GREENPEACE

Challenging the Aquaculture Industry on Sustainability

Technical overview

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EXECUTIVE SUMMARY

The farming of aquatic plants and animals is known as aquaculture. The production of fish, crustaceans and shellfish by aquaculture has become the fastest growing animal food sector in the world. Today, aquaculture supplies an estimated 43% of all fish that is consumed by humans globally.

Species that dominate world aquaculture are those at the lower end of the food chain, that is aquatic plants, shellfish, herbivorous fish (plant eating) and omnivorous fish (eating both plants and animals). However, marine aquaculture of carnivorous (animal eating) species is also increasing, most notably salmon and shrimp and, more recently, other marine finfish.

The growth of commercial aquaculture has brought with it more intensified methods of production. In some instances, particularly for carnivorous species, intensive aquaculture has created serious environmental problems. There have also been human rights abuses associated with commercial aquaculture in a number of countries.

This report outlines some of the negative environmental and social impacts that have resulted from aquaculture practices. These issues are discussed by way of example for certain species –, shrimp, salmon, tuna, other marine fish and tilapia (section 2). Another key issue undermining the sustainability of some aquaculture is the use of fishmeal and fish oil as feedstuffs (section 3). Utilization of alternative feedstuffs is examined (section 4). Negative environmental impacts of aquaculture can be addressed in a variety of ways in order to place aquaculture on a more sustainable footing (section 5). Section 6 briefly explores certification of aquaculture products. Ultimately, aquaculture must become sustainable. In order to achieve this, the aquaculture industry will need to adhere to rigorous standards (section 7).

Negative Impacts of Aquaculture on People and on the Environment

Case study 1 – Shrimp

Destruction of Habitat: The creation of ponds for marine shrimp aquaculture has led to the destruction of thousands of hectares of mangroves and coastal wetlands. Significant losses of mangroves have occurred in many countries, including the Philippines, Vietnam, Thailand, Bangladesh and Ecuador. Mangroves are important because they support numerous species, serve to protect coastlines from storms and are important in the subsistence of many coastal communities. Mangroves provide nursery grounds for many species, including commercially important fish, and their destruction may lead to substantial losses for commercial fisheries.

Collection of Wild Juveniles as Stock: Aquaculture of some species relies on juvenile fish or shellfish being caught from the wild to supply stock, rather than using hatcheries to rear them. Shrimp farms in many areas rely on wild-caught juveniles. This has led to over-exploitation and shortages of wild stocks. Furthermore, capture of shrimp juveniles also leads to the by-catch of juveniles of numerous other species which are killed in the process.

Chemicals used to Control Diseases: Pesticides and disinfectants are known to be used on shrimp farms and are likely harmful to the surrounding environment when waters are discharged. Bacterial resistance to antibiotics used on shrimp farms has been reported. This constitutes a risk to human health should resistance be acquired in bacteria that cause disease in humans.

Depletion and Salinization of Potable Water; Salinization of Agricultural Land: Pumping of groundwater to supply freshwater to shrimp farms has resulted in depletion and, sometimes, salinization of local water supplies, causing water shortages for coastal communities. There have also been many reports of crop losses after agricultural land has become salinized by effluent water pumped out from shrimp farms onto land.

Human Rights Abuses: There has been large scale displacement of families to make way for shrimp farms in some developing countries, contributing to landlessness and food insecurity. Non-violent protests against the industry have frequently been met with threats, intimidation and violence. Protesters have been murdered in at least 11 countries, including an estimated 150 people in Bangladesh alone.

Case Study 2: Salmon

Nutrient Pollution: Organic wastes from fish or crustacean farming include uneaten food, body wastes and dead fish. The resulting "nutrient pollution" at salmon farms often causes a significant reduction in biodiversity on the seabed up to about 200 meters from the cages. Nutrient pollution has also been found to cause the increased growth of certain species of phytoplankton (microscopic algae), including some which are known to cause harmful algal blooms.

Threat of Escaping Salmon to Wild Fish: Farmed Atlantic salmon have escaped in vast numbers and are successfully breeding with their wild counterparts. Farmed salmon have a lower genetic variability than wild salmon and, when bred with wild fish, adaptations to the wild may be lost in the offspring. Furthermore, experiments show that the offspring are less fit than wild salmon and a high proportion die. Inter-breeding of farmed with wild salmon could therefore drive already vulnerable populations of wild salmon towards extinction.

Parasitic Infestation: Parasitic sea lice are problematic in salmon farming. When wild salmon migration routes pass close to salmon farms, wild salmon can become infected with lice from farms and may die. In Canada, a recent study shows that lice originating from farms have seriously impacted on wild pink salmon populations. Unless action is taken it is predicted that populations of pink salmon in affected areas will become extinct.

Human Rights Issues: Salmon farming in Chile has an appalling health and safety record. Over 50 people have died in work-related incidents in the past 3 years. Wages are around the national poverty line and sexual harassment of women is reported to occur.

Case Study 3: Other Marine Finfish

In addition to salmon, the aquaculture industry is now farming several species of other marine finfish such as cod and sea bass. Most are reared in cages in coastal waters. It is, however, inevitable that some of the environmental problems associated with salmon farming will be duplicated with farming of other marine finfish.

Case Study 4: Tuna ranching

Tuna are caught live and taken to floating offshore ranches where they are fed and fattened before being killed for the market. In the Mediterranean, the number of tuna ranches has increased rapidly since the late 1990s. Supplying the ranches with young bluefin tuna from the Mediterranean puts unsustainable pressure on stocks which are already severely depleted. There are serious concerns that commercial extinction of the species is just around the corner.

Case Study 5: Tilapia

Tilapia are native to Africa and the Middle East, but are also farmed in other areas including Asia and Latin America. These fish have regularly escaped into the wild and have become a widely distributed alien species. Once in the wild, the farmed tilapia threaten native fish by, for example, feeding on their juveniles. Consequently, tilapia have caused declines in some native fish species.

Use of Fishmeal/Fish Oil/Low Value Fish in Aquaculture Feeds and Associated Problems

Fishmeal and fish oil used in aquaculture feeds are largely derived from small oily fish caught by so-called "industrial fisheries". As aquaculture methods have intensified, there is a growing dependence on fishmeal/oil as a feed source. However, assessments show that industrial fisheries are not sustainable. In addition, overfishing of stocks has led to detrimental impacts on breeding of some seabird species which prey on the fish. Because industrial fisheries are inherently unsustainable, there is a clear need for aquaculture to reduce its dependence on these finite stocks.

Presently, the farming of carnivorous species, in particular, necessitates the use of fishmeal/oil in diets. In fact, the input of wild-caught fish as feed for farmed carnivorous fish and shrimp is higher than the output of fish. For example, each kilogram of salmon, shrimp or other marine finfish produced may use between 2.5 and 5 kg of wild fish as feed. For tuna ranching, the ratio of wild fish needed as feed to the amount of tuna fish produced is even higher, at 20 kg fish-feed to 1 kg farmed fish. Thus farming of carnivorous species therefore results in a net loss rather than a net gain of fish protein. Instead of alleviating pressure on wild fish stocks, aquaculture of carnivorous species therefore increases pressure on wild stocks of fish.

The issues of diminishing rather than increasing net fish supplies in aquaculture is also one of food security since certain fish used as fish meal can also be used directly for human consumption and because future demand for aquaculture products is set to increase further as populations grow. Even low value fish caught by traditional fisheries, an important food source for poor people in many developing countries, are nevertheless increasingly being diverted to the production of aquaculture feeds.

Moving Towards More Sustainable Feeds

Plant-based products are already widely used in aquaculture feeds, and research shows some plants could be suitable for greater use in the future. To be sustainable, however, the crops must come from sustainable agriculture and must not be genetically modified.

For some herbivorous and omnivorous fish, it has been possible to replace completely any fishmeal in the diet with plant-based feedstuffs without impacting on fish growth. Therefore, cultivating such species in this way suggests a more sustainable future path for aquaculture.

For carnivorous finfish, it has not been possible so far to replace fishmeal and fish oil completely in the diet. Problems include both the presence of certain compounds in plants that are not favourable to fish, known as anti-nutritional factors, and the lack of certain essential (omega 3) fatty acids. Studies on shrimp suggest it may be possible to replace fishmeal with plant-based feeds, although further research is needed.

Aquaculture that has been certified as "organic" often uses fish trimmings – offcuts of fish from the filleting and processing of fish for human consumption. This is more sustainable in that a waste product is being used. However, unless the fishery from which the fish trimmings are derived from is itself sustainable, the use of fish trimmings cannot be seen as sustainable because it perpetuates the cycle of over-exploitation of fisheries.

Moving Towards More Sustainable Aquaculture Systems

In order for aquaculture operations to move towards sustainable production, the industry needs to recognise and address the full spectrum of environmental and societal impacts caused by its operations. Essentially, this means that it will no longer be acceptable for the industry to place burdens of production (such as the disposal of waste) onto the wider environment.

In turn, this implies moving towards closed production systems. For example, in order to prevent nutrient pollution, ways can be found to use nutrients present in waste products beneficially. Examples include:

- Integrated multi-trophic aqua-culture (IMTA) - in which organic waste products from the farmed species (finfish or shrimp) are used as nutrients or food by other cultivated species which function at a lower level of the food chain (trophic level), such as seaweed and shellfish.
- Aquaponics - in which effluent wastes for fish farming are used as a nutrient source for growing vegetables, herbs and/or flowers.

Aquaculture Certification

Presently, there are a growing number of certification schemes of aquaculture products which seek to assure buyers, retailers and consumers about environmental, social, animal welfare and food safety issues. However, these certification schemes generally do not cover all of the relevant issues and present a confusing picture to retailers and consumers. Moreover, a 2007 assessment of 19 certification programs found they all had major shortcomings in terms of the way they considered environmental standards and social issues.

In any case, certification criteria alone will not ensure the sustainability of the aquaculture industry worldwide. In order to do so, a more fundamental rethink and restructuring of the industry is essential

Greenpeace Recommendations for Sustainable Aquaculture

Greenpeace considers the culture of species that require fishmeal or fish oil-based feeds derived from unsustainable fisheries and/or which yield conversion ratios of greater than one (i.e. represent a net loss in fish protein yield) as unsustainable. There needs to be a continued move towards plant-based feeds. Plant-based feeds should originate from sustainable agriculture, and sources of omega 3 should be algal derivatives, grape seed oils, etc.

Greenpeace considers aquaculture that results in negative environmental impacts in terms of discharges /effluents to the surrounding environment as unsustainable.

Greenpeace recommends that only species which are native should be cultivated in open water systems, and then only in bag nets, closed wall sea pens or equivalent closed systems. Cultivation of non-native species should be restricted to land-based tanks.

Greenpeace considers aquaculture which causes negative effects to local wildlife (plants as well as animals) or represents a risk to local wild populations as unsustainable.

Greenpeace considers aquaculture which relies on wild-caught juveniles as unsustainable.

Greenpeace demands that genetic engineering of fish for commercial purposes should be prohibited.

Greenpeace recommends cultivation at stocking densities that minimise the risk of disease outbreaks and transmission and, therefore, minimise requirements for therapeutic treatments.

Greenpeace considers aquaculture that depletes local resources, for example, drinking water supplies and mangrove forests, as unsustainable.

Greenpeace considers aquaculture that threatens human health as unfair and unsustainable.

Greenpeace considers aquaculture that does not support the long-term economic and social well-being of local communities as unfair and unsustainable.

1.INTRODUCTION

The farming of aquatic plants and animals is known as aquaculture and has been practiced for around 4000 years in some regions of the world (Iwama (1991). Since the mid-1980s, however, production of fish, crustaceans and shellfish by aquaculture has grown massively. Globally, aquaculture production has become the fastest growing food production sector involving animal species. About 430 (97%) of the aquatic species presently in culture have been domesticated since the start of the 20th century (Duarte *et al*. 2007) and the number of aquatic species domesticated is still rising rapidly. It was recently estimated that aquaculture provides 43% of all the fish consumed by humans today (FAO 2007).

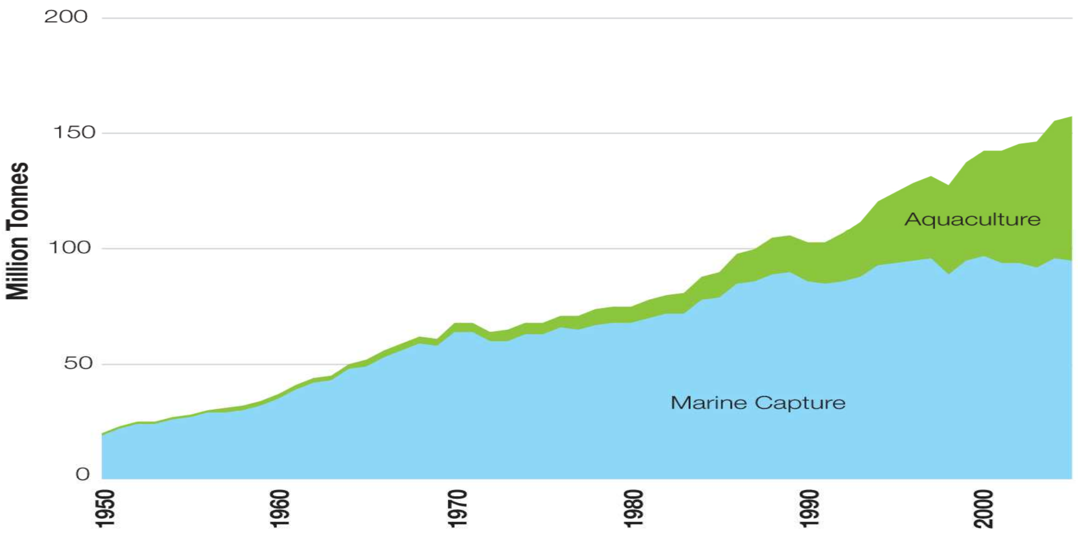
The landings of fish from the world's oceans have gradually declined in recent years as stocks have been progressively overfished (Pauly *et al*. 2002). At the same time, demand for seafood has been steadily rising and, in parallel, aquaculture production has expanded significantly (see figure 1). This expansion is both a response to increasing demand for seafood and, especially in the case of luxury products such as salmon and shrimp, an underlying cause of that rising demand.

