fujian and Guandong provinces, where most cage operators still use trash fish/low-value fish directly as feed (Xianjie, 2008). Nationally, about 10 percent of marine finfish cage-culture production is estimated to use pellet feeds. Another 30 percent of the production involves the use of trash fish/low-value fish mixed with other feeds or farm-made feeds using trash/low-value fish as the main ingredient. The remaining 60 percent of the production depends solely on the direct use of trash fish/low-value fish as feed. Trash fish consumption by the marine cage-culture industry in the country is estimated at 2 million tonnes per year.

The use of trash fish as feed has a direct bearing on the sustainability of aquaculture development in China. Relying only on fish as feed can cause nutritional imbalance, a lack of minerals easily leading to malnutrition, impaired immunity and reduced growth rates in cultured stocks. Also, the supply of trash fish is inconsistent (seasonal variations in availability impact on price; in China during the closed season, the price of trash fish can rise to more than Chinese yuan (CNY) 3.0 per kg), its quality is often variable, and transport and storage are much more difficult than for artificial feeds. By contrast, the development and use of artificial feeds for the culture of cobia and yellow croaker have demonstrated the following advantages:

- reduced culture period;
- less pollution of the culture environment and hence lower risk of disease outbreaks;
- higher yield and economic efficiency, and
- better resource utilization and environmental friendliness.

5.1.3 Economic aspects of use of trash fish/low-value fish in grouper farming in Indonesia, Thailand and Viet Nam

This section summarizes a recent cost-benefit analysis by Sim (2006) for small-scale grouper farming based on the use of trash fish/low-value fish and commercial feed in three Asian countries. Feed was a major recurring cost throughout a single production cycle. There were two main factors that determined the cost of feed: cost efficiency and feeding effectiveness. In this study, an economic comparison between the use of commercial pellet feed and trash fish/low-value fish was undertaken to reflect the "true" economic benefits of the two feed types. The study dealt with: (i) the economic efficiency of the feed as determined by the level of feed input and production output and (ii) the corresponding CE for each grouper farm.

[5] CE = [Total feed input (fed wet weight in kg] ÷ [Biomass harvested – Biomass stocked (wet weight in kg)]

To examine the economic efficiency of the two feed types, CE and feed cost were used. CE was calculated for each grouper farm based on the feed and production data collected with a questionnaire and in field surveys. The standard formula for calculating CE[5] was used.

Trash fish is widely used in the studied areas, particularly in Thailand and Viet Nam, where availability of commercial pellet feed and its use in grouper culture are still very limited. Farmers in Indonesia reported that stocks fed commercial pellet feed performed poorly in comparison with stocks fed trash fish/low-value fish and that feed costs were much higher, often becoming unaffordable.

The CE for commercial pellet feed averaged about 2.64 on the four farms in Lampung, Indonesia, producing humpback grouper (*Cromileptes altivelis*) (Table 15). By contrast, the CE for trash fish/low-value fish ranged from as low as 3.1 to a high of 18.8 across the three countries. In Indonesia, CE for trash fish averaged 7.8, in Thailand, it averaged 12.6 for cage culture and 8.1 for pond systems, and in Viet Nam, it was 8.2. Grouper produced using commercial pellet feed cost an average of US$2.64/kg, while fish raised using trash fish cost from US$0.62 to US$4.80/kg to produce, with an average production cost of US$2.20/kg for grouper produced from a total of 21 farms. Table 15 shows the details of CE for various farms on the study sites and the associated feed costs.

The equilibrium price level for trash fish/low-value fish at various price and CE levels of commercial feed is presented in Table 16. At the lowest trash fish/low-value fish price of US$0.20/kg, a CE below 13.2 provides farmers a saving on feed cost if they use trash fish/low-value fish, while at a trash fish/low-value fish price of US$0.26/kg, a CE lower than 10.3 permits farmers to make a significant saving on feed cost.

Based on the current study, nine of the 21 farms that used trash fish/low-value fish had CE greater than 10.0 and three farms had CE below 6.0. It is likely that CE greater than 10.0 is a result of overfeeding or wastage, and six farms in Thailand encountered this problem. Survey observations indicated that farmers in Thailand tend to buy in bulk to obtain a discount, and consequently they tend to overfeed, as they do not have good refrigeration facilities. By contrast, farmers that have CE lower than 6.0 are likely to be underfeeding. These farms are mostly located in Cat Ba Island, Viet Nam, where grouper are not fed on a daily basis during winter.

Feed costs in Indonesia account for 32.2 and 40.2 percent of total production costs for grouper (*Epinephalus fuscoguttatus* and *C. altivelis*) farmers feeding trash fish/low-value fish and commercial pellet feed, respectively. In Thailand, feed accounts

TABLE 15

Conversion efficiency (CE), feed costs and cost of production of humpback grouper in Indonesia (grouper) and humpback and brown-marbled grouper in both Thailand and Viet Nam

Indonesia				Thailand				Viet Nam			
Farm No.*	CE	Cost (US$)		Farm No.	CE	Cost (US$)		Farm No.	CE	Cost (US$)	
		Feed	Production			Feed	Production			Feed	Production
L1	2.63	2.63	11.28	K1**	15.00	3.84	10.00	CB1	4.70	0.94	5.56
L2	2.65	2.65	11.40	K2**	12.50	3.20	8.74	CB2	7.80	1.56	10.18
L3	2.65	2.65	9.43	K3**	11.40	2.93	7.99	CB3	6.70	1.34	8.80
L4	2.63	2.63	8.22	K4**	18.80	4.80	11.04	CB4	10.40	2.08	9.06
S1	7.20	1.80	8.78	K5*	7.80	2.00	5.48	CB5	16.40	3.28	11.32
S2	8.35	2.09	9.42	K6**	12.00	3.08	8.53	CB6	4.00	0.80	7.78
				K7**	10.50	2.69	6.89	CB7	12.70	2.54	9.37
				C1	8.10	2.07	4.40	CB8	8.10	1.62	5.68
								CB9	6.00	1.20	7.37
								CB10	3.10	0.62	6.73
								CB11	10.00	2.00	5.38

*L1 to L4 – farms using commercial compounded pellet feeds; all others use trash fish/low-value fish
**Cage systems

Source: Sim (2006)

TABLE 16
Equilibrium feed costs at various prices (in US$/kg) and conversion efficiencies (CE) for trash fish/low-value fish in comparison with commercial pellet feed

Country	Commercial pellet feed			Trash fish		
	Price	CE	Cost	Price	CE	Cost
Indonesia	1.00	2.64	2.64	0.25	10.55	2.64
Thailand				0.26	10.30	2.64
Viet Nam				0.20	13.20	2.64

Source: Sim (2006)

for 51.8 percent of the total production costs in cage systems and 57.5 percent of the costs in pond systems. By comparison, feed cost in Viet Nam is relatively lower at 23.4 percent. This is mainly due to the lower cost of trash fish/low-value fish (US$0.20/kg), the associated feeding practices, and the fact that farmers often procure their own trash fish/low-value fish, thereby reducing the need to purchase this resource. Farmers in Cat Ba Island tend to withhold feeding if trash fish/low-value fish are not available or when the weather limits active feeding by fish.

As feed accounts for a major portion of the production costs for grouper farming, it is important that the cost is kept as low as possible and that feed efficiency is improved. Figure 16 depicts the trends of CE and cost of production of one kilogram of grouper on farms in Thailand, Viet Nam and Indonesia. Analysis of the available data on CE (X) and cost of production (Y) for Thai and Vietnamese grouper farmers who use trash fish/low-value fish shows a positive linear relationship between these two parameters. These trends are:

Thailand (Figure 16a): $Y = 0.587X + 0.837$ ($R^2 = 0.907$; $P<0.01$), and

Viet Nam (Figure 16b): $Y = 0.292X + 5.536$ ($R^2 = 0.337$; $P<0.05$).