Table 1. World Aquaculture Production for the Years 2000 to 2005

World Production (Million tonnes)	2000	2001	2002	2003	2004	2005
Marine Aquaculture	14.3	15.4	16.5	17.3	18.3	18.9
Freshwater Aquaculture	21.2	22.5	23.9	25.4	27.2	28.9

Source: Adapted from FAO (2007).

Figure 1. Global Fish Harvest, Marine Capture Fisheries and Aquaculture, 1950-2005.

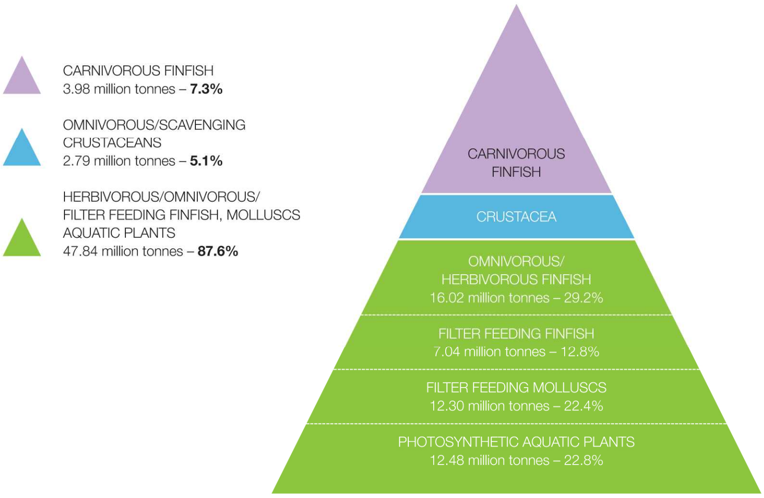


Source: FAO.

The animal species that tend to dominate world aquaculture are those at the lower end of the food chain – shellfish, herbivorous fish (plant eating) and omnivorous fish (eating both plants and animals) (see figure 2). For example, carp and shellfish account for a significant share of species cultivated for human consumption in developing countries (Naylor and Burke 2005). However, production of species higher in the food chain, such as shrimp, salmon, and marine finfish, is now growing in response to a ready market for these species in developed countries (FAO 2007; Naylor and Burke 2005). Common types of aquaculture are described in box 1.

Against a continuing background of diminishing and over-exploited marine resources, aquaculture has been widely held up as panacea to the problem of providing a growing world population with ever-increasing amounts of fish for consumption. With expansion of the industry, however, the tendency has been for methods of production to intensify, particularly in the production of carnivorous species. This has resulted in many serious impacts on the environment and also human rights abuses.

Figure 2 Global aquaculture production pyramid by feeding habit and nutrient supply in 2003



Source: TACON et al (2006)

Box 1. Types of Aquaculture

For freshwater aquaculture, ponds are either used or created and they are often located on areas of agricultural land. For the purposes of marine aquaculture, production takes place along the coast either in ponds, or in cages or netpens in the sea. Land-based systems include raceways (channels through which water from a natural sources flows) or recirculating systems in which fish are enclosed in tanks and through which treated water is recirculated.

Different types of aquaculture are described as being extensive, semi-intensive or intensive. These descriptions refer to the input of food into the system:

- In extensive aquaculture, the farmed organisms largely take their nutritional requirements from the environment (Beveridge *et al.* 1997). However, nutrient-rich materials are often given to encourage the growth of algae on which the farmed species feeds (Naylor *et al.* 2000). Traditional systems of aquaculture tend to be extensive and can be sustainable.

- In semi-intensive aquaculture, food from the environment is supplemented with fertilizer and/or food. This food is usually sourced from agricultural by-products, manures for example, or from rice bran (Beveridge *et al.* 1997). Some fish protein in the form of fishmeal may also be used in semi-intensive aquaculture (Naylor *et al.* 2000).

- In intensive aquaculture, all or virtually all of the nutrition is provided directly from added feeds and/or fertilizer. Food is usually fishmeal (Beveridge *et al.* 1997). The farming of carnivorous species is generally intensive. In recent years there has been a general trend towards greater intensification of aquaculture.

2.NEGATIVE IMPACTS OF AQUACULTURE ON PEOPLE AND ON ENVIRONMENT

The following case studies of negative impacts of aquaculture are far from exhaustive. Rather they provide examples that illustrate the wide spectrum of problems associated with aquacultural activities, and cast serious doubts on industry claims of sustainability.

2.1 Case Study 1: Shrimp Farming

Commercial shrimp farming has boomed. It began in the 1970s and grew rapidly during the 1980s. By 2001, 40% of shrimp sold were of farmed origin rather than wild caught (Goldburg and Naylor 2005).

2.1.1 Collection of Wild Juveniles as a Stock for Aquaculture

Aquaculture of many species in the marine environment relies on juvenile fish or shellfish being caught from the wild to supply stock rather than using hatcheries to rear them. Naylor *et al.* (2000) list several examples of aquaculture which use the practice of collecting juveniles from the wild. They include shrimp farming in south Asia and Latin America, milkfish in the Philippines and Indonesia, eels in Europe and Japan and tuna in South Australia and the Mediterranean. In some cases the collection of wild juveniles has led to their overexploitation. In addition, the practice may also result in the capture of juveniles of numerous other species which are discarded and die.

Globally, it has been estimated that 65–75% of all shrimp juveniles (known as post larvae) used by shrimp farms are produced in hatcheries, but shrimp farms in many areas still rely on juveniles caught from the wild. Natural stocks of shrimp are now overexploited as a result of juvenile collection from the wild (Islam *et al.* 2004, Islam and Haque 2004). As noted by Islam *et al.* (2004), several reports suggest an extreme shortage of shrimp juveniles in some parts of the world. Furthermore, once caught, the shrimp juveniles only represent a small fraction of each catch – there is a large incidental catch (by-catch) and mortaility of other species. For example, the loss of numerous species has been reported in Honduras, India and Bangladesh:

- In Bangladesh, for each single tiger shrimp (*Penaeus monodon*) juvenile collected, there were 12–551 shrimp larvae of other species caught and wasted, together with 5–152 finfish larvae and 26–1636 macrozooplanktonic animals.
- In Honduras, the reported annual collection of 3.3 billion shrimp juveniles resulted in the destruction of 15–20 billion fry of other species (Islam *et al.* 2004).
- In the Indian Sundarbans, each tiger shrimp juvenile only accounted for 0.25–0.27% of the total catch. The rest of the catch consisted of huge numbers of juvenile finfish and shellfish which were left aside on the beach flats to die (Sarkar and Bhattacharya 2003).

Islam *et al.* (2004) noted that the collection of shrimp fry not only posed serious impacts on regional biodiversity and aquatic community structure through such indiscriminate discard of juveniles but also by reducing the availability of food to other species in the food web such as aquatic birds and reptiles.

2.1.2 Destruction of Habitat

Marine aquaculture for tropical shrimp and fish has typically used previously unexploited areas of land for pond construction (Beveridge *et al.* 1997). In many countries this has led to the irreversible destruction of thousands of hectares of mangroves and coastal wetlands.

Mangrove forests consist of trees and other plants that grow in brackish to saline tidal waters on mudflats, riverbanks and coastlines in tropical and subtropical regions. They are home to a diverse array of marine animals and some animals from inland (Field 2000). Mangroves provide important nursery grounds for many marine and estuarine species such as finfish and shellfish since they give shelter and food. This includes providing habitat for juveniles of many commercially important species of marine fish (Islam and Haque 2004). For example, for Fiji and India it has been estimated that about 60% of commercially important coastal fish are directly associated with mangrove habitats and, in eastern Australia, an estimated 67% of the entire commercial catch is composed of mangrove-related species (Rönnbäck 1999). Mangroves also protect coastal water quality and stabilize coastlines from storm and tidal surges (Boyd 2002). For example, in the province of Phang Nga in Thailand, the presence of mangrove forests significantly mitigated the impact of the 2004 tsunami (UNEP 2006). Mangroves provide vital subsistence for coastal communities in many countries since they provide food, wood and medicinal plants (UNEP-WCMC 2006).

A review of aquaculture and mangrove destruction by Boyd (2002) suggested that human activities other than aquaculture have led to the majority of losses of mangrove forest. However, the literature clearly shows that coastal aquaculture, and in particular shrimp aquaculture, has itself caused substantial losses in mangrove habitat. For example:

- Beveridge *et al.* (1997) cited research published in 1991 which reported that, in the Philippines, 60% of the total reduction in mangrove areas was due to aquaculture. This was predominantly for shrimp aquaculture (Beardmore *et al.* 1997).

- In Bangladesh, it has been reported that more than 50% of the mangroves were lost, in particular for shrimp aquaculture (Das *et al*. 2004).

- In Vietnam, mangroves declined from 2500 km^2 in 1943 to 500 km^2 in 1995, caused mainly by the encroachment of shrimp farms (Singkran and Sudara 2005).

- In Thailand, between 1961 and 1986, 38% of the total mangrove loss was attributed to aquaculture (Flaherty and Karnjanakesorn 1995). Another study in Thailand estimated that, between1979 and 1993, 16–32% of the total mangrove area lost was converted to shrimp culture (Dierberg and Kiattisimkul 1996).

- In Ecuador, the Coordinator of Organizations for the Defense of Mangrove Forests (C-Condem) estimates that over 60% of its mangroves forests were lost in the second half of the last century. Between 1969 and 1992, Boyd (2002) estimated that 15–20% of the mangrove loss was caused by shrimp culture alone.

Destruction of mangrove habitat exposes large areas of soil to erosion and destroys former nursery grounds for aquatic organisms. Consequently, it leads to a reduction in species diversity and a decline in genetic diversity (that is, diversity within a species) (Singkran and Sudara 2005; Beardmore *et al.* 1997). Islam and Haque (2004) noted that destruction of mangroves has caused a reduction in the natural production of fish and shrimp larvae. This reduction in juvenile shrimp, in turn, decreases the availability of shrimp juveniles for aquaculture farms and has resulted in the abandonment of farms. Furthermore, Flaherty and Karnjanakesorn (1995) highlight the potential for negative impacts to inshore fisheries due to the removal or modification of nursery grounds. The loss in wild fisheries stocks may be large. For example, in Thailand, it has been estimated that a total of 400 g of fish and shrimp are lost from fisheries for every 1 kg of shrimp farmed by aquaculture facilities developed in mangroves (Naylor *et al.* 2000).

The conversion of mangroves to shrimp farms can also lead to nutrients from the shrimp ponds draining into adjacent estuaries. This process can threaten estuarine animals, particularly fish (Singkran and Sudara 2005). Loss of mangroves can also cause increased sediment transport onto coral reefs if they are located down-current (Beveridge *et al.* 1997). Sediments can smother corals and reduce the light penetration through the water, potentially limiting photosynthesis by their symbiotic algae.

Despite the widespread conversion of mangroves for aquaculture, these habitats are by no means ideal for aquaculture. This is because ponds reclaimed from mangrove become too acidic to support shrimp aquaculture within a few harvests. For instance, it has been estimated that the mean lifetime for a Thai pond is seven years, although substantially shorter lifetimes are possible (Dierberg and Kiattisimkul 1996). As the decline in pond utility inevitably leads to abandonment, this may bring pressure to clear new areas and the whole ‘boom and bust’ cycle starts again (Naylor *et al.* 1998).

It has been noted that, with approximately 50% of the world’s mangrove ecosystems already destroyed or transformed by human activity, the incremental cost of mangrove conversion to shrimp ponds is high (Naylor *et al.* 1998). Indeed, in order to protect coastal estuarine habitats and water quality for aquatic life, shrimp farming in new existing mangroves has been banned in Thailand. Even so, illegal use of mangroves for shrimp farms is still apparent and the topic has become very controversial (Singkran and Sudara 2005). In many Latin American countries, mangrove forests are strictly protected by national environmental laws. Unfortunately, this has not impeded the shrimp farming industry, which has continued to occupy new mangrove areas illegally over the last two decades. This is still the case today. Boyd (2002) notes that most governments are coming to recognize the benefits of mangroves in their natural state and are beginning to regulate their use. However, there remains an urgent need to develop better policies and regulations regarding mangrove use and to enforce those regulations in a fair way.

2.1.3 Chemicals used to Control Diseases

Intensive aquaculture greatly increases the risk of disease outbreaks among stock by concentrating many individuals in a small volume (high stocking density), maintaining continuous production cycles for many years and allowing wastes to accumulate in ponds or beneath cages (Pearson and Inglis 1993, Buchmann *et al.* 1995). As consequence, a wide variety of chemicals and drugs may be added to aquaculture cages and ponds in order to control viral, bacterial, fungal or other pathogens (Gräslund and Bengtsson 2001; Wu 1995).

Pesticides and Disinfectants

Gräslund and Bengtsson (2001) noted that there is generally a lack of information about the quantities of chemicals used in shrimp farming in southeast Asian countries. However, based on knowledge of the types of chemical used there is a cause for concern. For instance, chemicals identified as being used at that time in Thai shrimp farms included copper compounds and triphenyltin, an organotin compound. These compounds are likely to leave persistent, toxic residues in sediments which can, in turn, cause negative impacts on the environment. In addition, copper is moderately to highly acutely toxic to aquatic life. The use of triphenyltin compounds had already been banned in some other Asian countries. A more recent survey of shrimp farms in Sinaloa, Mexico, reported that pesticides were not used (Lyle-Fritch *et al.* 2006).