Similar trends were recorded for the three countries (Thailand, Viet Nam and Indonesia) combined (Figure 16c). As expected, these analyses indicate that higher CE results in higher cost of production. There was insufficient data to determine the effect

BOX 6

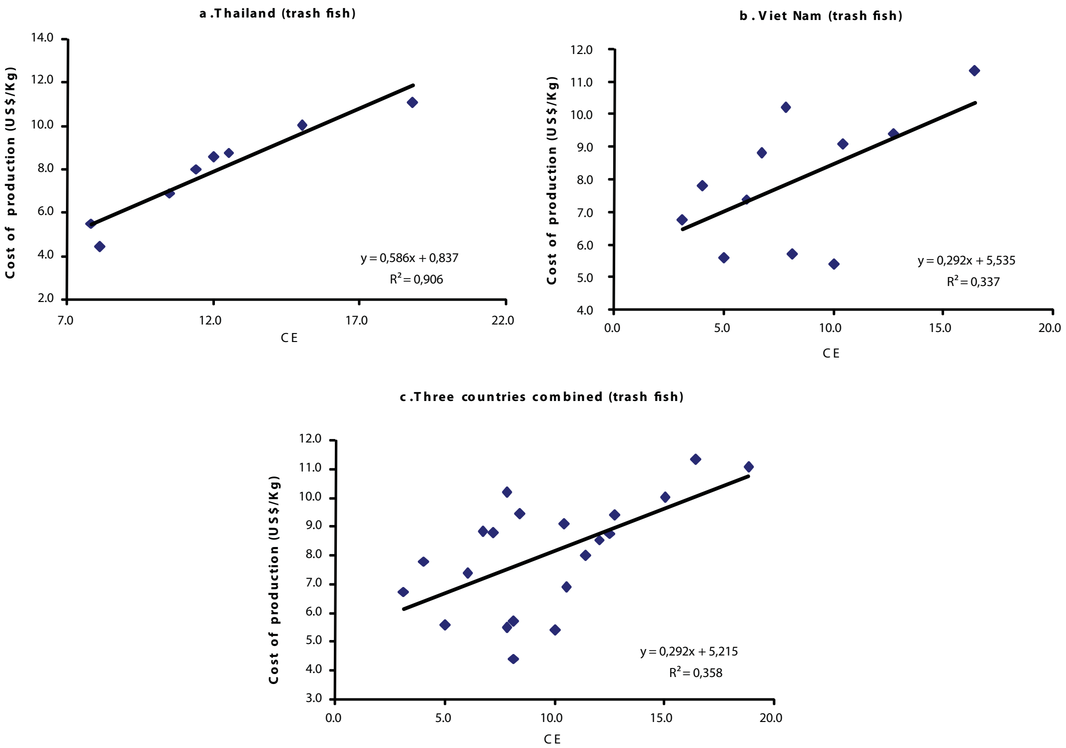
Small-scale farmers and the use of trash fish/low-value fish

From the study by Sim (2006), it is apparent that the only option available to many small-scale farmers in remote areas is to feed their cultured stocks with trash fish/low-value fish, which the farmers often catch on a regular basis. As these practices are linked to local tradition and culture, efforts to change them may jeopardize the livelihoods of many small-scale farmers, fishers and other small-scale operators. Attention should be focused on assisting these farmers to adopt better farming practices, including improved use of the trash fish/low-value fish that they procure themselves through transformation into moist pellet, improved feed management and proper husbandry and health management.

Photo: Fish farmer with fishing gear used to catch trash fish/low-value fish to feed cultured stock

FIGURE 16

Lines of best fit depicting the relationship of the cost of production to conversion efficiency (CE) on grouper farms in three countries (a) Thailand, (b) Viet Nam and (c) Thailand, Viet Nam and Indonesia combined



Note that for Indonesia data for only two farms were available

Source: Sim (2006)

of CE with commercial pellet feed and unit production. Furthermore, CE was not related to farm size in any of the countries.

Based on a simple comparison, trash fish/low-value fish appear to be economically more viable, if issues relative to sustainability and the environment are not taken into account. In Table 16, it is reported that the equilibrium price level for trash fish/low-value fish is at a price of US$0.20/kg and a CE of 13.20 for Viet Nam. If CE level is maintained below 13.0, feed cost saving (although minimal) will result in profitability for small-scale farmers. If the CE falls below 10.0, significant saving in feed cost leads to more a profitable business for small-scale farmers.

Overall, CE is an indicator of the feed efficiency of each farm. Leung, Chu and Wu (1999) reported that areolate grouper (*E. areolatus*) fed trash fish/low-value fish had a CE of 6.52. Although Yap *et al*. (2006) indicated that the CE for trash fish/low-value fish should range from 5 to 10, Orachunwong, Thammasart and Lohawatanakiul (2006) estimated that CE for trash fish/low-value fish ranged from 8 to 15. This suggests that improvements could be made in the efficacy of trash fish/low-value fish usage in grouper farming that would reduce the overall quantity of resource used, which in turn would improve the sustainability of grouper farming in the region (Box 6).

5.2 Trends in the use of trash fish/low-value fish in freshwater aquaculture in the Asia-Pacific region

Compared with the use of trash fish/low-value fish in marine and brackishwater aquaculture in Asia, its use in freshwater aquaculture is relatively less and is also localized. The number of freshwater carnivorous finfish species cultured in Asia

BOX 7

The golden apple snail as feed

The golden apple snail is considered a major invasive species in Asia (Halwart, 1994; Joshi *et al.*, 2005) and is very common in the Mekong Delta floodplain. Annually, some 20 to 25 tonnes of snail are collected and used as feed in giant freshwater prawn farming in the Delta. It is also used in farm-made feeds in pangasid catfish culture.

Photo: Golden apple snail frequently sold as fish and prawn feed in the Mekong Delta floodplain

is rather limited, the most important species being the pangasiid catfishes, walking catfishes and snakeheads. In all these instances and unlike in most mariculture, trash fish/low-value fish are used as a major ingredient to prepare, on farm, moist feeds that are fed to the stock. The greatest use of trash fish/low-value fish in freshwater finfish culture occurs in pangasiid culture in the Mekong Delta in southern Viet Nam, a sector that has grown over the last decade and which contributed an annual production of 1.2 million tonnes in 2007. The individual practices are small holdings with ponds, and the whole sector is estimated to provide employment to 160 000 people, the majority being in processing, of which over 80 percent are women (Nguyen, 2009; Phan *et al.,* 2009).

In the Mekong Delta, in addition to pangasiid catfish, giant freshwater prawn (*Macrobrachium rosenbergii*) and snakehead are also cultured extensively. The types of feeds used in these culture practices vary widely from region to region. However, in general, catfish culture is more dependent on farm-made feeds in which trash fish/low-value fish are a major ingredient (Hung and Huy, 2007). The level of inclusion of trash fish/low-value fish in farm-made feeds varies widely, ranging from 10 to 30 percent by wet weight, the other popular ingredients being rice bran and soybean meal. It should be stressed, however, that over the last two to three years pangasiid catfish culture has undergone a major shift from farm-made feeds to commercial feed use, driven primarily by the logistical difficulties of preparing large quantities of daily feeds on farm.

In giant freshwater prawn and snakehead farming in the delta, yields average 1.8 and 1.43 tonnes/ha/year, respectively. The farming practices are almost entirely dependent on trash fish/low-value fish but also include golden apple snail (*Pomacea canaliculata*) as a feed source (Box 7). According to Sinh (2007), the quantity of feed used in these two farming practices is 39 780 and 25 039 kg/farm/year.

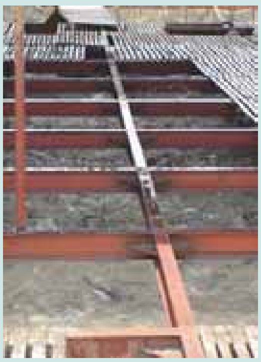
In addition to carps and tilapias, catfishes and snakeheads constitute two important species groups that are cultured in Asian freshwaters. The catfish species cultured vary from country to country; for example, the main species cultured in Viet Nam, which has the greatest catfish farming activity in the region, are the pangasiid catfishes (the sutchi catfish (*Pangasianodon hypophthalmus*) and *Pangasius bocourti*), while catfish culture in Thailand is based on the hybrid of the bighead catfish (*Clarias macrocephalus*) and the North African catfish (*C. gariepinus*) (Na-Nakorn, Kamonrat and Ngamsiri, 2004). In the past, in both these culture practices, particularly during grow-out, trash fish/low-value fish were the main ingredient used for farm-made feeds, and this is still the case in Viet Nam. However, with the decline in the market value of farmed catfish in Thailand, the farmers have become more innovative, remaining viable by almost totally

BOX 8

A vertically integrated catfish farm in Myanmar

An almost complete vertical integration is seen in a Myanmar catfish farming venture. The processing waste in turned into fishmeal that is mixed with other locally produced agricultural by-products such as soybean meal, peanut meal, etc., to produce a pellet feed that is fed to its own catfish cultured in cages in the Nagwun River.

Photo: Bags of pellet feed produced on farm and in catfish rearing facilities



opting out of using trash fish/low-value fish in grow-out feeds.

Snakehead is relished in Thailand and neighbouring countries such as Cambodia and Lao PDR. In Thailand, snakehead production has been increasing steadily and in 2006, 9 800 tonnes were produced, accounting for only 2.6 percent of total inland aquaculture production but about 10 percent of value. Snakeheads are carnivorous, and the farming of snakehead is based mainly on wild-caught young, which are readily available throughout most of the year. Wild-caught fish cannot be easily weaned onto dry feeds in grow-out unless this is done in the very early stages. Almost all grow-out operations depend on farm-made, moist feed, which is dispensed in the form of a dough. The feeds are essentially a mixture of trash fish and rice bran, mixed in 7:3 proportion. For example, a farmer in Suphanburi, Thailand, who produces 3 to 4 tonnes of market-size snakehead uses 20 tonnes of trash fish, purchased at an average price of Thai baht (THB)7.5/kg (US$1=THB38). However, some changes aimed at reducing the dependence on trash fish/low-value fish are also beginning to take place in Thai snakehead farming.

In Myanmar, a number of significant trends in feed development and management that have a bearing on dependence on fishmeal/low-value fish and or fishmeal from external sources are taking place. These changes are related to the recent developments in the farming of Indian major carps, in particular, rohu (*Labeo rohita*) and sutchi catfish (*P. hypophthalmus*) (Aye *et al*., 2007). These trends are in turn associated with the rapid development of the processing sector for these species, which is totally export oriented. Indian major carp are exported whole, and the processing wastes (essentially offal and gonads) are separated and processed to extract oil that is used in fish-feed manufacture. By contrast, a large catfish farming enterprise that produces 740 tonnes of filleted catfish/year uses the offal, the frames and the strips of muscle for its own fishmeal production. On average, one tonne of fishmeal is produced daily in this relatively small-sized plant, and this fishmeal is used in its own feed plant to produce 70 tonnes of pellet feed per day. The feed produced is used exclusively for feeding catfish on its own farm. This is an example of an almost completely vertically integrated aquaculture system (Box 8).

The inland aquaculture sector in Myanmar is in a relatively high growth phase, with relevant patronage and support from the government (Aye *et al*., 2007). For example, the targeted exports of freshwater cultured finfish for 2007 are valued at US$120 million, a two-fold increase from the previous year. Such ventures will increasingly come into being, but they will not be resourcing trash fish/low-value fish and or fishmeal from the market place but will attempt to produce in adjunct facilities using raw material sources available to the farm *per se*. Although the feeds used may not be of the highest nutritional quality, the growth rate of the fish is acceptable to the farmers, as almost all such ventures make substantial profits. Past experience has shown that actual practices may defy nutritional wisdom (Wood *et al*., 1992), and Myanmar's freshwater finfish culture could just be another example.

FIGURE 17
Softshelled crab farm

a. Individual holding facilities

b. Trash fish/low-value fish used for feed

c. Preparation of trash fish/low-value fish to be fed

Courtesy of U Hla Win, Myanmar

5.3 Efficacy of use of trash fish/low-value fish in finfish culture

The use of trash fish/low-value fish as feed in aquaculture may have advantages, particularly for the many small-scale farmers in Asia. One advantage are low cost, resulting in less problems for farmers' cash flows, ready availability of feed in areas where trash fish/low-value fish are caught, perceived and/or real efficiency in feeding, and the possibility of the farmers themselves being able to procure at least a proportion of the daily feed requirements. The main disadvantages in using trash fish/low-value fish are irregularity in supplies and variability in quality, and also higher discharge of nitrogen and phosphorus from indigestible constituents, such as bone, than from pellet feeds.

5.4 Use of trash fish/low-value fish in crab and lobster fattening

5.4.1 Crab fattening

Farmed crab production, almost all of which occurs in Asia, has exceeded wild-caught production. Production has increased from a mere 14 500 tonnes in 2002 to 117 000 tonnes in 2004, the highest growth rate for any of the cultured commodities in the world. Crab farming is predominantly based on the mangrove crabs such as Pacific swamp crab (*Scylla serrata*), purple mud crab (*S. tranquebarica*) and green mud crab (*S. paramamosain*) and swimming crabs (such as *Portunus sanguinolentus*). Although the life cycle of the mangrove species has been closed (Quinitio *et al*., 2001), commercial hatchery production is still in its infancy (Kathrivel, 2007). Consequently, crab farming in Asia is primarily a fattening process, and the main food source is trash fish/low-value fish, often presented by chopping into suitable sizes, depending on the size of the stock. The main mangrove crab farming countries are Thailand, Myanmar, the

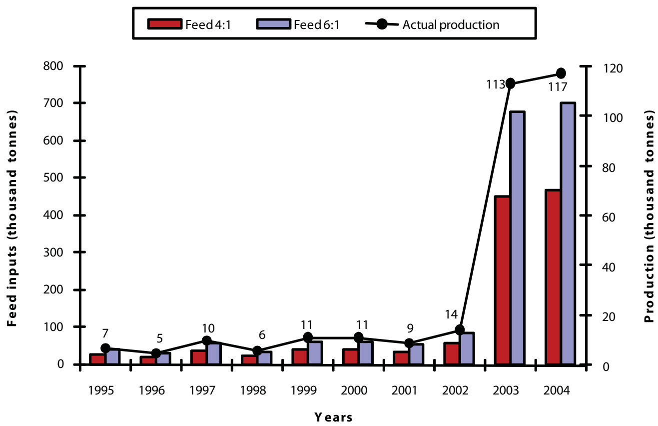
Philippines, China and Viet Nam, and to a lesser extent India and Sri Lanka. The crabs demand a relatively high market price and are almost always sold live even at the end point, the consumer.

The production of softshelled crabs for the up-market restaurant trade is a relatively recent development that enables under-sized crabs to be sold (Figure 17). Wild-caught crablets are farmed in intensive operations in which no more than two crablets are held together and all are checked every other day for molting. This is a relatively labour-intensive farming process, but the economic value of softshelled crabs more than compensates for the increased labour costs. On average, a crablet goes through over eight molts during fattening for the market, whereas a softshelled crab is ready for the market after two molts. Based on the prevailing market price and demand, farms that have the required infrastructure may switch from fattening crabs to a weight of 400 g to producing softshelled crabs weighing up to 150 g.

In all the countries, the number of operations producing softshelled crab is relatively small. For example, in Myanmar there are only two crab fattening farms. In India, crab farming commenced primarily as a means of reviving the livelihoods of 2004, tsunami-affected fishing communities (M. Sakthivel, Aquaculture Foundation of India, personal communication, 2005). A major factor that has encouraged the rapid growth of crab farming along the southeastern coast of India is the ready availability of trash fish/low-value fish at a relatively low price of IDR10 to 12/kg (US$1 = IDR48) during the grow-out period of the crabs (during the northeast monsoon of November to February). Hardshell crabs take eight months to reach a market size of approximately 1 kg or more (price of IDR400/kg), whereas the turnover period for softshell crabs (price of IDR325/kg) is only 25 days. In both cases, the average conversion efficiency is 6.

FIGURE 18

Changes in cultured mangrove crab production over the years and estimates of trash fish/low-value fish required as feed at conversion efficiencies of 4 and 6



Source: Production data is based on FAO (2006a)

In Thailand, softshell crab farms maintain an average of 50 000 individual rearing boxes. Crablets, wild-caught locally, are purchased at approximately THB85 to 90/kg (10 to 15 individuals per kg) (US$1=THB38) and are kept for 45 to 90 days until molting. The molting size ranges from 70 to 175 g, and the farmgate price varies according to the size. For example, 70 to 100 g crabs are sold at THB180/kg, as opposed to crabs exceeding 175 g, which bring THB240/kg. Crabs are fed once every other day with trash fish, and approximately 60 to 70 kg of feed per 10 000 boxes are used at any one feeding.