Antibiotics

A range of antibiotics are in use worldwide in aquaculture to prevent or treat diseases caused by bacteria. With regard to the usage of antibiotics in aquaculture, the Food and Agricultural Organization of the United Nations (FAO) has developed a Code of Conduct for Responsible fisheries (FAO 1995). The Code indicates that preventative use of antibiotics in aquaculture should be avoided as far as possible and any use of antibiotics should preferably be under veterinary supervision (Holmström *et al.* 2003). Preventative (or prophylactic) use of antibiotics entails their use on a regular basis to prevent disease rather than to treat disease when it occurs. Holmström *et al.* (2003) noted that, whereas for shrimp farming in general, there is little published documentation on usage patterns of antibiotics, there was evidence that prophylactic use of antibiotics was a regular occurrence on many shrimp farms in Thailand. Such regular preventative application increases the risk of bacteria becoming resistant to the antibiotics in use, leading to serious problems if resistance is developed by a bacterial strain that can cause disease in the aquaculture stock.

Furthermore, there is a risk that bacteria which are pathogenic (cause disease) in humans could become resistant to an antibiotic which is used to treat the disease in humans. This could be a serious risk to public health (Miranda and Zemelman 2002).

Research has confirmed as number of instances in which the use of antibiotics in aquaculture has already led to the development of bacterial resistance. In Vietnam, one study found a relatively high incidence of bacterial resistance to antibiotics which were in use on shrimp farms in samples of water and mud (Le *et al.* 2005). In the Philippines, bacteria from shrimp ponds were found to be resistant to four different antibiotics. Such multiple resistance was also reported to occur in a hatchery for shrimp aquaculture in India (Holmström *et al.* 2003). In Thailand, one of the factors which led to the collapse of the shrimp farming industry in 1988 was the indiscriminate use of antibiotics. This led to the development of resistant strains of bacteria which, in turn, were left free to cause disease in the shrimp (Holmström *et al.* 2003).

2.1.4 Depletion and Salinization of Potable Water; Salinization of Agricultural Land

Intensive shrimp farming in ponds requires the pond water to be brackish. Water must continuously be renewed and the salinity adjusted accordingly in the ponds. Up to 40% of the water in shrimp ponds is flushed out on a daily basis. This results in a high demand for seawater, freshwater, and brackish water resources. In some areas, this places an unsustainable demand on freshwater supplies needed by communities for domestic use and food production (Public Citizen 2004). In addition, pumping fresh-water from ground water aquifers into shrimp ponds can result in a lowering of the water table. In turn, this causes seawater to seep in and water becomes unfit for consumption (Barraclough and Finger-Stich 1996).

Problems of salinization and depletion of groundwater have been reported for many major shrimp producing countries including Thailand, Taiwan, Ecuador, India, Sri Lanka, Indonesia and the Philippines (Environmental Justice Foundation 2004). In Sri Lanka, for example, it has been reported that 74% of coastal peoples in shrimp farming areas no longer have ready access to drinking waters due to excess salt in the water (Environmental Justice Foundation 2003).

Agricultural land can become polluted by salinization from seawater that has been pumped into shrimp ponds and is often flushed out within terrestrial environments (Barraclough and Finger-Stich 1996). The result can be increased soil salinity, which can prevent vegetable growth and kill plants used for cattle fodder (Environmental Justice Foundation 2003). For example, in Bangladesh there have been numerous reports of crop losses due to salinization of land following the onset of shrimp aquaculture (Environmental Justice Foundation 2004).

2.1.5 Human Rights Abuses

An Environmental Justice Foundation (EJF) report on shrimp farming in some less developed countries is a testimony to the human conflict and human rights abuses that have been suffered as a result of the setting up and running of this industry (Environmental Justice Foundation 2003). Although shrimp farming has been promoted by international financial institutions as a way of alleviating poverty, in reality this has often not been the case. Whilst a few entrepreneurs and investors have become rich, for many people shrimp farming has led to a degraded quality of life. Impacts associated with the industry include increased landlessness, decreased food security, child labour, intimidation, violence and murder.

Landlessness and Food Insecurity

The positioning of shrimp farms has often blocked coastal areas that were once common land to be used by many people. As a consequence, in areas of shrimp farming, access to fishing sites and mangrove forest resources for local people can become severely limited. There is often a lack of formalized land rights in such areas and this has led to large-scale displacement of communities from areas that have been inhabited for generations. This has led to landlessness and reduced food security for thousands of local families. In addition, farmers have also been displaced from their agricultural land because of the development of shrimp aquaculture. In some instances, displacement from land has been inflicted by invasion from gangs operated by shrimp farm owners or by cheap pay-offs from the state. A number of cases studies of land seizures for shrimp farm construction are given in box 2.

Box 2. Case studies of land seizures for shrimp farm construction

- Some Indonesian shrimp farms have been constructed following forced land seizures in which companies, supported by police and government agencies, provided either inappropriate compensation or none at all. Such cases have been reported from Sumatra, Maluku, Papua and Sulawesi.

- In Ecuador, reports indicate that there have been thousands of forced land seizures, only 2% of which have been resolved on a legal basis. Tens of thousands of hectares of ancestral land have allegedly been seized. This has often involved use of physical force and the deployment of military personnel (Environmental Justice Foundation 2003).

- Between 1992 and 1998, many coastal dwelling people dwelling in the Gulf of Fonseca, Honduras, lost access to their traditional food sources and access to fishing sites because of encroachment on land by commercial shrimp farming companies (Marquez 2008).

- In Burma, the military has seized land without compensation in order to construct shrimp farms (Environmental Justice Foundation 2003).

Intimidation, Violence, Rape and Murder

According to a report by the Environmental Justice Foundation (2003), non-violent protests about the shrimp industry have frequently been met with threats, intimidation and even violence from guards and musclemen associated with the shrimp industry, as well as false arrest and aggression from police. In at least 11 countries, protestors have been murdered (see figure 3). In Bangladesh, it has been estimated that 150 people have been killed since 1980 in violent clashes related to shrimp farming. There are also cases of sexual harassment to women from guards at shrimp farms in Bangladesh and 150 cases of rape were reported in one district.

Figure 3 Worldmap showing 11 countries where there has been murder associated with the shrimp industry

Countries include Mexico, Guatemala, Honduras, Ecuador, Brazil, India, Bangladesh, Thailand, Vietnam, Indonesia and the Philippines.
Source: Environmental Justice Foundation.

In some countries the shrimp industry has become very powerful and has tight links with individuals in governments, police, military and judiciary. The perpetrators of violence in relation to the shrimp industry have rarely been brought to justice (Environmental Justice Foundation 2003).

2.2 Case Study 2: Salmon Farming

Farmed salmon are raised in hatcheries from eggs and are cultivated to market size in marine net pens. The industry has grown dramatically in recent years, with global production increasing four-fold between 1992 and 2002, such that it now exceeds the wild salmon catch by about 70% (Naylor *et al.* 2005).

Nutrient pollution

Organic wastes from fish or crustacean farming include uneaten food, fecal matter, urine, and dead fish (Goldberg *et al.* 2001). In the case of cage aquculture (e.g. salmon farms), this waste matter enters marine waters directly. Waste from some pond aquaculture (e.g. shrimp farms) may also be deliberately released into the aquatic environment.

Fish excreta and decaying food or fish contains, and releases into the surrounding waters, among other thing, sources of organic and inorganic nitrogen (including ammonia and nitrate) and phosphorous. These substances act, in turn, as nutrients and can support the growth of marine plants, including both macro-algae (seaweeds) and micro-algae (phytoplankton) (Scottish Executive Central Research Unit 2002). However, if discharged in excess, especially in poorly flushed areas, waters can become so enriched with nutrients that the results is nutrient pollution and excessive growth of algae (termed eutrophication). Impacts of nutrient pollution, whatever the source of nutrients, can include (Goldberg *et al.* 2001, Scottish Executive Central Research Unit 2002):

- Foaming of seawater and murky water
- Low dissolved oxygen levels
- Killing of wild fish or farmed fish or seabed animals
- Increased abundance of micro-algae possibly leading to harmful algal blooms
- Changes in marine food chains

Such effects of nutrient pollution have been reported to occur in the vicinity of salmon farming facilities. The quantity of nutrients discharged from aquaculture can be significant on a local scale. For example, according to literature cited by Naylor *et al.* (2003) a salmon farm of 200,000 fish releases an amount of nitrogen, phosphorous and fecal matter roughly equivalent to the nutrient waste in untreated sewage from 20,000, 25,000, and 65,000 people respectively. Many salmon farms in the Pacific Northwest and Norway contain four to five times that number of fish. Nutrient wastes from salmon farming has been a cause for concern among governments and some non-government organizations in Canada, Ireland, Norway and Scotland where wastes are released into what are considered to be otherwise unpolluted or sensitive coastal waters (Mente *et al.* 2006). In addition, in coastal areas salmon farms are often placed in important coastal fish spawning and nursery areas and thus farms can therefore have a negative impact on local productivity, fisheries and livelihoods.

Effects on the Seabed

The most visible effects of nutrient pollution at salmon farms are those which impact on the seabed. When organic wastes reach the seafloor, oxygen can become depleted primarily through the activities of bacteria. Only a few animal species can survive these conditions and biodiversity in such areas therefore decreases. In severe cases this can result in a 'dead zone' devoid of life beneath cages, surrounded by an area of decreased animal diversity (Goldberg *et al.* 2001). Significant impacts have been reported to extend up to 100 meters from cages and more subtle effects up to 150 meters away although, generally, the impact extends 20–50 meters around the cages (Mente *et al.* 2006). For example:

- Research near finfish farms in the Bay of Fundy, Canada in the 1990s showed that diversity of animal fauna (macrofauna) was reduced close to farms throughout the area and, after five years of operation of farms, changes were documented up to 200 meters away from cages (Fisheries and Oceans Canada 2003).
- In the west of Scotland, diversity of fauna was found to decrease around salmon farms (Mente *et al.* 2006).
- Research at eight salmon farms in Chile along a 300 km stretch of coastline showed that biodiversity was reduced by at least 50% on average in the vicinity of the farms. The loss of biodiversity seemed to be related to the quantity of organic matter and low oxygen levels in the sediments as well as the deposition of copper (Buschmann *et al.* 2006).

Even if severe impacts may be restricted to an area of a few hundred meters surrounding individual cages, the presence of multiple cages and/or farms in any particular area may contribute to greater cumulative impacts.

In an attempt to alleviate the problem of nutrient pollution, research is being conducted into cultivating seaweeds and shellfish near to farms because these species can use nutrient fish farm wastes for growth (see section 4 on integrated multi-trophic aquaculture).

Effects on Algae

Although aquaculture wastes release nitrogen and phosphorous into the water, they are not rich in silica. This creates conditions that less favorable to diatoms and more favourable to the growth of other types of phytoplankton which are usually slow growing (dinoflagellates and cyanobacteria) (Mente *et al.* 2006). The rapid growth of such species as a result of nutrient pollution, in combination with other poorly understood factors, may lead to dense 'algal blooms' which can deplete oxygen at depth, reduce light penetration to other plants and, in some cases, even generate potent toxins. Such harmful algal blooms can thereby cause the death of marine plants and animals through a range of mechanisms. Some particularly harmful species are associated with shellfish poisoning in humans, which can occur when toxins produced by the algae are accumulated in shellfish such as mussels and oysters (Scottish Executive Central Research Unit 2002).

There is only limited research on the association between harmful algal blooms and salmon farming. In Chile, there have been increased reports of harmful algal blooms in the past three decades, and research on salmon farms indicated that the presence of farms has led to a significant increase in the abundance of dinoflagellates (Buschmann *et al.* 2006).

In the inter-tidal zone, nutrient pollution can result in an increase in green macroalgal (seaweed) mats that form a dense cover over the surface of the seabed. Most commonly this occurs with species of *Enteromorpha* and *Ulva*. An increase in *Enteromorpha* mats covering greater than 30% of the sediment has been found adjacent to salmon farms in the Bay of Fundy, Canada. This can have negative impacts on the growth rates of mollusks due to the creation of anoxic conditions within and below the mats (Fisheries and Oceans Canada 2003).

2.2.2 Escaped Farmed Salmon – Threats to Wild Fish

Individual populations of wild salmon are each specifically adapted to the rivers which they inhabit. This is reflected in a high genetic variability between different salmon populations. Naturally, there is also high genetic variability within each population. By contrast, farmed salmon have been selectively bred and have a low genetic variability (Naylor *et al.* 2005, Scottish Executive Central Research Unit 2002).

Unfortunately, farm-raised salmon have frequently escaped into the wild in vast numbers. Here they can compete with wild salmon for food and space putting pressure on wild populations. Moreover, they can interbreed with wild fish. This is problematic because of their genetic differences. Their lower genetic variability can lead to loss of unique gene pools in offspring, thereby potentially reducing their long-term adaptability to the environment. The offspring of wild salmon crossed with farmed salmon have been shown to be less fit than their parents (Naylor *et al.* 2005, Scottish Executive Central Research Unit 2002). One experiment cited by Naylor *et al.* (2005) showed that the lifetime success of wild fish crossed with farmed fish was significantly less than their wild cousins and that 70% of the embryos in the next generation died. The study demonstrates how interbreeding could drive vulnerable salmon populations to extinction. It is therefore of great concern that significant numbers of escaped farm salmon are surviving long enough to breed in the wild (Hindar and Diserud 2007). Continuing escapes may mean that the original genetic profile of the population will not re-assert itself (Goldburg *et al.* 2001).

What is the scale of the problem?

Small-scale escapes of salmon from net pens arise routinely due to poorly maintained pens or damage from seals. Moreover, net pens are open at the top such that, in stormy conditions, thousands of fish may escape. In just one incident in Norway in 2005, almost half a million fish escaped (Tidens Krav 2007). Naylor *et al.* (2005) cite literature which estimated that two million farm salmon escape each year into the North Atlantic.

Worldwide, over 90% of salmon which are farmed are Atlantic salmon (*Salmo salar*). In their native range, Atlantic salmon of farm origin are now successfully breeding in the wild, including in Norway (Hindar and Diserud 2007), Ireland, the UK and eastern North America. Outside of their native range in the Pacific, farmed Atlantic salmon have reportedly formed feral populations in rivers in British Columbia and in South America (Naylor *et al.* 2005). According to a study cited by Naylor *et al.* (2005), farmed salmon in Norway have been estimated to form 11–35% of the population of spawning salmon; for some populations they constitute greater than 80%.

What impact are escaped salmon having?