TABLE 17

Comparison of the production of softshelled crab in Thailand using trash fish and formulated feed*

Feed type	% molting	% survival	Feed/crab (kg)	Cost/molted crab (THB)
Trash fish	51.7	52.3	0.292	19.8
Formulated feed	60.7	61.0	0.042	15.6

*Softshell crab production trials based on four-month average.
Source: Modified from Wilson (2005)

BOX 9

Production of gravid female crabs for niche markets, Chanthaburi province, Thailand

Crablets weighing about 140–150 g are brought a long distance (travel time of up to 22 hr) from the Adaman Sea area. They are fattened for two to three weeks in a pond by feeding with trash fish/low-value fish that is purchased at THB10–13/kg. The crabs are individually observed at the change of the tide, and when the first signs of eggs appear they are kept in net cages suspended in the ponds. The fully gravid females, determined by using a torch or by making a small incision in the abdomen, and weighing on average 240 to 250 g, are exported weekly. Daily feeding is at a rate of approximately 100 kg of trash fish per 10 kg of crab. The mortality rate is nearly 70 percent during the rearing period; however, the dead crabs are cooked and sold in the local market. An approximate cost-benefit analysis, per cycle of 45 to 60 days, of the practice is as follows (all figures in THB):

Revenue from crab egg production	=	270 000
Revenue from crab meat	=	99 000
Total revenue	=	369 000
Crablet costs	=	282 750
Feed costs	=	16 100
Labour costs	=	10 000
Total expenses	=	308 850
Net profit/loss	=	60 150

Photo: Monitoring of early indications of eggs development in female crabs during low tide in suspended net cages

In general, in both forms of crab farming the wild-caught crablets are fed chopped trash fish/low-value fish. Given an estimated production of about 120 000 tonnes of crab and an average conversion efficiency of 4 to 6, the total quantity of trash fish used in mangrove crab farming is between 480 000 and 720 000 tonnes (Figure 18).

Although crabs are relatively inefficient in feeding on pellet feeds and such feeds are not widely available, evidence suggests that pellet feeds can be more effective than feeding trash fish and that they can significantly reduce the cost of production (Table 17).

In view of the rapid growth in crab farming in the last few years, and taking into consideration that a proportion of crablet supplies is likely to come from hatcheries, an overall growth rate of 25 percent from the current level is expected by 2010. This would mean that a trash fish/low-value fish supply of 600 000 to 750 000 tonnes will be required given an average CE ranging

BOX 10

Lobster fattening in Viet Nam

In addition to finfish, certain aquaculture practices use other aquatic animals that are collected on a small scale and fed to cultured stocks. Among these are various molluscs (also see Phan, 2007). However, the use of non-finfish aquatic organisms as feeds in aquaculture is relatively uncommon and may be specific to certain regions and culture practices. In Viet Nam, a variety of aquatic food sources including trash fish/low-value fish, molluscs, etc., is used in lobster fattening, and the feed material is often processed prior to feeding.

Photos: Cockles used in lobster fattening in central Viet Nam

from 4 to 5. In crab farming and fattening, the use of compounded feeds is relatively insignificant. Another of the more recent developments is the production of gravid females for niche markets, such as in Chanthaburi province, Thailand (see Box 9).

5.4.2 Lobster fattening

Lobster fattening is a relatively recent activity that is most intensely practiced in Viet Nam (Phan, 2007). Two species of spiny lobster are fattened in Viet Nam, *Panulirus ornatus* and *P. homarus,* which are now almost always reared in floating net cages as opposed to net pens, as in the past. It is estimated that the current annual fattened lobster production in Viet Nam is 1 000 tonnes (www.spc.int/aquaculture/site/commodities/rock_lobster.asp?ou=pdt&pdt=rock_lobster&comm_name=Rock%20Lobster).

In lobster fattening, the food source used includes trash fish/low-value fish, as well as molluscs such as blood cockle (*Andara* spp.), small crabs (*Calappa* spp.) and swimming crabs (*Portunus* spp.) (Box 10). In general, the quality of the trash fish/low-value fish fed to lobster is relatively high, with prices ranging from VND10 000 to 13 000 per kg, and often accounting for between 60 to 70 percent of all recurrent costs. However, the farmgate price for fattened lobster is one of the highest among cultured species, averaging VND312 000 and 627 000/kg for *P. homarus* and *P. ornatus,* respectively, of average weights ranging from 0.2 to 0.4, and 0.8 to 1.6 kg. In view of the “mixed” nature of the aquatic feeds used in lobster fattening and also because the total production is relatively small, no attempt was made to estimate the volume of trash fish/low-value fish used in this practice.

5.5 Use of trash fish/low-value fish in mollusc culture

The majority of molluscs cultured are filter feeders, in particular, bivalves. Among other molluscs, feeding is associated with the culture of the high-valued abalone species (*Haliotis* spp.). However, in certain Asian countries, the culture of the gastropod commonly known as the spotted Babylon has developed rapidly, particularly in Thailand, Viet Nam and China (Box 11). Sixteen species of Babylon are known from Indo-Pacific waters. However, the most commonly cultured species is *Babylonia areolata*, which is reared only in Thailand, Viet Nam and China. Little published information is available on culture methods, growth rates, production and other related parameters (Chaitnawisuti, Kritsanpuntu and Natsukari, 2005; Kritsanpuntu *et al*., 2005). The total production of Babylon in Asia is unknown, but is currently conservatively estimated to be 70 tonnes. Babylon is sold live to the restaurant trade, China being the main market.

Babylon is fed trash fish/low-value fish throughout its grow-out phase, which lasts from three to five months depending on the market of destination. In Thailand, the grow-out period is generally longer and the harvesting size ranges from 50 to 60 g/individual

BOX 11

Babylon snail culture

The growth of Babylon snail culture in the region, which commenced about six to eight years ago, has resulted in a marked decline in farmgate/export price. For example, a kg of Babylon produced in Thailand that was exported at THB500–580/kg (US$1=THB40) consisted of 15 to 20 individual animals that were sold live. However, increased Chinese production over the last three years, along with increased production and export from Viet Nam to China, has caused the overall farmgate price to decline markedly. The farmgate price of live Babylon exported to China from Thailand has decreased from THB200–250 kg in late 2005 to THB150–180/kg in December 2006, making the culture practice almost economically unviable, especially within the context of increasing prices for trash fish/low-value fish.

Photo: *Babylonia areolata*

FIGURE 19

Trash fish/low-value fish species used for Babylon snail culture. In some practices, the relatively high-quality trash fish/low-value fish may be filleted, the fillets used for other purposes and the frames fed to Babylon, which feed on the attached bits of flesh, leaving the frame clean

with a shell length of 6 to 8 cm (Kritsanpuntu *et al*., 2005). In China, the harvesting size ranges from 20 to 30 g per individual and a shell length from 4 to 6 cm.

Interestingly, in Babylon snail culture, which tends to involve small-scale, backyard operations, the trash fish/low-value fish are often bought from the fish market and are fish destined for human consumption, such as for example, in Thailand (Figure 19). By contrast, in Viet Nam, the culture practices occur mostly outdoors in net pens, and the stock is fed trash fish/low-value fish that is normally unsuited for direct human consumption. The purchase of fish used for feeding is often done on a daily basis, and the average conversion efficiencies range from 5:1 to 7:1.

5.6 Total direct use of trash fish/low-value fish in Asia-Pacific aquaculture

Using the data provided in the foregoing sections, an attempt was made to estimate the total amount of trash fish/low-value fish used as a direct feed source in aquaculture in the Asia-Pacific region. High and low predictions for the year 2010 were also estimated based on the assumptions on production increases and changes in feed management previously discussed (Table 18). Accordingly, in 2004 the usage of trash fish/low-value fish in aquaculture in the Asia Pacific region is estimated to have ranged from 2 465 000 to 3 882 000 tonnes, and the corresponding low and high estimates for 2010 are 1 890 490 and 2 745 495 tonnes, respectively. Although the range in these estimates is significant, nevertheless, they provide a figure that could be used in planning and development activities that recognize the need to reduce the dependence of Asia-Pacific aquaculture on trash fish resources.

TABLE 18

The total use of trash fish/low-value fish as a direct feed source in Asia-Pacific aquaculture, based on production estimates of the present study

Activity	Country/region	Grade[a]	Quantity (thousand tonnes)		
			2004	2010a	2010b
Marine fish[b]	Asia	A, B	1 603–2 770	913	1 663
Southern bluefin tuna	South Australia	B	50–60	45	50
Freshwater fish	Asia	A, B	332	332[c]	332[c]
Crab fattening	Asia	B	480–720	600	750
Total			**2 465–3 882**	**1 890**	**2 795**

[a]Grade A – low grade, unsuitable for human consumption; Grade B – may be suitable for human consumption.

[b]2010 low and high predictions are based on increased production rates (10 and 20% increments) and associated changes in feed management given in previous tables (Tables 10 and 11). For crabs, the predictions are based on an overall increase of 25% production from the current levels and trash fish/low-value fish use calculated at conversion efficiencies of 4 and 5, respectively, for two predictions (2010a and 2010b).

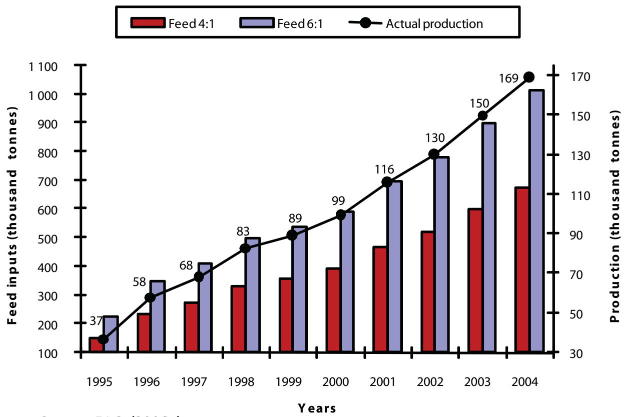
[c]Prediction is not attempted and the value of 2004 is used instead.

Sugiyama, Staples and Funge-Smith (2004) estimated that in China, 3 615 000 tonnes and in the Philippines 144 638 tonnes of trash fish/low-value fish were used as feed for cultured stocks. Edwards, Le and Allan (2004) estimated that in Viet Nam 323 440 tonnes were used in aquaculture, the bulk of them being used in the preparation of farm-made feeds for pangasiid culture in the Mekong Delta.

The above estimates, as well as that of the present analysis, are significantly lower than those of Allan (2004), who estimated that the global usage of trash fish/low-value fish as a direct feed source in aquaculture was 5 million tonnes per year. Assuming that the Asia-Pacific region accounts for 80 percent of the global trash fish/low-value fish usage in aquaculture, it is believed that the current estimates are closer to reality, as these are based on observed production levels and farm surveys. Importantly, the predictions for the future indicate a significant reduction in trash fish/low-value fish use in aquaculture in the Asia-Pacific.

FIGURE 20

Changes in Mandarin fish production in China and the estimated live fish feed needed based on two conversion efficiencies



Source: FAO (2006a)

6. USE OF LIVE FISH AS FEED IN ASIAN AQUACULTURE

Instances of live cultured fish being raised for the sole purpose of feeding to another, generally much higher-valued cultured species are uncommon. There is one such example known from Asia, that of the mandarin fish (*Siniperca chuatsi*). There are also less significant instances where low-value fish such as small-sized tilapias have been used as food for culturing higher-valued species. In addition, there is the farming of species such as milkfish (*Chanos chanos*) to fingerling size for use as live bait for tuna fishing.

The mandarin fish, a percichthyid, is one of the most highly valued freshwater species cultured in Asia. Mandarin fish culture is almost totally confined to a few provinces of China, such as Guangdong and Hubei. This top carnivore cannot be weaned onto dry or moist feed and thus has to be fed on live fish only, unlike the closely related Murray cod (*Maccullochella peelii peelii*), a large Australian iconic freshwater fish. In spite of this limitation, it is cultured extensively in reservoirs (in cages) and in ponds, and the total production from aquaculture has grown from 37 000 tonnes to almost 170 000 tons over the last ten year period (1995–2004) (Figure 20). With the increase in production, there had been a decline in the farmgate price, which dropped from about CNY80 to 120 per kg (US$1=CNY7.85) in the early 1990s to the current price of CNY35 to 60. This decrease in farmgate price, as well as other development demands has resulted in the reduction of the area used for mandarin fish culture. For example, in Hang Lang Township, Zongshan Prefecture, Guangdong

FIGURE 21

Mandarin fish from a culture pond at Hang Lang Township, Zongshan Prefecture, Guangdong Province, China with its live fish feed, mud carp. Prey fish are introduced into the mandarin fish grow-out ponds, on average, every fifth day

province, China, the pond area has decreased from 3 300 ha in the mid-1990s to the current 650 ha (however, production intensity and efficacy have increased).

Species commonly cultured as food for mandarin fish include Chinese mud carp (*Cirrhinus chinensis*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*H. nobilis*) and black carp (*Mylopharyngodon piceus*), all cultured and popular foodfishes. In general, mandarin fish culture goes hand in hand with the culture of its foodfish species, either in cages or ponds, often adjacent to the culture site of the mandarin fish. The live fish are fed at a size ranging from about 2 cm to a maximum of 8–10 cm, depending on the size of the mandarin fish stock (Figure 21). Fish are fed every fourth to fifth day, and the amount of live feed presented is determined by the farmer based on the response of the mandarin fish to the feed, the more aggressive the feeding, the more feed provided. During a culture cycle of 4.5 to 5.5 months, the average yield obtained in pond culture of mandarin fish ranges from 7 500 to 10 500 kg per ha, and the average conversion efficiency is 4. Even though mandarin fish culture demands more space, it remains significantly more profitable than culturing the filter-feeding Chinese carps, based on pond fertilization only, because the market price of Chinese carps is only about CNY12 to 15 per kg at the best of times. A simple cost-benefit analysis (Table 19) indicates that economic gains from mandarin fish culture are, as might be expected, sensitive to market price. Mandarin fish culture typically requires three times the space

TABLE 19
A cost-benefit analysis of mandarin fish culture on a farm in Hang Lang Township, Zongshan Prefecture, Guangdong province, China

Parameter	Unit price (CNY)	Stocking density (no.)	Harvest (kg)	Value (CNY)	Profit (CNY)
Mandarin fish seed (5 cm)	5	15 000	–	75 000	–
Harvest (ave. 700 g; 80% survival)	40/kg	–	4 800	192 000	117 000
	60/kg		4 800	288 000	213 000

The cost of feed is CNY/kg totalling CNY201 600 (US$1=CNY7.85). In mandarin fish culture, mud carp fingerlings are commonly used as a live feed.
Source: Personal observations

(pond and or cage) than the culture of its live food (carps). However, because of the very low market price of carps, the total gains from their culture up to market size are less attractive than the highly demanding but highly profitable culture of mandarin fish. By contrast the risks associated with mandarin fish culture (a form of monoculture), particularly potential mortality from disease, are far greater than for the culture of carps, and more often than not the average farmer is unwilling to take this risk.

7. USE OF FISH IN FEEDS IN ASIA-PACIFIC AQUACULTURE: AN OVERALL ANALYSIS

Fish are used, directly (e.g. as fishmeal) or indirectly (as animal food) in significant quantity in the aquaculture sector in the Asia-Pacific region. This usage falls into three categories that are summarized in Table 20. Overall, fishmeal accounts for the highest usage, and in this regard, Asia-Pacific aquaculture uses the greatest proportion of global fishmeal production.

Tacon, Hasan and Subasinghe (2006) estimated that in 2003, global aquaculture used 2.94 million tonnes of fishmeal (53.2 percent of global fishmeal production), which was considered to be equivalent to the consumption of from 14.95 to 18.69 million tonnes of trash fish/low-value fish, primarily pelagics. These authors also reckoned that nearly 5 million tonnes of such fish were used directly as a feed source for cultured stocks, thereby totalling a consumption of 20–25 million tonnes, primarily for the production of 30 million tonnes of farmed finfish and crustaceans.

In the Asia-Pacific region, an estimated 9.8 million tonnes of the total capture fishery of 40 million tonnes (approximately 25 percent) are used directly (e.g. as fishmeal) or

TABLE 20
A summary of the quantities of fish used, directly or indirectly, in aquaculture in the Asia-Pacific region

Type	Current (tonnes)		Predicted usage in 2010 (in tonnes)	
	Low*	High*	Low	High
Reduced forms (fishmeal)	2 388 058 (10 270 894)	–	1 999 866 (6 999 531)	2 190 729 (7 667 552)
Trash fish/low-value fish	2 465 000	3 882 000	1 890 000	2 795 000
Live fish	675 000	1 012 000	n/a**	n/a

*Based on different food conversion efficiencies as indicated in the relevant sections; the live-weight equivalent, where relevant, is given in parentheses;
**n/a–not attempted
Source: Data derived from Tables 9 and 18 and Figure 20.

indirectly (as animal food), which contributes to a production of 28 million tonnes of foodfish for human consumption (Funge-Smith, Lindebo and Staples, 2005; FAO, 2007). FAO (2007) also highlighted the potential competition for trash fish/low-value fish and suggested that economic considerations will channel this resource to different usages. However, the results of the present analysis contradict the suggestion that there will be an increase in the channelling of trash fish/low-value fish into aquaculture; overall, by 2010 it is predicted that the use of these resources to support an increase in aquaculture will decrease significantly.