Because farmed salmon are reproductively inferior to wild salmon, initially it was assumed that their chances of survival in the wild were poor. If they bred, natural selection should terminate their maladapted domestic traits. However, the sheer numbers of escaped fish, together with depleted wild salmon populations in the North Atlantic, means that natural populations may be dwarfed by the escapees such that inter-breeding could lead to reduced fitness in a population and increase mortality of offspring (Naylor *et al.* 2005; Scottish Executive Central Research Unit 2002).

There is also the potential for direct competition for food and habitat. Farmed salmon juveniles are more aggressive than wild salmon and their behavior can severely stress wild salmon, even increasing their mortality. The larger more aggressive farmed fish can cause wild fish to move to poorer habitats, again increasing their mortality. In non-native regions, the farm escapees have competed for food and habitat with other fish in Pacific streams of North America and South America (Naylor *et al.* 2005).

What can be done?

Naylor *et al.* (2005) notes that salmon farming companies have attempted to reduce the number of escapee fish by using stronger net materials as well as using tauter nets to discourage seals. However, the numbers of escaping fish is still large and is having serious impacts on wild fish. One solution that has been suggested is to use land-based tanks or closed-wall sea pens so the fish are kept in closed containment. This would bring extra financial costs (Naylor *et al.* 2005), but when put in context of current threats to natural ecosystems, such costs are entirely justifiable.

2.2.3 Disease and Parasitic Infestations

There are concerns that disease from farmed species may be transferred to wild populations if farming is not contained from the environment. In salmon aquaculture, parasites and diseases are a major constraint on production (Naylor *et al.* 2003) and there is evidence that disease incidence in wild populations has been increased by salmon farming.

One example is sea lice (*Lepeophtherirus salmonis*) which are parasites that feed on salmon skin, mucous and blood. The lice can be seriously problematic on farms and can even cause the death of fish (Goldburg *et al.* 2001). In the wild, sea lice generally have a low natural abundance and damage to salmon is minimal. Protection is afforded when salmon move from the sea to freshwater as most lice fall off in freshwater. However, when infestations occur on farms which are located in wild salmon habitat or on migration routes, wild salmon are at greater risk from infection (Naylor *et al.* 2003). Escaped farm salmon may also transmit the parasites directly to wild salmon. In British Colombia, there is evidence that pink salmon were affected by lice originating in farming areas (Naylor *et al.* 2003), while in Norway the highest infection levels in wild salmon have been found in salmon farming areas

(Goldburg *et al.* 2001). In Chile, preliminary research also suggests that salmon farming can cause increases in sea lice infestations in native fish populations (see Buschmann *et al.* 2006).

In Canada, a study revealed that farm-origin lice caused 9–95% mortality in several wild juvenile pink and chum salmon populations (Krkošek *et al.* 2006). The study noted that migratory cycles of salmon normally separate juveniles from adults and this protects juveniles from contracting lice from the adults, important because juveniles are very susceptible to health impacts and death from lice infestation. Further work provided strong evidence that lice from farmed salmon have resulted in infestations in wild juvenile pink salmon that have depressed their populations (Krkošek *et al.* 2007). The authors suggested that, if the outbreaks continue, local extinction of pink salmon is certain. A 99% collapse in pink salmon abundance is expected to occur within their next four generations.

Sea lice can act as host in the transfer a lethal disease called Infectious Salmon Anaemia (ISA) between fish. ISA has been found on salmon farms in Norway, Canada, Scotland, the United States and other countries. The disease was detected for the first time in 1999 in wild salmon in a Canadian river and in escaped farmed salmon in the same river. There were serious outbreaks of ISA on Chilean salmon farms in 2007 which necessitated a major culling operation (The Fish Site News Desk 2007).

Another disease, furunculosis, is caused by bacteria. It spread to Norwegian farms from infected fish transported from Scotland in 1985. Escaped fish from infected farms caused the spread of the disease to wild salmon and, by 1992, it was detected in fish from 74 rivers (Naylor *et al.* 2005). Presently, this disease is no longer a problem in fish farming due to vaccination programs (Scottish Executive Central Research Unit 2002).

2.2.4 Impacts on Marine Mammals and Birds

In Chile, sea lions (*Otaria flavescens*) have been found to attack farmed salmon net pens to feed. The expansion of salmon farming in Chile has caused increased mortality of sea lions due to their accidental entanglement in nets and by deliberate shooting by the farms. Deterrents include the use of acoustic devices to ward off the sea lions, but only the siting of anti-predator nets around the cages has resulted in a permanent reduction in attacks (FAO 2007b).

In Scotland, acoustic devices and anti-predator nets have been used to protect salmon netpens from seal attacks, though seals have also been shot. There is concern relating to the use of acoustic devices on cetaceans (dolphins, porpoises and whales) because these animals are highly sensitive to acoustic noise, whereas seals are less sensitive. For example, a Canadian study found that killer whales were excluded from a 10 kilometer radius of an acoustic device. Therefore, while acoustic devices probably have no negative impact on seal populations, these devices may exclude cetaceans from a much larger area (Scottish Executive Central Research Unit 2002).

Birds attempting to prey on fish become entangled in aquaculture nets (Australian Marine Conservation Society 2008) and may also be shot.

2.2.5 Human Rights Issues

In southern Chile, the salmon farming industry has grown rapidly since the late 1980s with high levels foreign investment. It exports its product to western nations such as Japan and America (Phyne and Mansilla 2003; Barrett *et al.* 2002). In 2005, Chile produced nearly 40% of the world production of farmed salmon (see Pizarro 2006).

In some countries human rights abuses stem from the desire of aquaculture industry producers and processors to maximize profits within a highly competitive market, while meeting the low prices demanded by consumers. Presently, in the Chilean salmon farming industry, there are a number of serious human rights issues, as described below.

An Appalling Safety Record

One study has researched whether salmon-farming in southern Chile has had negative or positive impacts on employees (Barrett *et al.* 2002). The study found that on salmon farms and in salmon processing plants, there were poor or non-existent health and safety regulations in place. For instance, on the salmon farms, working conditions were often cold, wet or unhygienic and there were no doctors or nursing staff. Another survey in 2004 found that there were a high number of accidents and job related illnesses in the Chile salmon industry with 30% of workers suffering in that year (see Pizarro 2006). It has recently been reported that there have been more than 50 deaths in the Chilean salmon industry over the past three years, mostly of divers. By contrast, no-one has died in work-related incidents in the Norwegian salmon industry (Santiago Times 2007).

Low Wages and Long Working Hours

Barrett *et al.* (2002) and Pizarro *et al.* (2006) reported that wages at salmon farms and processing plants were low. The average wage was insufficient for a single earner to raise a family of four out of poverty. The per capita income generated by the average wage is around the national poverty line (Pizarro 2006).

Barrett *et al.* (2002) reported that working hours in the processing plants could be long. For example, process workers in two sites worked an 8-hour day for six days a week and, during the high season, worked for 10–12 hours a day. In one of these plants, time missed because of illness had to be made up on Sundays.

Women Harassed

The number of women engaged in the salmon farming and processing plants is increasing. However, complaints of sexual harassment are constant, particularly at isolated farms. There is insufficient protection of maternity rights and an increasing number of related judicial cases. It has been reported that women who make use of their maternity rights later lose their jobs. It has been suggested that the reason for the high number of women in salmon farming and processing plants is due to the possibility of paying lower salaries (Pizarro 2006).

No Union Rights

Barrett *et al.* (2002) reported that, with the exception of one plant in southern Chile, there were no unions present to protect workers rights in the salmon industry. This is because a strong union mentality does not generally exist in Chile due to the fact that, during the military dictatorship (between 1973 and 1989), union activity was particularly devastated and persecuted. The study noted that companies take advantage of this situation to attach a negative stigma to any type of union activities and commented that it is the fear of the workers in regard to their jobs that prevents union pressure to fight for better wages. A 2007 news report on salmon farming in Chile noted that the labor organization in Chile is fragmented and does not have the power adequately to protect workers rights (Santiago Times 2007).

2.3 Case Study 3: Other Marine Finfish Aquaculture

Marine finfish aquaculture is an emerging industry. Improvements in technology of salmon farming, together with decreasing market prices for salmon, have inspired the industry to start farming other marine finfish species. Species which are now being farmed include Atlantic cod (*Gadus morhua*), sablefish (*Anoplopoma fimbria*), Atlantic halibut (*Hippoglossus hippoglossus*), Pacific threadfin (*Polydactylus sexfilis*), mutton snapper (*Lutjanus analis*), turbot (*Psetta maximus*), sea bass (*Dicentrachus labrax*), and gilthead seabream (*Sparus aurata*) (Naylor and Burke 2005; Naylor *et al.* 2005). Most are reared in net pens or cages in coastal waters but Atlantic halibut and turbot are mostly reared in tanks on land.

Atlantic cod is now being farmed in Norway, UK, Canada and Iceland. Haddock is being farmed in Canada, Norway and northeastern United States; Pacific threadfin is farmed in Hawaii; and farms for black sablefish are being developed in British Columbia and Washington State. Bluefin tuna and grouper are captured live and then fattened in coastal net pens. This 'ranching' of tuna is already being carried out in the Mediterranean (see section 2.4), Mexico and Australia and is under development in the United States (Naylor and Burke 2005).

It is likely that many of the environmental problems encountered for salmon farming will also become evident for other marine finfish, e.g.:-

(1) nutrient pollution (section 2.2.1),
(2) a reliance for some species on the capture of wild juveniles (section 2.11)
(3) an increased risk of diseases with the potential risk of disease spreading to wild populations (section 2.2.3)
(4) a risk of fish escapes from cages to the wider environment leading to competition with wild fish species, disturbance of ecosystems and possible interbreeding with wild fish leading to reduction of genetic variability in populations (section 2.2.2).

For farmed finfish like tuna and cod, where the current practice is to catch wild fish for further fattening in captive state, the environmental risks presented by escapes to the marine environment is not that high, as the fish will be genetically identical as the wild populations. However, as the work towards full-scale cod farming continues, including captive breeding of more and more domesticated farmed fish, these risks will be increased. In addition, farmed cod tend to be more active in seeking escape than salmon including searching for holes and biting through the nets.

There is also the major issue of the dependence on wild caught fish to provide feedstuffs for these carnivorous species and the fact that more fish is required to feed the farmed species than the weight of fish actually produced (see in detail section 3).

With regard to nutrient pollution, research has shown that farmed cod produces considerably more waste than Atlantic salmon and that waste from farmed turbot is higher still. In the United States (and in other countries), offshore aquaculture is being developed in which submersible cages are located in areas often several miles offshore in rough waters. It is likely that high flushing rates in the open seas will reduce the threat of nutrient pollution on seabed organisms. Even so, other environmental threats remain. Cod, for example, produce fertilised eggs in ocean enclosures which could pass into the ocean and may lead to an even bigger number of escapees than are encountered with salmon farming (see Naylor and Burke 2005). For some species, interbreeding between escaped farm fish and wild fish may have less of a negative genetic impact than for salmon, which are particularly vulnerable because they have subpopulations that are genetically adapted to local river conditions. Nevertheless, others (including Atlantic cod) do exhibit distinct subpopulations and so could be adversely affected (Goldburg and Naylor 2005). This problem is so far limited as long as the farmed cod comes from the local wild stocks, but may be serious in the future, in particular if farming is allowed in key spawning areas (like the Lofoten area in Norway where most of the Barents Sea cod is spawning). Presently, 'cod ranching' also has the potential to confuse quota and landing data, as has been proven for Mediterranean tuna (section 2.4).

2.4 Case Study 4: Tuna Ranching – Wiping Out Tuna in the Mediterra-nean Sea

The present level of fishing for northern bluefin tuna (*Thunnus thynnus*) in the Mediterranean threatens the future of this species in the region and, therefore, the future of hundreds of fishermen. There are serious concerns that commercial extinction of the species is just around the corner (Greenpeace 2006).

Figure 4 Tuna farming proliferation

1985	1996	2000	2001	2002	2003	2004	2006
Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain
	Croatia	Croatia	Croatia	Croatia	Croatia	Croatia	Croatia
		Malta	Malta	Malta	Malta	Malta	Malta
			Italy	Italy	Italy	Italy	Italy
				Turkey	Turkey	Turkey	Turkey
					Cyprus	Cyprus	Cyprus
					Libya	Libya	Libya
						Greece	Greece
						Lebanon	Tunisia
							Morocco
							Portugal
							Lebanon

Source: Lovatelli (2005), ICCAT (2008)

In May 1999, Greenpeace released a report denouncing the depletion of bluefin tuna in the Mediterranean (Gual 1999). It noted that the spawning stock biomass (weight) of tuna was estimated to have decreased by 80% over the previous 20 years. In addition, huge amounts of juvenile tuna were caught every season. Greenpeace reported that the main threat to the bluefin tuna at that time was illegal, unreported and unregulated (IUU) fishing, also called 'pirate fishing'. IUU fishing operates outside of any management and conservation rules and, in effect, steals fish from the oceans. It has become a serious global problem, is a threat to marine biodiversity and an obstacle to achieving sustainable fisheries (Greenpeace 2006b; High Seas Task Force 2006).

Seven years on in 2006, further analysis of the situation undertaken by Greenpeace showed that threats to the tuna had worsened. Pirate fishing is continuing, but now with the further incentive of supplying tuna to an increasing number tuna ranches in Mediterranean countries. While in the past, it was countries from outside the region that were mainly responsible for pirate fishing, these days it is vessels from the region which are the main culprits. Tuna are caught live and taken to ranches where they are fed and fattened before being killed and exported, mainly to Japan. Tuna ranching began in the late 1990s and has expanded rapidly, spreading to 11 countries by 2006 (figure 4). Today, due to poor management, nobody knows the exact amount of tuna taken from the Mediterranean Sea each year, but it is clear that current catch levels are well above the legal quota (Greenpeace 2006; Losada 2007).