8. IMPACTS OF FISH-BASED FEED INPUTS USED IN ASIA-PACIFIC AQUACULTURE

This section deals briefly with four types of impact: impacts on the environment, on wild fish stocks, on human health and on employment and food supplies for the poor.

8.1 Environmental impacts

General treatments of environmental impacts on aquaculture include those of Goddard (1996) and Black (2001). It has been aptly demonstrated that the provision of the most nutritionally wholesome and digestible diet to a finfish species results in, at best, an accumulation of nitrogen in the body of 28–32 percent and an average accumulation of 20–25 percent, the rest being excreted. The excessive discharge of phosphorus and nitrogen via undigested faecal matter in freshwater aquaculture and of nitrogen in mariculture, particularly in areas where water replenishment is inadequate, can lead to serious environmental impacts. In the Asia-Pacific region, such impacts have been observed in freshwater

BOX 12
Environmental impacts of cage culture
Intensive cage culture operations can lead to exceeding the carrying capacity of the waterbody, resulting in fish kills when the bottom anoxic water (resulting from the accumulation of large quantities of nutrients) is upturned by changed weather conditions. Such regular occurrences can lead to abandonment of the facility.

Photos: Intensive cage systems in a reservoir in West Java, Indonesia, and the aftermath of fish kills

systems where clusters of cage farms exceed the carrying capacity of the waterbody. The environmental effects can be both direct and indirect. The direct effects result in fish kills, not only of the farmed fish but also of wild stocks. The latter results in conflicts with the artisanal fishers who make a livelihood from fishing in the waterbody (Abery *et al.*, 2005). Moreover, intensive feeding and the accumulation of excessive amounts of nutrients tend to elevate the levels of ammonia and at times, even toxic hydrogen sulphide, which may not cause direct mortalities, but can stress the stock so that it becomes susceptible to disease. The adverse impacts can often be remedied by siting the cage systems in different areas of the waterbody and reducing the feeding intensity (Box 12).

In addition, the feeding of fish as a direct food source to cultured stocks is known to be even more environmentally damaging than feeding of pellet feeds because of the likelihood of lower digestibility. However, there is limited evidence to show the efficacy of pellet feeds as opposed to trash fish/low-value fish as feed. Often, gross conversion efficiencies are used for comparative purposes. However, this approach does not take into account the moisture content of trash fish/low-value fish as feed, which amounts to about 70–75 percent.

Similarly, little is known about the efficacy and resultant environmental effects of the use of farm-made feeds. This is understandable, as the composition, method of preparation and feed management of farm-made feeds are diverse (De Silva and Davy, 1992; De Silva, 1993; Tacon and De Silva, 1997), and more often than not, the quality of feeds used could differ between adjacent farms culturing the same species. As such, comparisons become difficult if not impossible. The environmental effects of the use of farm-made feeds are also difficult to evaluate, and to the authors' knowledge no such studies have been made. However, the small-scale farmers are the best judges of the efficacies and the cost-benefits of the feeds they use. The recent shift to the use of compound feeds in catfish farming in the Mekong Delta and the shift to the use of poultry processing waste in snakehead and catfish farming in Thailand, perhaps are evidence of the increased efficacy that farmers obtain by such changes.

In China, current techniques for finfish culture in ponds and cages are believed to result in 30 percent of feeds being wasted or uneaten by the cultured stock. Compared with artificially formulated feeds, the discharge of nitrogen and phosphorus into the environment by using trash fish/low-value fish as feed is three to four times higher. The uneaten feed together with the excreta of cultured fish impacts the culture environment,

FIGURE 22

A very unhealthy practice in Asia: feeds in drums, improperly sealed and exposed to the elements for a week or more, a practice that could lead to loss of quality and even make the feed rancid, and accordingly result in reduced performance of the stock and lowered feed conversion efficiency

giving rise to fish diseases and the need to use veterinary drugs and chemicals for their prevention and treatment, leading to many problems associated with food safety.

In the Asian context, disease transmission resulting from the use of trash fish/low-value fish in aquaculture is scantily documented (Figure 22). One such example is the reported by Subasinghe and Shariff (1992), who attributed mass mortalities of cage-cultured barramundi (*Lates calcarifer*) in Malaysia to infections of *Pseudomonas anguilliseptica*, *Vibrio alginolyticus* and the spoilage bacterium *Shewanella putrefaciens,* possibly brought about by poor husbandry and the feeding of spoiled coarse fish.

By contrast, the risks and impacts on local fish populations and ecosystems from the use of imported fish to feed the tuna farming industry in the Mediterranean (WWF Mediterranean Programme, 2005) have been highlighted. This report, however, fails to show a direct cause and effect between the use of imported fish to feed the tuna and negative impacts. All in all, it has to be agreed that there are risks associated with using trash fish/low-value fish (particularly imports) to feed cultured stocks and that precautionary approaches have to be applied. However, in most Asian practices, such feed is often obtained from the immediate habitats.

In a recent study on southern bluefin tuna farming in Australia, Fernandes *et al.* (2007) demonstrated that the amount of phosphorous available for leaching from solid waste ranged from 5–6 percent to 17–21 percent from pellet and baitfish [*Sardinops neopilchardus* (syn. of *S. sagax*)]-fed tuna, respectively, and the corresponding nitrogen discharge was 15 and 35–43 percent.

A number of strategies have been suggested to reduce the use of trash fish/low-value fish in aquaculture, and thereby contribute to minimizing the sector's impact on a dwindling biological resource. Among these are reducing fishmeal use in aquafeeds and enhancing the efficacy of trash fish/low-value fish use in aquaculture, culminating in the weaning of stocks to pellet feeds. The limitations on the reduction of fishmeal content in aquafeeds in the region are discussed in Section 4 (also see De Silva and Hasan, 2007).

The environmental gains that are made through the use of trash fish/low-value fish for aquaculture purposes have often gone unnoticed. For example, the live fish restaurant trade, a lucrative upper-end market, was almost entirely dependent on wild-caught reef fish, primarily groupers (Box 13). Destructive fishing methods that not only

BOX 13

Grouper culture and coral reef preservation

Among the major fish species cultured using trash fish/low-value fish are the groupers (family Epinephalidae). In the past, almost the entire market for grouper, especially that of the live fish restaurant trade, was based on wild-caught fish that were often obtained using destructive fishing methods such as poisoning and explosives. These destructive practices resulted in major environmental impacts on aquatic habitats, mainly coral reefs, which resulted in public denunciations. However, this niche market is increasingly being filled by cultured groupers, and this has contributed significantly to the conservation of tropical coral reefs.

Photo: Brown-marbled grouper (*Epinephelus fuscoguttatus*) and humpback grouper (*Cromileptes altivelis*) killed other species but also destroyed the coral environment were often employed to catch these fish (Pet, 1997; Sim, 2005). With the development of grouper mariculture through the closing of the life cycle of many cultured groupers (whose culture is, of course, dependent on trash fish/low-value fish as a feed source), the restaurant trade has switched almost completely to cultured live fish. This change has undoubtedly helped preserve coral habitats and also reduced impacts on biodiversity.

8.2 Impacts on human health

Reports indicating that human health has been impacted because people have eaten cultured fish which were fed unhealthy fish do not seem to exist. However, the public, animal and environmental health impacts of aquaculture have become a relatively controversial issue that has attracted much public attention in recent years from a series of viewpoints (Garrett, dos Santos and Jahncke, 1997; Feare, 2006). It has been speculated that adverse impacts resulting from aquaculture can negatively influence human health and indeed could nullify the relatively well defined health benefits that are known to be derived from fish consumption (e.g. de Deckere *et al*., 1998; Horrocks and Yeo, 1999), at least from a public perspective. The accumulation by farmed stocks of organic and inorganic contaminants from feed and/or the environment is one such issue (Hites *et al*., 2004). The dioxins (which include polychlorinated dibenzo-p-dioxins and dibenzofurans) have attracted the most attention (Lundebye *et al.*, 2004). However, by using properly formulated feeds, the dioxin-like polychlorinated biphenyls (PCBs) can be significantly reduced in farmed fish (Berntssen, Lundebye and Torstensen, 2005).

Legislation on the level of dioxins permitted in farmed fish was introduced by the European Union (EU), while public health concerns such as mad-cow disease (bovine spongiform encephalopathy (BSE) have led to a ban on the use of animal industry by-products in animal feeds. The legislative and regulatory aspects of feeds have been reviewed by Tacon, Hasan and Subasinghe (2006), and it is sufficient to state that Asian aquaculture currently lacks such regulations. Indeed, to make matters worse, some banned animal industry by-products are being exported to Asia and are being used in feeds (authors' personal observations). Unfortunately, very little research on these aspects is being conducted in Asia, where the main thrust is to adopt better management practices (BMPs) for different culture systems, with the expectation that this would avoid extensive contamination of the final product. However, the BMPs have not yet addressed the issue of feed quality, and it is now opportune to introduce this through proper feed certification procedures.

8.3 Impacts on employment and food supplies for the poor

In Asia, which is not a major fishmeal producer but a major consumer (De Silva and Hasan, 2007), two major issues are apparent: (i) Is the trash fish/low-value fish used in the reduction industry sustainable? and, (ii) If so, what are the pros and cons of using the fish for reduction as opposed to direct human consumption? In Asia and the Pacific, all wild fish used in farm-made aquaculture feeds come from Asian fisheries, most being bycatch. However, the fact is that the fish caught as bycatch affect the supply of fish available as food, and bycatch is also of importance for employment and income generation for the poor. The impacts of the use of fish as feeds on employment and food for the poor in Asia are of a much lesser magnitude than elsewhere in the world, the main reason being that much of the fishmeal used in such feeds is imported, mainly from South America.

8.3.1 Food supplies

The great bulk of trash fish/low-value fish landings in Asia are from small-scale artisanal fisheries and may not necessarily be in a state suitable for direct human consumption.

Nevertheless, the degree to which this resource can be used for direct human consumption is difficult to determine. In Asia, trash fish/low-value fish are mostly landed in areas where there are other suitable fish commodities for human consumption. In order to make the trash fish/low-value fish suitable for human consumption, some degree of processing, storage and transportation is needed. However, the costs involved are unlikely to be commensurate to a price that is acceptable to consumers, particularly in remote rural areas.

However, there are situations in Asian fisheries when the use of bycatch as aquaculture feeds pre-empts the use of these fish as food, particularly by the poor. This happens when fish are landed in densely populated areas and then purchased to be used as feed. However, it should be noted that fishmeal is not the only competitor; in several parts of Asia, trash fish/low-value is also a source of raw material for the production of foods based on fish.

In many Asian countries (e.g. India, Bangladesh and part of China) trash fish/low-value fish are sold for direct human consumption. Eating low-value fish caught from the sea has been a tradition for centuries among coastal communities, particularly in Hainan, Guangxi, Guagdong, Fujian and Zhejiang provinces in China. In recent years, increased demand for trash fish/low-value fish as feed in aquaculture has suppressed the supply of seafish to local markets, resulting in higher prices. Furthermore, China has a long history of making surimi-associated products based on trash fish/low-value fish, and there is a wide range of such products in the country. In 2002, China produced 102 400 tonnes of surimi products. Along with technological advances, domestic and overseas markets for surimi products are expected to expand gradually.

Perhaps this is an area that warrants detailed investigations that would generate quantitative information, including data on the socio-economic aspects of the various uses of trash fish/low-value fish. Such information may put an end to the current debate, which is philosophical, moral and/or ethical in nature but rarely, if at all, supported by relevant data[6].

8.3.2 Employment

In parts of Asia, a significant number of artisanal fishers ensure their livelihood by supplying fish as feed to mariculture operations. Moreover, in some remote areas in Asia (e.g. North East Sulawesi, Indonesia), small-scale farmers catch low-value/trash fish for their practices (Aslan *et al*., 2008). Here again, the quantitative data that would allow an objective assessment of the issue of the use of trash fish/low-value fish in aquaculture are lacking.

Fishmeal production plants provide both direct and indirect employment in packaging, transportation and other ancillary inputs for the product. The possibility that more personnel are employed in the reduction industry than would have been the case if the raw material was marketed directly cannot be excluded. However, quantitative information on the employment opportunities in the fishmeal production sector is scant; such information needs to be sought as a matter of urgency.

9. LOOKING AHEAD

In the ensuing decades, fish as a human food source is bound to gain higher global significance. In the developed world, this will occur primarily because of its nutritional benefits (de Deckere *et al*., 1998; Horrocks and Yeo, 1999; Stickney, 2006), whilst in the developing world it will be driven by the fact that fish is the most affordable animal protein source for poorer, rural communities. Most importantly, Delgado *et al*. (2003) have observed that fish consumption among rural, poor communities has increased

[6] In this context, it may be worth recalling that tens of thousands of tonnes of fish are used for commercial production of pet foods (Gooley, Gavine and Olsen, 2006).

significantly over the last decade, and that freshwater fish accounts for about 20–25 percent of the animal protein intake, particularly in rural populations in the developing world. It has even been suggested that farmed fish will become a nutritionally necessary alternative to meat (Sargent and Tacon, 1999). With the near stagnation of wild-caught fish supplies, the increasing demand for foodfish will have to be met by aquaculture; the issue is how much of the shortfall can be met by increased aquaculture production. Currently, 50 percent of foodfish demands are met by the aquaculture sector (FAO, 2006b); but can this proportion grow and if so, by how much?

Fish has become one of the largest exported commodities of developing countries, with exports having shown a continuing rise from US$4.6 billion in 1984 to US$20.4 billion in 2004, an increase that is considerably higher than that shown by traditionally exported commodities such as rice, coffee and tea (Kurien, 2005; FAO, 2007). Among the top-ten fish exporting nations in the world are three Asian countries, China, Thailand and Viet Nam. Viet Nam registered an increase of 17.4 percent in annual growth for the period 1994–2004 (FAO, 2007), the largest contribution being from the aquaculture sector, primarily catfish and shrimp farming. The catfish farming sector in Viet Nam employs an estimated 160 000 to 170 000 people (over 80 percent of them women), within the relatively small geographical area of the Mekong Delta, contributing significantly to food security and poverty alleviation in this region (Phan *et al.,* 2009).

As evident from the data presented previously, aquaculture has shown considerable growth over the last two decades and hence its current importance as a means of addressing global foodfish needs. It was also evident that the proportion of the different cultured commodities has remained relatively static, the increased volumes in each of the commodities meeting the demands of the growing social strata. The Asia-Pacific, overall, has witnessed significant economic growth during the last decade, resulting in a higher proportion of "disposable income" in significant numbers of the population. Such changes result in different consumer demands (Gehlhar and Coyle, undated), including those related to fish consumption (De Silva, 2001).

Cultured marine species (especially groupers) have a high market demand in the region that, barring unforeseen global calamities, is likely to grow (Sim, 2005) by catering to an increasing middle class while also contributing to food security for small-scale producers. In meeting the increased demand for these relatively high-valued species, a certain degree of compromise is needed in the use of exhaustible resources and the potential effects of the sector on the environment. Such compromises may be accompanied by improvements to the technologies and practices that impact natural resource usage, reducing environmental effects to a minimum. There is a need to minimize the direct use of trash fish/low-value fish in marine fish culture by encouraging fish farmers to use formulated feeds, which have significantly lesser dependence on trash fish/low-value fish and higher overall environmental integrity.

The aquaculture sector in the region has to improve its collaboration with the feed industry. One area of aquafeed development that has not kept pace in the region is the use of animal industry by-products in feed formulation. This could be due to the fact that the animal processing industries (apart from the poultry industry) are relatively less centralized than in the west. Consequently, there is no large-scale production of blood meal and bone meal. However, this problem could be solved by improved dialogue between sectors and targeted research.

In Asia, almost all aquaculture, as is the case of most agriculture, is small scale, rural and clustered. These small holdings, which are often farmer owned, operated and managed, generate synergies and work in harmony (Figure 23). In the case of marine finfish culture, there is an urgent need to encourage these smallholders to adopt better feed management practices, commencing with a shift from using trash fish/low-value fish to using formulated feeds, if the use of formulated feed is a more efficient form of resource use. The general impression that such changes are difficult to bring about is untrue, as exemplified by the recent adoption of best management practices (BMPs) by small-scale shrimp farmers in India (Umesh, 2007).