Quotas

The International Commission for the Conservation of Atlantic Tunas (ICCAT) is responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and adjacent seas, including the Mediterranean. In 2002, ICCAT ignored warnings by scientists that "*current catch levels were not sustainable in the long term*" and adopted an unsustainable quota of 32,000 tonnes for the years 2003 to 2006 for the eastern bluefin tuna stock (tuna taken from largely from the Mediterranean). Based on figures for catches in 2005, Greenpeace estimated that over 44,000 tonnes may have been caught in the Mediterranean, which is 37.5% over the legally sanctioned catch limit and, disturbingly, 69% above the scientifically recommended maximum catch level (Greenpeace 2006). More recently the catch was estimated to be over 50,000 tonnes (Losada 2007). The 2006 Atlantic Bluefin Tuna Assessment Session of the Scientific Committee on Research and Statistics of ICCAT, which took place in Madrid in June 2006, stated that *"the volume of catch taken in recent years likely significantly exceeds the current Total Allowable Catch and is likely close to the levels reported in the mid-1990s, i.e. about 50,000 t in the East Atlantic and the Mediterranean"* (SCRS 2006). This high level of piracy in the region is a clear threat to tuna stocks and cannot be sustainable.

Ranching and Pirate Fishing

Currently, most of the bluefin tuna catch in the Mediterranean goes to tuna ranches. The total reported farming capacity of the tuna ranches at 51,012 tonnes, exceeds the total allowable catches set by ICCAT of 32,000 tonnes by 60%. This is an indisputable incentive for illegal fishing in the region. Indeed, an examination of available trends in the industry clearly suggests illegal fishing is supplying ranches. This is borne out by data which show that, while exports of farmed tuna to Japan (and therefore inputs for tuna farming) have grown in recent years, at the same time the declared tuna catches by purse seine fishers have decreased. The only way to explain this is that unreported – and overall illegal – catches are increasing.

2.5 Case Study 5: Tilapia Farming

Tilapia is the common name which refers to three genera of fish in the family Ciclidae: *Oreochromis*, *Sarotherodon* and *Tilapia*. The species that are most important in aquaculture are in the genus *Oreochromis* and include the Nile tilapia (*O. niloticus*), the Mozambique tilapia (*O. mossambicus*), and the blue tilapia, *O. aureus* and *O. ureolepis hornorum* (Watanabe *et al.* 2002). Tilapia are native to Africa and the Middle East but, over the past 30 years, their use in aquaculture has expanded and they are now farmed in about 85 countries in different areas of the world. Presently, tilapia are second only to carp as the most important farmed fish in the world. China and Taiwan are the biggest producers of tilapia and increasing production is occurring in the Caribbean, Latin America and temperate regions (which use artificially heated water) (Monterey Bay Aquarium 2006).

Tilapia are farmed under extensive, semi-intensive and intensive systems (FAO 2007b). In extensive systems the fish rely on natural food in the water. Extensive systems have been used historically and operate today in subsistence farming. Some tilapia farming is classified as integrated agriculture–aquaculture, wherein fish ponds are fertilized with agricultural wastes which, in turn, improve the growth of aquatic plants on which the tilapia feed.

Tilapia are also cultured under semi-intensive systems which requires some feed and fertilizer input, and under intensive systems which are more heavily dependent on formulated feeds. In recent years, tilapia farming is becoming more intensified in order to produce higher yields and this necessitates the use of fishmeal and fish oil in feeds. Developing countries such as China are increasingly using formulated feeds for tilapia farming (Monterey Bay Aquarium 2006).

In systems using formulated feeds, it has been calculated that production of 1 kg of farmed tilapia requires the input of 1.41 kg of wild fish as feed. Therefore, this type of tilapia farming leads to a net loss of fish protein (see section 3). However, much tilapia culture does not require formulated feeds so that, overall, tilapia farming actually adds to fish protein production – there is a net gain (Monterey Bay Aquarium 2006). Nevertheless, with intensive farming of tilapia set to increase, this could add to demand for wild caught fish, already fished at unsustainable levels, to provide aquaculture feeds (section 3).

2.5.1 Introduction of Alien Species

When a species is released into an environment where is it not native, it may reproduce successfully and have negative consequences on native species. Pérez *et al.* (2003) notes that the introduction of alien species into new environments, as a consequence of human activities, contributes to an irreversible and devastating impact to natural ecosystems. Tilapia have escaped from sites where they are cultured into the environment, invaded new habitats, and have become a widely distributed exotic species around the world.

About 98% of farmed tilapia is now cultivated outside of its native habitat. Escapee fish are an inevitable consequence of culture in open systems of aquaculture such as cages/nets. Even closed ponds, tanks and raceways may allow fish to escape to waterways in storm conditions. The only way of preventing escapes in such systems is to enclose them in a suitable structure (Monterey Bay Aquarium 2006).

Once in a non-native environment, tilapia threaten native fish by feeding on their juveniles as well as on plants that are habitat refuges for juveniles. Monterey Bay Aquarium cite literatures providing examples of negative impacts of tilapia invasions into non-native regions including:

(1) the decline of an endangered fish species in Nevada and Arizona,

(2) the decline of a native fish in Madagascar,
(3) the decline of native cichlid species in Nicaragua and in Kenya, and
(4) the breeding of escaped tilapia in Lake Chichincanab, Mexico to become the dominant species at the cost of the native fish populations.

Because tilapia are able to invade and adapt to non-native habitats, experts strongly suggest that non-native species should not be farmed in new or pristine areas because of the likelihood of escapes occurring (Monterey Bay Aquarium 2006).

3. USE OF FISHMEAL, FISH OIL AND LOW VALUE/"TRASH FISH" IN AQUACULTURE FEEDS AND ASSOCIATED PROBLEMS

3.1 A Growing Demand

Fishmeal and fish oil [1] are produced largely from the processing of small oily fish such as anchovies, herrings and sardines which are caught for non-food purposes by so-called 'industrial' fisheries. Some types of aquaculture, notably the farming of carnivorous species such as salmon and shrimp, use fishmeal and fish oil in feeds. Farming of some species also relies on the use of whole fish of low market value. Generally, fishmeal is used because it is digestible, energy rich and is a good source of protein, lipids (oils), minerals and vitamins (Miles and Chapman 2006), and is economically viable.

In 2003, more than 28 million tonnes of fish and shellfish were landed by industrial fisheries for non-food purposes, representing just over 30% of the total of capture fisheries landings[2]. The quantity of fishmeal and fish oil utilized by aquaculture has increased over the years as the aquaculture industry has grown. For example, most recent estimates indicate that, in 2003, the aquaculture industry consumed 53.2% of the total world fishmeal production and 86.8% of world fish oil production (Naylor and Burke 2005; Tacon *et al.* 2006). The increasing trend for the use in fishmeal and fish oil for shrimp, salmonids, other marine finfish and tilapia between 1992 and 2003 is shown in table 2.

This increasing demand for fishmeal and fish oil by aquaculture has been met by diverting these products away from their use as feed for farmed animals, now increasingly restricted to starter and breeder diets for poultry and pigs. Fish oil was once used for hardening margarines and bakery products but is now mainly used in aquaculture (Shepherd *et al.* 2005). Figure 5 depicts the estimated global use of fishmeal within compound aquafeeds in 2003 by major species.

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[1] "Fishmeal" and "fish oil" are terms for those aquatic products derived from the processing of whole fish and/or fish/shellfish waste wherein they have been processed through cooking, pressing, drying and milling, fish oil usually being a valuable by-product of the fishmeal manufacturing process (Tacon *et al.* 2006).

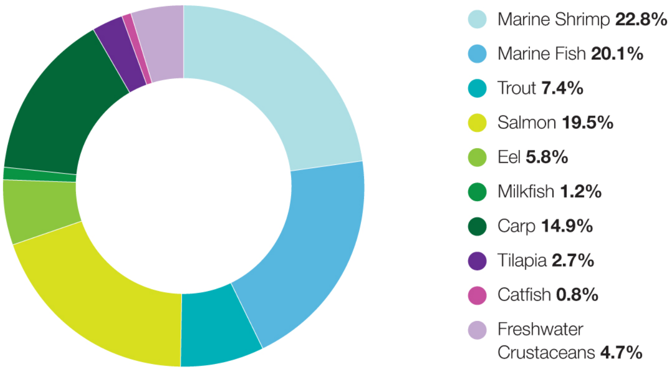
[2] The quantity of the fisheries catch which is reduced into fishmeal and fish oil each year has stabilized at about 25 million tonnes since the beginning of the seventies, although it has fluctuated between 20 to 30 million tonnes (Tacon *et al.* 2006).

Table 2. Estimated use of fishmeal and fish oil in 1992 and in 2003 for four types of aquaculture products

Aquaculture product	1992 Usage (tonnes)		2003 Usage (tonnes)	
	Fishmeal	Fish oil	Fishmeal	Fish oil
Salmonid	343,000	107,700	789,000	535 000
Shrimp	232,000	27,800	670,000	58,300
Marine finfish	180,000	36,000	590,000	110,600
Tilapia	29,000	0	79,000	15,800

Source: Adapted from Tacon *et al.* (2006)

Figure 5 Estimated global use of fishmeal within compound aquafeeds in 2003.



Source: TACON et al

If marine aquaculture production continues to rise, and farming of carnivorous species is indeed set to increase, then the demand for fishmeal and fish oil could outstrip the current supply (Goldberg and Naylor 2005). However, some have the opinion that the use of fishmeal and fish oil by aquaculture industry will decrease in the long term due to a number of factors, including prohibitively expensive prices (Tacon *et al.* 2006).

In recent years there has been much research and practical progress into substituting fishmeal with plant-based proteins, thereby lessening the inputs of fishmeal into diets, although the fraction of fishmeal, fish oil, low value fish (inappropriately termed 'trash fish') used for diets of carnivorous species remains high (see section 4). Substitution with plant-based ingredients is positive providing that this feed is derived from sustainable agriculture. However, the current shift to more plant-based feeds for aquaculture has not occurred fast enough to reverse the trend in fishmeal consumption caused simply by an increase in the overall number of farmed carnivorous fish produced. For example, the quantity of wild fish required as feed to produce one unit of farmed salmon was reduced by 25%

between 1997 and 2001, but the total production of farmed salmon grew by 60% over the same period (Naylor and Burke 2005).

The sustainability of using fishmeal and fish oil in aquaculture is already under serious question, both in terms of the industrial fisheries themselves (section 3.2 below) and of the aquaculture operations themselves (section 3.3). Without innovations by the aquaculture industry to lessen its use of fishmeal, it may be faced with constraints to growth and increasing costs in the long-term (Kristofersson and Anderson 2006). Indeed, the aquaculture industry can never be seen to be sustainable unless it radically reduces its dependency on fishmeal and fish oil.

3.2 Sustainability of Industrial Fisheries

In simple terms, a particular seafood is sustainable if it comes from a fishery whose practices can be maintained indefinitely without reducing the target species' ability to maintain its population, and without adversely impacting on other species within the ecosystem directly, by removing their food source or by damaging their physical environment (Dorey 2005). On the basis of these basic criteria, most current world fisheries cannot be considered to be sustainable.

There have been increases in commercial fishing effort and efficiency over the past 50 years but, despite this, figures show that global seafood catches have been declining slowly since the late 1980s (Pauly *et al.* 2002). This is provides further evidence that fishing at a global level has not been sustainable. Indeed, statistics from the FAO in 2005, indicate that that 77% of the world's assessed fisheries stocks were either fully exploited (52%), overexploited (17%), depleted (7%), or recovering from depletion (1%) (FAO 2007). Furthermore, research has revealed that about 90% of stocks of some of the world's predatory fish, such as codfishes, flat fishes, skates, rays and tuna have already been lost (Christensen *et al.* 2003; Myers and Worm 2003). The principle cause of the poor shape of commercial fish stocks is, without doubt, due to overfishing.

Table 3. Top pelagic fish mainly caught for reduction in 2003

Species	Total Reported Production (millions of tonnes)	Production by Country (%)
Peruvian anchovy (*Engraulis ringens*)	6.2	Peru 86.2%, Chile 13.2%
Blue whiting (*Micromesistius poutassou*)	2.38	Norway 35.7%, Iceland 21% Russian Federation 15.1%, Faeroe Islands 13.7%, Denmark 3.7%, Sweden 2.7%, Netherlands 2.4%
Japanese anchovy *Engraulis japonicus*	2.09	China 62.3%, Japan 25.6%, Korea Republic 12%
Atlantic herring (*Clupea harengus harengus*)	1.96	Norway 28.7%, Iceland 12.8%, Canada 10.2%, Russian Federation 7.4%, Denmark 5.9%, United States 5%, Netherlands 4.8%, United Kingdom 4.6%, Sweden 4.4%
Chub mackerel (*Scomber japonicus*)	1.85	Chile 30.9%, China 23.6%, Japan 17.8%, Korea Republic 6.6%, Peru 5.1%
Chilean jack mackerel		Chile 81.9%, Peru 12.5%,

(*Trachurus murphyi*)	1.73	China 5.4%
Capelin (*Mallotus villosus*)	1.15	Iceland 59.2%, Norway 21.7%, Russian Federation 8.4%., Faeroe Islands 4.4%, Greenland 2.6%, Denmark 1.5%
European pilchard (*Sardina pilchardus*)	1.05	Morocco 62.8%, Algeria 7.3%, Portugal 6.3%
Californian pilchard (*Sardinops sagax*)	0.691	Mexico 89.6%, United States 10.4%
European sprat (*Sprattus sprattus sprattus*)	0.631	Denmark 41.5%, Poland 13.3%, Sweden 12.1%
Gulf menhaden (*Brevoortia patronus*)	0.522	United States 100%
Sandeels (*Ammodytes* sp.)	0.341	Denmark 82.9%, Norway 8.7%, Sweden 6.4%
Atlantic horse mackerel (*Trachurus trachurus*)	0.214	Ireland 21.5%, Norway 9.5%, Germany 8.7%, Portugal 8.7%, Denmark 6.5%, France 5.4%
Norway pout (*Trisopterus esmarkii*)	0.037	Denmark 60.9%, Norway 32.8%, Faeroe Islands 6.2%

Source: Tacon *et al.* (2006)

Ecological Impacts

It is important to note that fish species commonly exploited for reduction to fishmeal and fish oil (refer to table 3 for the key species) are low in the food chain, and as such they form a critical base for the marine food web providing food for marine predators including many commercially valuable fish, marine mammals and seabirds (Naylor and Burke 2005). Consequently, there may be adverse impacts on marine ecosystems and in particular for predatory species where there is competition from overfishing. Research on the ecosystem effects of overfishing is, unfortunately still quite limited. Examples of impacts are given in Box 3.