As previously noted, feed development for a wide range of cultured aquatic species, in particular the newly emerging marine finfishes, has lagged behind the progress that has been made by the animal husbandry sector. With the increasingly negative public perception of the use of fishmeal and fish oil by the aquaculture sector, as well as of the use of trash fish/low-value fish for feeding cultured stocks, there needs to be a concerted effort directed towards the development of diets with lower fishmeal/fish oil content and to decrease the use of trash fish/low-value fish by small-scale farmers as feed for cultured stocks. Perhaps this can be accomplished through a regional initiative that brings together researchers, feed manufacturers, raw material suppliers and farming communities. There also needs to be an emphasis on the improvement of farm-made feeds, which are an important element in Asian aquaculture. Although this point has been advocated previously (De Silva and Davy, 1992; New, Tacon and Csavas, 1995; Tacon and De Silva, 1997), little headway has been achieved. Again, a regional approach may be needed to determine ways and means of improving the efficacy of farm-made feeds and the dissemination of appropriate strategies.

In China, the problems associated with the direct use of trash fish/low-value fish as feed in aquaculture have recently drawn increased attention. During the National Freshwater Aquaculture Development Planning Meeting in 2004, the concept of "feed-fish culture", based on the success in mandarin fish culture in southern China, was endorsed as a new thrust for developing high-value fish culture in the country.

The policy of the Chinese fisheries authority is to promote the development and use of complete formulated feeds to gradually replace the direct use of trash fish/low-value fish in marine finfish farming. Apart from the research and development in feeds, feeding and culture technology, the central and local fisheries authorities are now studying the feasibility of launching policies to provide suitable incentives to encourage marine finfish farmers to shift to formulated artificial feeds.

Given the social, economic and technical factors associated with the use of trash fish/low-value fish in China's marine finfish culture, it is unrealistic to expect that trash fish/low-value fish use will disappear in the near future. However, it is envisioned that the use of trash fish/low-value fish for fish culture will come under stricter government regulation and that the general trend in finfish culture will be towards an industry that is more knowledge-based, healthier and more environmentally friendly.

FIGURE 23

An aerial view of cage-culture practices in XinCun Bay, Hainan Island, China, where 570 families conduct marine cage farming. Although each holding is small, the families collectively produce 100 000 tonnes of high-value marine finfish, almost all of which are fed trash fish/low-value fish

10. CONCLUSIONS

The fisheries sector is an important contributor to the GDP of most Asian countries. Interestingly, the percent contribution to the GDP from aquaculture in Bangladesh, the Lao People's Democratic Republic, the Philippines, China, Thailand and Viet Nam has exceeded that from capture fisheries, while the contribution of captured fish is still slightly higher in Cambodia, Indonesia, Sri Lanka and Malaysia (Sugiyama, Staples and Funge-Smith, 2004). However, in the latter group of countries, the contribution to the GDP from aquaculture has also been increasing, but not that from the capture fisheries sector, except in Cambodia.

The increasing predominance of the aquaculture sector is a most welcome sign. However, the aquaculture sector in the Asia-Pacific region is the largest consumer of fish, reduced or otherwise, as feed sources for the cultured stocks (but not the highest consumer of fish oil). Overall, it is predicted that aquaculture will use an equivalent of between 9 228 453 and 13 970 887 tonnes of trash/low-value fish by 2010. This is equivalent to 33 to 50 percent of this global resource. While it can be argued that such a high consumption of these resources for foodfish production in the Asia-Pacific (which accounts for over 90 percent of global aquaculture production), is justified, this is a simplistic stance. A more responsible development of the aquaculture sector in the region necessitates that the availability of foodfish to an ever changing and demanding population is enhanced and that the livelihoods of poor farmers and the associated provisions of food security and poverty alleviation are ensured.

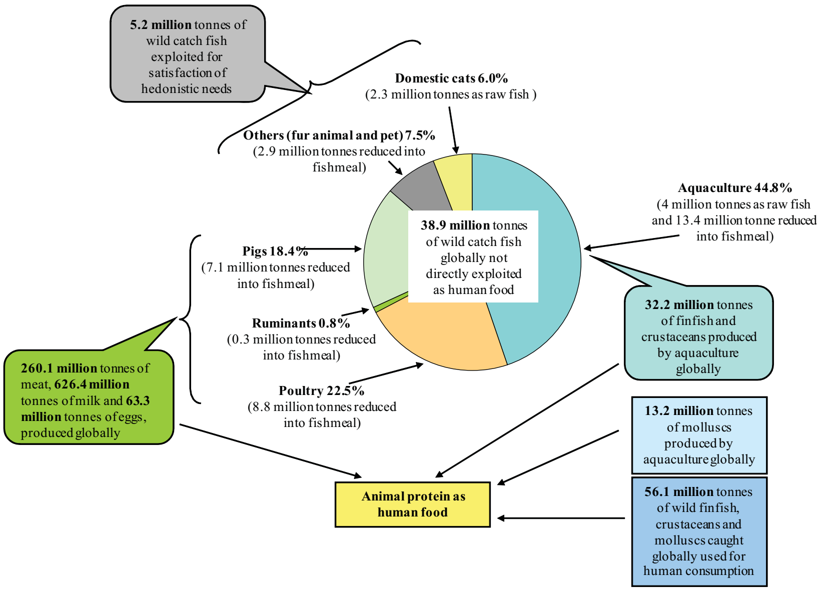
The responsibility of the aquaculture sector in the region is further exacerbated by the decline in wild catches, even if we do not give serious consideration to the rather pessimistic scenarios suggested by some workers. The equation is not straight forward; there are thousands of artisanal fishers who cater directly to the needs of the aquaculture sector and whose fishing methods are probably not destructive as often described. These artisanal fishers mostly use gillnets of appropriate mesh size and which do not negatively impact the sustainability of such fisheries, unlike the case of industrial fishing (e.g. trawling).

It is also important to consider the use of trash fish/low-value fish in aquaculture in relation to the changes that are occurring in the marine capture fisheries in the region *per se*, rather than globally. It has been shown (Sugiyama, Staples and Funge-Smith, 2004) that major changes have occurred in the marine capture fisheries in the region over the last two decades. For example, the landing of trash fish in China rose from 1.3 million tonnes in 1980 to 5 million tonnes in 2002, and in the South China Sea these landings exceeded 60 percent of the total production. Comparable figures are reported from the Gulf of Thailand fisheries and in the western Malaysian trawl fishery, trash fish accounted for 51 percent of the landings. Given that trash fish/low-value fish are generally not preferred for human consumption (particularly near landing sites where better aquatic products are available at an affordable price), and that their distribution to inland areas is hampered by issues related to poor quality and high transportation costs that affect marketability, the question therefore arises: what is the best and most appropriate use of this resource?

The aquaculture sector in the Asia-Pacific region has undergone an unprecedented growth over the last two decades and has done so to a significant degree through an increased reliance on fish as feed, in one form or another. It is important to note that the fish produced via feeding of trash fish/low-value fish are not necessarily destined for high-end markets, e.g. tilapia and catfishes, which generate incomes that in turn ensure food security and contribute to poverty alleviation. It is also important to highlight the contribution of fish culture based on trash fish/low-value fish to the protection of coral reefs, the preferred habitats of groupers.

It is important to note that all predictions indicate that the aquaculture sector in the Asia-Pacific region is becoming increasingly prudent and conscious of the use of

FIGURE 24
The proportion of global trash fish/low-value fish used by different sectors



Source: De Silva and Turchini (2008)

fish, directly and indirectly, as feed sources for cultured stocks. There is clear evidence that such usage will decrease significantly in the future, and this perhaps can be further promoted by better translation of research into feed formulation, adoption of simple but effective feed management practices and improvements to farm-made feeds. The assumption that the use of formulated feeds is better than the direct use of trash fish/low-value fish has to be scientifically substantiated from the viewpoints of both efficacy and primary resource utilization, however, before attempting to encourage resource-poor small-scale farmers to shift to the use of formulated feeds.

Most importantly, the issue of channelling trash fish/low-value fish to the production of food for human consumption as opposed to its use for other purposes needs to be carefully addressed. De Silva and Turchini (2008) endeavoured to show the approximate breakdown of the usages (Figure 24). These authors also point out that with living standards increasing throughout much of the world, the consequent demands for foods that are perceived to be better, and other human recreational needs, all of which impact on the demand of a dwindling biological resource, there is a need for a global approach to the problem.

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