Box 3. ECOLOGICAL IMPACTS OF INDUSTRIAL FISHING

An example of a detrimental impact of overfishing by industrial fisheries is the collapse of the Norwegian spring-spawning herring stock (*Clupea harengus*) in the late 1960s. While stocks were at their lowest between 1969 and 1987, the breeding success of Atlantic puffins at Røst in the Norwegian sea was severely impacted by lack of food (Anker-Nilssen *et al.* 1997).

More recently, a negative impact of the North Sea sandeel fishery was reported on the breeding success of black-legged kittiwakes (*Rissa tridactyla*) (Frederiksen *et al.* 2004). Closure of the sandeel fishery east of Scotland was recommended by the International Council for the Exploration of the Sea (ICES) between 2000 and 2004 in order to safeguard populations of puffins (*Fratercula arctica*) and kittiwakes (*Rissa tridactyla*).

There are growing concerns among experts for a number of seabird species in Nordic waters (Petersen *et al*. 2007). Food shortages have caused negative impacts on reproduction in the past four years. A number of contributory factors are suspected, including impacts of commercial fisheries and climate change. It was suggested that "*new regulations in the management of commercial fish species of direct or indirect significance to seabirds must be assessed*".

It has been suggested that continuing pressure exerted by industrial fisheries at low levels of the food web, combined with an ever-increasing demand for fishmeal by the expanding aquaculture industry, also puts pressure on marine fish predatory species higher up the food chain. Further, it may be difficult for populations of fish occupying higher trophic levels to recover even if pressure on industrially fished species was significantly decreased (Deutsch *et al.* 2007).

Unsustainable Fisheries

Huntington (2004) made an assessment of the sustainability of six industrially fished species which are used for feed in Scottish finfish aquaculture (mainly salmon). These industrially fished species included capelin (*Mallotus villosus*), blue whiting (*Micromesistius poutassou*), sandeel (*Ammodytes* spp.) and horse mackerel (*Trachurus trachurus*) from the Northern Hemisphere and Chilean jack mackerel (*Trachurus murphyi*) and Peruvian anchovy (*Engraulis ringens*) from the Southern Hemisphere. The study found that most of the fisheries did not meet requirements for sustainability. For example, it concluded that the Chilean jack mackerel was overfished and is still recovering from previous overfishing; the catch limit on horse mackerel was too high to sustain the fishery; the harvest of blue whiting was considered to be unsustainable and the sustainability of both capelin and sandeel fisheries was uncertain. There were insufficient data on the Peruvian anchovy to determine whether the fishery was sustainable. However, the species has been subjected to heavy fishing pressure over the years and stock levels are also extremely vulnerable to climatic changes due to the El Niño phenomenon. Currently, stocks are considered to be fully or over-exploited (Tacon 2005, Tacon *et al.* 2006). Tacon (2005) has reported further industrially fished species, in addition to those considered by

Huntington (2004), that were listed as fully exploited or overexploited.

The sustainability of industrially caught species is clearly a great concern for the sustainability of the aquaculture industry itself. Aquaculture products that are produced using overfished species cannot themselves be considered as sustainable. Therefore, there is a clear need for aquaculture that relies on fishmeal to reduce its dependence on finite fish stocks.

In addition, there is an urgent need for the sustainable management of industrial fisheries and, indeed, all fisheries.. This would require an approach that is precautionary in nature and has the protection of the whole marine ecosystems as its primary objective, i.e. an 'ecosystem approach'. It is necessary that such an approach is adopted to manage all fisheries including industrial fisheries. An ecosystem approach is a holistic approach which considers both environmental protection and marine management together. Vital to its application, among many other measures, is the establishment of a global network of fully protected marine reserves. Marine reserves have been likened to national parks of the sea – they are completely protected from all extractive and destructive activities. Experience shows that marine reserves help biodiversity to replenish and thrive as well as benefiting fisheries in surrounding waters (e.g. Williamson *et al.* 2004; McClanahan and Arthur 2001). Greenpeace is advocating that a global network of marine reserves covering 40% of the oceans is necessary to promote conservation and to achieve the desired benefits to fisheries (Roberts *et al.* 2006). Outside of the marine reserves, implementing an ecosystem approach requires the sustainable management of fisheries and other resources. This necessitates that marine resources be managed within the limits of what the ecosystem can provide indefinitely rather than, for example, fishing simply to meet market demands (Allsopp *et al.* 2007).

Huntington (2004b) reported that the use of fishery discards to produce fishmeal and fish oil is common practice in South America, the United States and Norway. In the recommendations that this report makes for improving the sustainability of fisheries for aquaculture feeds, it was suggested that (with caution) that discards should be better utilized to avoid waste. However, this should be accompanied by continued efforts to reduce discarding and to improve the selectivity of fishing gear. Maintaining a strong price differential between marketable fish and low value fish that would otherwise be discarded would ensure that there is an incentive for selective fishing. One measure implemented under Norwegian and Icelandic fisheries regulation is to ban discards and require that all species caught are landed whether intentionally targeted or not.

The use of 'trash fish', already used as direct feed in some aquaculture practices has been estimated to be in the range of 5–6 million tonnes per year (Tacon *et al.* 2006). The percentage of 'trash fish' in a total catch can be very high in some areas, for instance, over 60% in the South China Sea and Gulf of Thailand and 30–80% in Vietnam. As such, it has been noted that harvesting large quantities of 'trash fish' likely has negative ecological impact because it creates a void in the food chain and which could eventually lead to reductions in populations of larger, predatory fish species (FAO 2007).

3.3 Sustainability of Aquaculture Utilizing Wild Caught Fish as Feed

Farming Carnivores – A Net Loss of Protein

It is often advocated by the industry that aquaculture will alleviate the pressure on stocks of wild fish in the oceans. This is not the case. Rather, the sustainability of farming some fish species is highly questionable because it results in a depletion rather than an increase in fish supplies as a result of high feed inputs of fishmeal, fish oil or 'trash fish' in the diet. This is particularly the case for carnivorous species. For example, Naylor *et al.* (2000) calculated that carnivorous species including salmon, other marine finfish, and shrimp, require 2.5 to 5 times as much fish as feed (by weight) as the amount of fish produced. Thus, 1 kg of carnivorous fish produced can use up to 5 kg of wild fish in its production. For tuna that is caught wild and then fattened in ranches before harvesting, the conversion efficiency is even lower, with up to 20 kg of fish feed required for each kg of tuna produced (Volpe 2005).

Farming of carnivorous species that require such high inputs of wild fish as feed and produce a net loss of fish supplies cannot be viewed as sustainable. Only if the ratio of input of wild fish as feed to the output of cultured fish is less than one is there an overall net gain in fish. To be classified as sustainable, not only should the conversion ratio of wild fish input to cultured fish output be less than one, but also the wild caught fish used as feed must come from fisheries that are sustainable.

It has been suggested that, if the expanding industry in carnivorous species is to sustain its contribution to world fish supplies, it must cut the inputs of wild fish as feed (Naylor *et al.* 2000), otherwise this farming only adds to pressure on wild stocks which are already fished to their limits or beyond. Fortunately, many types of aquaculture rely more on plant-based foods and do not result in an overall decrease in fish. However, to be sustainable, the plant-based feeds on which they rely must come from sustainable agriculture (see section 4).

Food Security

The issue of diminishing rather than increasing net fish supplies is also one of food security since some species caught for fishmeal or classed by the industry as 'trash fish' can be important for human consumption (FAO 2007). For example, in Southeast Asia and Africa, small pelagic (open water) fish such as those targeted by industrial fisheries are an important staple in the human diet (Sugiyama *et al.* 2004). Demand for such fish is likely to grow as human populations increase, bringing them under further pressure from both aquaculture and direct consumption (Naylor *et al.* 2000). Increased demand for use in aquaculture of high value carnivorous species and/or for livestock feeding has led to increases in prices of 'trash fish' and this may mean that the rural poor can no longer afford to buy it (Tacon *et al.* 2006). Without intervention to prevent this from happening, economics rather than human need will drive the market supply. With these factors in mind, the FAO has recommended that there is a "*need for governments within major aquaculture-producing countries to prohibit the use of' trash fish' or low value fish species as feed for the culture of high value fish or shellfish species, and in particular within those countries where 'trash fish' is consumed directly by the rural poor*" (Tacon *et al.* 2006).
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4. MOVING TOWARDS MORE SUSTAINABLE AQUACULTURE FEEDSTUFFS

As the aquaculture industry has grown, there been a concurrent rapid expansion in aquafeed production (Gatlin *et al.* 2007). The growth and intensification of aquaculture in some countries, together with the increased farming of carnivorous species, has caused a rise in demand for fishmeal and fish oil for such aquafeeds. Further increases in the use of finite fishmeal and fish oil resources for aquaculture could, however, simply be impossible. It is already apparent that industrial fishing of many stocks is unsustainable (see section 3), and the anticipated growth of aquaculture could outstrip supplies of fish for aquafeeds within the next decade. Consequently, it has been recognized for many years by the aquafeed industry that use of more plant-based feedstuffs, rather than fishmeal and fish oil, is essential in the future development of aquaculture (Gatlin *et al.* 2007).

The price of fishmeal has also been an important driving force. It has been noted that as the price of fishmeal increases, there is a considerable incentive for the aquaculture industry to innovate by, for example, substituting with plant-based ingredients (Kristoferssson and Anderson 2006). In recent years, there has also been concern about elevated levels of persistent environmental contaminants present in fish oils, especially chlorinated dioxins (PCDD/Fs) and polychlorinated biphenyls (PCBs). This has increased pressure on feed manufacturers to produce oils with lower levels of these chemicals and thereby created an even greater interest in the use of vegetable oils (Scottish Executive Central Research Unit 2002).

Research on the reduction of fishmeal and fish oil in aquafeeds has focused on identifying and using products that can keep up with aquaculture growth. This has included using plant-based ingredients, single cell proteins, animal by-products and by-products from fish processing and is discussed here.

4.1 Utilization of Plant-Based Products

Plant-based products are, to some extent, therefore already used widely in aquaculture and research is ongoing to investigate their suitability in the diets of individual fish species. The plant products utilized in aquaculture are protein-rich oilseed and grain by-product meals and include soybean, rapeseed, corn gluten, wheat gluten, pea and lupin meals, palm oil, soybean oil, maize oil, rapeseed oil, canola oil, coconut oil, sunflower oil, linseed oil and olive oil (see Tacon *et al.* 2006).

It is important to note that if the use of plant-based feeds in aquaculture is to be sustainable, they must be sourced from agriculture that is sustainable. Among other requirements, sustainable agriculture precludes the use of any genetically modified (GM) crops. The use of GM plants creates its own dangers in terms of food and environmental safety. The process of inserting novel genes into plants or other organisms can cause unintended deletions or re-arrangements of existing genes or change the regulatory function of genes, with unpredictable results; for example, it is possible that new toxins or allergens may be produced. GM crops currently being grown in various parts of the world, including soya, corn and canola, have already caused environmental damage and contamination of conventional and organic crops (Greenpeace and Gene Watch UK 2008).There also remain many unresolved food safety concerns (Greenpeace 2007). Thus, GM plants (or indeed GM fish, which have also been proposed) present additional environmental and health concerns not solutions.

To be suitable for use in aquaculture feeds, plant feedstuffs must fulfill criteria of being widely available and cost-effective to produce, and must provide an adequately nutritious diet so as to produce high-quality fish flesh that will deliver human health benefits (Gatlin *et al.* 2007). Gatlin *et al.* (2007) reviewed various plant feedstuffs that are potential candidates for use by the expanding aquaculture industry. Briefly, the following conclusions were drawn in relation to feedstuffs that held promise:

- **Soybean** (*Glycine max*). Soybean is an oilseed crop. Soybean products are regarded as economical and nutritious feedstuffs and soybean meal is the main form used in aquaculture. However, in order to achieve concentrations of the 10 essential amino acids equivalent to those in fishmeal, a form of processing is required which is not yet economical for large-scale production of aquafeeds.

- **Barley** (*Hordeum vulgare*). Barley is used in feeds for many animal species, but is not yet widely used in aquaculture. However, in its native form it has a good nutrient profile and is likely suitable for aquafeeds. In addition, barley shows considerable promise for aquaculture feed when in the form of a co-product from ethanol production.

- **Canola** (*Brassica rapa*). Canola meal is currently used in Canadian aquafeeds. Canola protein concentrate has been widely tested as a protein source for salmon and trout. It has a protein content similar to that of high-quality fishmeal and, with supplementation, it supports similar growth rates in fish as fishmeal diets. However, canola protein concentrate is not yet widely available for use in aquafeeds and market prices have not been established.

- **Corn** (*Zea mays*). Presently, corn gluten meal is widely used in aquafeeds for several species including salmon, European sea bass, and gilthead seabream at levels generally in the range of 10–15%. The corn gluten is deficient in one essential amino acid which precludes its use at higher concentrations in aquafeed. However, if the protein content of corn gluten were to be made higher by processing, it would be more suitable for aquafeeds although more expensive. Also, research is underway to produce a corn protein concentrate as a co-product from ethanol production which could be a readily available product for aquaculture.

- **Cottonseed** (*Gossypium hirsute*). Cottonseed meal has a high protein content, low market price and, as such, it has huge potential for incorporation in high-protein aquafeeds. Studies on several species have shown that it can be successfully used as a proportion of protein in the diet or even as the sole protein source.

- **Peas/lupin** (*Pisium sativum* and *Lupinus* sp.). Peas and lupin are already under consideration and being used for aquafeeds. Nutritionally speaking, these plants have the potential to replace significant proportions of fish meal protein in aquafeeds and results of studies in fish fed with these plants is favourable.

It must be stressed, however, that plant products can have nutrient profiles that are not entirely suitable for fish and may contain bioactive compounds that are also not favourable. These are commonly referred to as anti-nutritional factors and can preclude the use of plant feedstuffs in diets at high concentrations. Gatlin *et al.* (2007) discussed processing methods which can help in this regard, as well as the possibly of using supplementation where nutrients are lacking. For example, nearly all plants contain phytic acid, a compound which is not digestible by fish. A recent study reported that, to counteract this problem, the enzyme phytase can be supplemented in feeds when they are formulated. This improves utilization of plant based protein by fish, thereby positively effecting their growth (Gabriel *et al.* 2007). It has also been suggested that selective breeding of fish can be used to improve the ability of fish to use plant proteins (e.g. Quniton *et al.* 2007).

Feeding Herbivorous and Omnivorous Species

Tacon *et al.* (2006) reported that the best results to date for utilizing plant feed in aquaculture feed is for herbivorous or omnivorous fish (carps, tilapia, milkfish, channel catfish). Total dietary fishmeal replacement has been possible with these species without negative impacts on growth or feed efficiency. Rearing such species in this way suggests a more sustainable future for aquaculture provided that the feeds themselves are produced through sustainable agriculture.

Feeding Carnivorous Species

For carnivorous fish species, the proportion of fishmeal and fish oil in diets can be reduced by at least 50%, but complete substitution with plant-based ingredients has not been possible for commercial production. The level of fishmeal in diets for salmon is now commonly about 35% while the level of fish oil is about 25% (although these proportions vary somewhat between different countries). Table 4 shows the level of replacement by plant-based feed and animal by-products in the diet of farmed salmon in various countries.

The basic problems encountered in trying to replace all fishmeal and fish oil for carnivorous species are not limited only to concerns regarding anti-nutritional factors, but also include the lack of essential amino acids such as lysine and methionine and of the essential fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Tacon *et al.* 2006; Scottish Executive Central Research Unit 2002). The amino acids which are lacking can be added to the diet. However, EPA and DHA fatty acids are more problematic. Fish is considered to be an important source of DHA and EPA (omega 3) fatty acids in the human diet, but these fatty acids are significantly reduced in fish when they have been fed with plant oils instead of fish oil. Nevertheless, recent research has shown that by using plant oil-based diets during the fish growing phase and switching to fish oil-based diet during the period prior to slaughter, the fatty acid composition that is beneficial to human health is restored in the fish flesh. Use of such finishing diets has been suggested as a suitable way to deliver the required fatty acid content in farmed fish (Pickova and Mørkøre 2007). However, even though fish oil use could be reduced by this method, it seems unlikely that it can be replaced completely.

Recent research suggests that the diet of marine shrimp can be largely replaced by plant-based diets. Amaya *et al.* (2007) reported that Pacific white shrimp (*Litopenaeus vannamei*) could be fed a diet consisting of soy and corn ingredients instead of fishmeal without adverse impacts on shrimp growth. The plant-based diet did, however, contain 1% squid meal and fish oil. The study suggested that further research is needed to evaluate the replacement of fish oil and to evaluate potentially limiting nutrients in such diets. Another study also reported that growth of the Pacific white shrimp fed on an entirely plant-based diet (with no fishmeal or fish oil) was no different from shrimp fed on a fishmeal and fish oil diet (Browdy *et al.* 2006). However, the plant-fed shrimp had lower levels of the same two key fatty acids EPA and DHA. The authors of the study suggested that it would be possible to add supplements to remedy the problem, although it is not known whether this modification to feed would be cost effective. It was also suggested that further research could be conducted into achieving the desired fatty acid content of the shrimp by using finishing diets which contain fishmeal/fish oil and are given for a period shortly before harvesting.

Table 4. Dietary Replacement of Fishmeal and Fish Oil in Farmed Salmon Feed in Various Countries in 2005

Country	Replacement with non-marine forms of dietary protein and lipid (%)	Possible sources of replacement protein and lipid
Canada	≤ 70% protein ≤ 50% lipid	canola meal, pea meal, soybean meal, canola (rapeseed) oil, maize gluten meal, soybean protein concentrate, feather meal, poultry by-product meal, poultry oil and the crystalline amino acids lysine and/or methionine
Chile	≤ 60% protein ≤ 20% lipid	canola meal, soybean meal, rapeseed oil, maize gluten meal, lupin, feather meal, poultry by-product meal, and the crystalline amino acids lysine and/or methionine
Norway	≤ 55% protein ≤ 50% lipid	soybean protein concentrate, soybean meal, corn gluten meal, wheat gluten, rapeseed oil, and the crystalline amino acids lysine and/or methionine
UK	≤ 45% protein ≤ 5–10% lipid	maize gluten, soya products (mostly extracted), wheat gluten, rapeseed oil, and crystalline amino acids

Source: Tacon (2005).

4.2 Utilization of Single Cell Proteins (SCP) and Microbial Flocs

So-called 'single cell proteins' are comprised of bacteria, yeasts and unicellular and filamentous algae. Single cell proteins offer the potential to produce proteins to replace fishmeal or the production of essential fatty acids using fermentation processes. For example, there has been some research on the production of essential fatty acids from algae and micro-organisms known as thraustochytrids (see Wilding *et al.* 2006). According to Tacon *et al.* (2006), relatively few studies have been carried out on the replacement of fishmeal with single cell proteins in fish diets. Further research is needed, although single cell proteins hold promise because they can be produced from renewable resources, agricultural wastes and even petrochemical waste streams, and provide a high protein content which generally does not contain anti-nutrients (Tacon *et al.* 2006).

During the 1990's, methods were developed to use little (minimal) or no (zero) water exchange in aquaculture. This practice has become a standard for some aquaculture (Conquest and Tacon 2006; Wasielesky *et al.* 2006). Such systems allow for the build up of suspended 'floc' material (known as microbial floc or biofloc) which is composed of phytoplankton, zooplankton, bacteria, protozoans, micro-algae and detritus (Conquest and Tacon 2006, Serfling 2006). The microbial floc can be maintained by the addition of carbonaceous compounds.

Microbial flocs have a major advantage of mediating water quality by reducing levels of ammonia and nitrate and can eliminate the need to use costly bio-filters (Avnimelech 2006). Secondly, flocs provide an additional feed source for the species being farmed (Conquest and Tacon 2006). Research has shown that microbial flocs contain essential amino acids at ample levels, and vitamins and trace metals at levels which negate the need to add these ingredients to feeds (see Avnimelech 2006).

Shrimp and tilapia have been successfully farmed in systems using microbial floc as a supplementary feed source in greenhouse covered systems. For example, in 10 years of farming tilapia in which the fish used microbial floc as a natural food, no disease problems occurred and no effluent was discharged off-site (Serfling 2006). Other research has shown that tilapia grew better, seemingly because they could feed on floc in between their routinely given aquaculture feeds (Avnimelech 2006). For shrimp, research has shown that microbial floc can be a significant nutrient source and supplement a higher protein diet (Wasielesky *et al.* 2006). Moss *et al.* (2006) noted that the use of microbial floc in minimal or zero-water exchange systems can minimize shrimp diseases and enable growth of shrimp at high densities, while negating the need for a biofiltration system to control the build up of toxic nitrogenous compounds.

The use of minimal or zero water exchange system technology is currently out of the financial reach of many rural small-scale farmers who rely on extensive aquaculture techniques. However, research has recently been carried out on the utilization of biofloc in rural ponds which are used in the extensive aquaculture of shrimp (Verdegem *et al.* 2006). Tapioca flour was added as a carbohydrate source to maintain biofloc. Results showed that biofloc maintained by the carbohydrate source reduced nitrogenous wastes, increased shrimp yields and reduced feed costs.

4.3 Utilization of Fish Trimmings and Other Fish By-products

When fish for human consumption is filleted and processed for the market, more than half the fish is considered waste. Such fish trimmings can be used in the production of fishmeal by the aquaculture industry. In 2002, it was estimated that about 33% of the raw material supplied to the fishmeal and oil sector in Europe came from fish trimmings (Huntington 2004b). It has been estimated that the use of fish trimmings, or processing scraps from sustainable fisheries, could produce marine protein and oil yielding up to 20% of the world supply (Hardy 2007).

In some cases, the organic aquaculture sector is utilizing fish trimmings as feed. For example, certification of organic Scottish salmon by the Soil Association specifies that all of the fishmeal, and the majority of the oil, comes from trimmings of fish caught for human consumption (Raven 2006).

The use of fish trimmings from fish caught for human consumption can be seen as more sustainable than using normal fishmeal in that a waste product is being used. However, unless the fishery from which the fish trimmings come is itself sustainable, the use of fish trimmings cannot be seen as sustainable because it perpetuates the cycle of over-exploitation of fisheries.

A recent study investigated the use of fish processing by-products (fish bone and crab by-product meal) in the diet of Atlantic cod (*Gadus morhua*) (Toppe *et al.* 2006). Results from the study showed that these products could be successfully used as ingredients in the fish diet.

4.4 Utilization of Other Marine-Based Products

Wilding *et al.* (2006) discuss the potential for the use of non-fish marine feed sources for salmon farming feeds including krill, copepods, mussels, worms and marine plants.

Krill were identified as having potential as an aquaculture feed. The Antarctic krill fishery is currently the largest fishery for krill (Wilding *et* *al.* 2006). However, there are ecological concerns with the use of Antarctic krill because they are a key species in Southern Ocean food webs supporting, for example, penguins, albatrosses, seals and whales. Furthermore, krill abundance has been reported to have declined significantly in recent years, most likely as a result of climate change (Atkinson *et al.* 2004; Moline *et al.* 2004; Fraser and Hoffmann 2003).

Copepods are crustaceans for which over 12,000 marine species have been described. They are dominant members of zooplankton communities (tiny animals living near the sea surface), but many also live near the seafloor. There is interest in culturing copepods to act as a living food source for larval fish. For more bulk production, there is also interest in developing a fishery for copepods in the North Atlantic, although there are both technological problems in harvesting sufficient quantities (Wilding *et al.* 2006), and ecological concerns because copepods play a vital role in marine food webs.

It is possible that mussels could be used to provide an alternative source of protein for salmon though further research is needed to assess their suitability. Mussel farming generates some wastes including small, cracked or heavily fouled mussels. It has also been suggested that mussels could be grown alongside salmon farms in integrated multi-trophic aquaculture systems (see section 5) which would provide additional sites for their growth (Wilding *et al.* 2006).

Marine ragworms (*Nereis virens*) and lugworms (*Arenicola marina*) are cultivated in the UK for fishing bait though culture is now being expanded into aquaculture feeds, particularly for shrimp and finfish broodstocks (animals kept for breeding purposes). Research is being conducted into the partial replacement of fishmeal in diets of cod, trout and cobia (Wilding *et al.* 2006).

Seaweeds are cultivated for direct human consumption as well as other purposes. Research on the use of seaweed in farmed fish diets is scarce. A few studies have shown that its inclusion at a proportion of 5% is possible, but may have deleterious effects on growth and performance at higher levels (Wilding *et al.* 2006).

5. MOVING TOWARDS MORE SUSTAINABLE AQUACULTURE SYSTEMS

In order for aquaculture operations to move towards sustainable production, the industry needs to recognise and address the full spectrum of environmental and societal impacts caused by its operations. Essentially, this means that it will no longer be acceptable for the industry to place burdens of production (such as the disposal of waste) onto the wider environment.

In turn, this implies moving towards closed production systems. For example, in order to prevent nutrient pollution, ways can be found to use nutrients present in waste products beneficially. Examples include integrated multi-trophic aquaculture (IMTA), aquaponics and integrated rice-fish culture.

In the IMTA system, the waste products and nutrients of fed species (finfish or shrimp) are utilized as food by other species which function at a different level of the food chain (trophic level). Economically important species which fall into this category include plants, such as seaweed, and shellfish. In such a system, these are referred to as extractive organisms because they derive their nourishment from the surrounding environment (Neori *et al.* 2004). In an IMTA system, seaweeds extract the dissolved inorganic nutrients while shellfish extract particulate organic matter (Chopin 2006b). In essence, IMTA systems aim to balance waste production and extraction and thereby mimic natural ecosystem functions as much as possible (Neori *et al.* 2007; Neori *et al.* 2004).

Modern IMTA systems have been developed using ideas from traditional aquatic polyculture, defined as the culture of more than one species together. The difference between the systems is that IMTA requires the cultivation of species from different levels of the food chain, thereby reducing waste products, whereas polyculture can involve the co-cultivation of any species. Some aquatic polyculture has been practiced in China for millennia, such as the co-cultivation of rice and fish (Neori *et al.* 2004). Today, some Asian marine polyculture in coastal waters can be classified as IMTA since it uses wastes from fish cages to enhance the growth of adjacent cultures of shellfish and seaweeds (see Neori *et al.* 2007).

Species involved in IMTA systems include fish or shrimp integrated with vegetables, microalgae, shellfish and/or seaweeds (Neori *et al.* 2004). IMTA can be set up in coastal waters, in ponds or in land-based systems and can be highly intensified (Chopin 2006b; Neori *et al.* 2004). Land-based systems which use waste products of fish/shrimp culture as fertilizer for growing vegetables, known as aquaponics, is a variation of the IMTA concept.

It has been suggested that seaweed-based IMTA systems offer a more sustainable way forward for mariculture (marine aquaculture). Seaweeds filter waste nutrients from fish/shrimp culture (particularly carbon, nitrogen and phosphorous) and add oxygen to the seawater, thereby restoring water quality. Seaweeds can be cultured for food or other uses and can also act as a nutrient source for other co-cultured species such as abalone and sea urchins. The growth of seaweed on mariculture effluents has been reported to be superior to that on fertilizer-enriched clean seawater. Because ecological harm can be caused by the introduction of non-native species it is important that the seaweed used in IMTA systems should be a native species. Ideally the seaweed would be a species that would be of ecological value, in terms of removing excess waste products, as well as of economic value (Neori *et al.* 2004).

The use of IMTA systems is likely to become a way of negating costs for the 'polluter pays' charges. For example, Denmark is reconsidering more finfish aquaculture development only on the condition that there is adequate planning for bioremediation and use of bio-filters (seaweed and shellfish). In other words, the use of extractive species is now a necessity for the license to operate in Denmark (Chopin 2006b).

5.1 Examples of IMTA Systems

Examples of some experimental IMTA systems in commercial operation are given below. A more extensive list, which includes IMTA systems under development, is given in appendix 1.

- SeaOr Marine Enterprises on the Israeli Mediterranean coast is a modern, intensive, land-based mariculture farm which cultivates marine fish (gilthead seabream), seaweed (*Ulva* and *Gracilaria spp.*) and Japanese abalone. Effluent waste from the fish culture is utilized for growth by the seaweed. In turn, the seaweed is fed to the abalone (Neori *et al.* 2004).

- Aquaponics involves using the effluent of fish farming as a nutrient source for growing vegetables, herbs and/or flowers. This negates the cost of a bio-filter used for other recirculating aquaculture systems and is more environmentally sustainable. Development of aquaponic technolgy since the 1980s has resulted in viable systems of food production. Plants such as lettuce, herbs, watercress, spinach, tomatoes and peppers are produced hydroponically (without soil, in a water medium) in greenhouses. In North America, the most common form of aquaponics farms freshwater tilapia (Diver 2006). Neori *et al.* (2004) gives examples of a farm producing tilapia and lettuce in US Virgin Islands and a farm producing tilapia and vegetables in Nova Scotia, Canada. A company in the Netherlands called 'Happy Shrimp' partially utilize waste from the farms for vegetable growing. The shrimp are fed on algae and bacteria as well as aquaculture feed containing a high proportion of plant protein. Unlike most shrimp farms, the feeding regime means that the ratio of input of fishmeal as feed to output of shrimp is less than one (1: 0.85). The shrimp are cultivated in greenhouses and no shrimp seed is extracted from the wild. (Happy Shrimp 2007).

When the fish being farmed in IMTA systems are carnivorous and require feeding with fishmeal, fish oil, or 'trash fish' the sustainability of this aquaculture is called into question. Common sense dictates that it is important that there is a shift towards the cultivation of omnivorous or herbivorous species which do not require fish-based feeds and that these are co-cultured in IMTA systems in which effluent wastes are controlled and utilized beneficially (by, for instance, seaweeds, vegetables and shellfish). It is therefore clear that, in order to expand sustainably, the industry needs to expand research and development on herbivorous and omnivorous fish (such as carps, tilapias, milkfish, gray mullet, and catfish). Ideally, sustainable IMTA aquaculture would aim to develop closed systems, as open water systems still carry a risk of nutrient pollution.

5.2 Integrated Rice–Fish Culture

Another promising form of aquaculture is the production of fish in rice fields, known as integrated rice-fish culture. This system optimizes uses of land and water and is benefited by synergies between fish and plant (Frei and Becker 2005). Rice-fish culture in China dates back to 220 AD and today is also practiced in Egypt, Indonesia, Thailand, Vietnam, Bangladesh and Malaysia among other countries. However, the extent of its use is presently rather marginal. It is important to note that integrated rice–fish culture is crucial for local food security rather than representing a method for supplying export markets to supermarkets in developed countries.

The most commonly used species used in rice–fish farming are common carp (*Cyprinus carpio*), Nile tilapia (*Oreochromis niloticus*) and silver barb (*Barbonymus gonionotus*), although numerous other species are also used. Due to the fertilizing effect of the fish excrement, it can be expected that there will be similar or slightly increasing rice yield compared to monocultures of rice. The practice of integrated rice–fish culture has been shown to be undeniably profitable by farmers. The practice has environmental benefits because effluents from the fish are absorbed as nutrients by the rice plants and therefore do not become problematic. Furthermore, a large portion of their feed requirement is derived from the natural environment. The demand for fish feed is therefore less than for other forms of aquaculture (Frei and Becker 2005).

There are a number of constraints preventing the expansion of rice–fish culture. These include a lack of education for farmers, education which is needed to attain the necessary skills in fish-culture management. It has therefore been suggested that policy makers need to provide much more active support to integrated rice–fish culture using, for example, education and extension programmes, or by providing the necessary infrastructure (Frei and Becker 2005).

6. AQUACULTURE CERTIFICATION

The growth of aquaculture has led to concerns relating to environmental impacts, social issues, food safety, animal health and welfare or economic and financial issues (FAO 2007c). The industry and market have responded by establishing certification schemes in order to assure buyers, retailers and consumers. Presently, there are at least 30 certification schemes which could be relevant in some way to aquaculture (Funge-Smith *et al.* 2007). Since a wide range of certification schemes or accreditation bodies are appearing, there is a risk of confusion for both producers and consumers (FAO 2007c). Moreover, it is questionable whether any certification scheme to date is comprehensive in all relevant aspects.

Certification itself may be defined as "*a procedure by which a third party gives written or equivalent assurance that a product, process or service conforms to specified requirements*". (Funge-Smith *et al.* 2007). The fact that certification needs to be undertaken by an independent third party (a person or body that is recognized as being independent of the parties involved, as concerns the issue in question) is essential for it to be robust and credible (FAO 2007c). If, for example, certification was undertaken by the aquaculture industry, for the aquaculture industry, it could not be considered to be a credible certification scheme.

The World Wildlife Fund (WWF) has very recently published a study which assesses 18 different certification programmes for aquaculture in terms of their credibility on environmental impacts, social issues and animal welfare (WWF 2007). The report sets out benchmark criteria on these issues which are deemed to be comprehensive and essential for environmental, social and animal welfare. It quantifies how the different certification schemes measure up to the criteria by using a scoring system. The WWF report goes on to appraise the final scores by looking at the compliance level wherein

(1) a high compliance (recom-mended as a 'better choice') is given to scores in a given criteria of at least 83%,
(2) a medium compliance (recom-mended as 'needs improvement') is given to scores in a given criteria of at least 50%, and
(3) a low compliance (recommended as 'serious shortfalls) is given to scores in a given criteria of below 50%.

The WWF report was a desk-top study which did not include any on-site evaluations or field studies. The following section discusses how a number of well-known certification programmes scored according to the WWF study. In some cases, other information is also given on certification programmes to give a more complete picture.

6.1 Certification Programmes

HACCP

Some certification schemes address issues of food safety by specifying standards of good management, sanitary and safe conditions of production. One regulatory system developed by the FAO is called Hazard Analysis and Critical Control Point (HACCP). It has been incorporated in the legislation of many importing countries of fish products, especially the United States and Europe (Spreij 2001). The HACCP approach is internationally accredited as a way of ensuring the safety and suitability of food for human consumption and increases the potential for international trade (Whitehead and Orriss 1995). HACCP does not take into consideration environmental impacts and social impacts of aquaculture and was not assessed in the WWF report.

GLOBALGAP
Integrated Aquaculture Assurance

GLOBALGAP, previously known as EUREPGAP, is a private sector body that publishes voluntary standards for the certification of agricultural products (including aquaculture) around the world. GLOBALGAP started in 1997 and is a partnership of agricultural producers and their retail customers. GLOBALGAP aims to develop standards and procedures for the global certification of Good Agricultural Practices (GAP). The GLOBALGAP standard was developed using HACCP guidelines. With regard to aquaculture, GLOBALGAP has developed the Integrated Aquaculture Assurance Standard (IAA), also using HACCP. Within the IAA standard is a species-specific standard for salmon which deals with food safety, worker health and safety and the management of chemicals and medicines management (EUREPGAP 2005).

According to the WWF assessment, GLOBALGAP Integrated Aquaculture Assurance scored very poorly on both environmental issues (30%) and social issues (22%). For example, the programmes had no regulation for using sustainable sources of fishmeal and fish oil, no regulation on excluding GM organisms (GMO) in feedstuffs, insufficient regulation on exclusion of farming operations from sensitive habitats, insufficient regulation on effluent discharges, and insufficient measures to protect against new introduction of non-native species. With regard to social issues there was no regulation of labour rights or on community impacts and resource rights. Because of their very poor scores, the certification programme was classified as having serious shortfalls on environmental and social issues though the certification programme did score more highly on animal welfare issues (89%).

Aquaculture Certification Council

The Global Aquaculture Alliance (GAA) was formed by the aquaculture industry and has developed a series of standards for aquaculture, predominantly shrimp. It has a certification body, the Aquaculture Certification Council (ACC), which certifies products to the GAA standards. However, the ACC has previously come under criticism because it is not fully independent from the GAA (i.e. it is not a true third party) and, therefore ACC certifications have reduced credibility (Environmental Defense, Monterey Bay Aquarium, WWF 2006).

The WWF assessment of the ACC gave low scores for environmental issues (46%), social issues (56%) and animal welfare (56%). For example, on environmental issues there was insufficient regulation to prevent escapees or the transfer of diseases and parasites, no regulation to prevent new introduction of non-native species, a lack of regulation on sourcing juveniles from the wild, insufficient regulation on the protection of local wildlife and no regulation on using more sustainable sources of fishmeal/oil in feeds. On social issues there was a lack of labour standards.

Friend of the Sea

Friend of the Sea is an Italian-based certification scheme promoted by the Earth Island Institute, an independent humanitarian and environmental organisation. In the WWF assessment of its aquaculture certification programme, Friend of the Sea scored low on environmental issues (49%), social issues (11%) and animal welfare issues (22%). For example, on environmental issues there was insufficient regulation on deforestation and restoration of mangroves, insufficient regulation on effluent discharges, and no regulation on prevention of transfer of disease and parasites. On social issues, there was no regulation on labour rights or on local land conflicts and land rights.

Naturland

Naturland is a major certifying organisation for organic agriculture and also has a certification scheme for organic aquaculture, certifying shrimp, salmon, tilapia and some other marine finfish (WWF 2007). In the WWF assessment, Naturland scored 69% on environmental issues, 100% on social issues and 94% on animal welfare issues. Shortfalls on environmental issues included no regulation regarding energy sources and no indicator for measurable improvements in effluent discharge, while non-native, newly introduced species were generally allowed. On social issues no shortfalls were identified. However, a study undertaken by the Swedish Society for Nature Conservation in 2004 in Ecuador identified social problems for local communities living near to a Naturland certified farm (Swedish Society for Nature Conservation 2004). Local residents had lost their normal access routes to fishing sites, lost land rights and lived in fear of the armed guards at the farms. The study also raised the concern that the farms may have been sited illegally in mangrove forest. Prior to this study, the Swedish Society for Nature Conservation also found that Naturland's eco-labelling criteria were not being totally adhered to in practice at Indonesian shrimp farms (Rönnbäck 2003).

Soil Association

The Soil Association is a UK based organization which campaigns on and certifies organic agriculture. It also certifies some organic aquaculture including salmon, shrimp and arctic charr (WWF 2007). The soil association certification had a high level of compliance on environmental issues (83%) in the WWF assessment, a high level of compliance on animal welfare (100%) but a lower compliance on social issues (61%). Shortfalls on environmental issues included non-native, newly introduced species were not excluded and no indicator for measurable improvements of effluent discharge. For social issues, there was a lack of regulation with regard to community land rights and regulation on labour rights only took the form of a recommendation rather than a regulatory measure.

Commenting on all 18 certification bodies that were analysed by the WWF assessment, the authors suggested that presently available aquaculture standards do have shortfalls and there is a lot of room and potential for improvements in almost all aquaculture certification standards (WWF 2007). Generally, organic aquaculture standards performed better than non-organic schemes. In relation to the environment, there were major shortcomings in relation to protection of sensitive habitats, regulation of effluent discharges, introduction of non-native species, prevention of escapes, use of GM species and general impacts on local wildlife. In regard to the use of fishmeal and fish oil as aquaculture feed, organic schemes were the only ones which required these ingredients to come from sustainable fisheries or from offcuts and by-products from fish processing plants. On social issues, many bodies did not even address basic labour rights (WWF 2007).

An earlier study which reviewed certification in aquaculture (Macfadyen 2004) suggested that, for social issues, Fair Trade schemes may be of significance in developing countries. By definition, fair trade should be fair and sustainable in terms of both social and environmental aspects.

On a cautionary note, representatives of local communities, NGOs, social movements and researchers from 17 countries of Africa, Asia, Europe, Latin America and North America recently met to address the continuing expansion and associated impacts of industrial shrimp aquaculture. In the light of the continued failure of certification bodies adequately to address these impacts, or involve local communities in developing standards, the meeting stated that,

"*We, therefore urge consumers, retailers, NGOs and governments to reject all the certification schemes developed thus far and those currently in development*" (Lampung Declaration Against Industrial Shrimp Aquaculture 2007).

6.2 Voluntary Guidelines on Standards for Aquaculture

The FAO have published draft guidelines which are designed to be used for the purposes of aquaculture certification (FAO 2007c). The guidelines were formulated in response to the need for globally accepted norms for standards development and consensus about how credible certification schemes should be verified. The guidelines apply to the planning, development and operation of aquaculture systems, sites, facilities, practices, processes or products.

The guidelines comprehensively outline the need for aquaculture to be socially responsible, such that it delivers net benefits to the local community, there are fair working conditions and, labour rights are respected. The guidelines list environmental impacts of aquaculture that should be addressed by certification in line with their previous guidelines on aquaculture in the Code of Conduct for Responsible Fisheries. The guidelines also give advice on food safety, animal health and welfare, and economic and financial issues. Any certification process, as an absolute minimum, needs to conform to all of these FAO guidelines.

With regard to shrimp farming, a consortium consisting of the FAO, the Network of Aquaculture Centres in Asia Pacific (NACA), the Coordination Office of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities of the United Nations Environment Program (UNEP/GPA), the World Bank (WB) and WWF, recently published, "*International Principles for Responsible Shrimp Farming*" (FAO/NACA/UNEP/WB/WWF 2006). The aim of the publication was to provide a basis on which stakeholders can collaborate for a more sustainable development of shrimp farming. It outlines in detail important environmental and social principles for obtaining more sustainable and fairer shrimp farming. The WWF's Centre for Conservation Innovation is also now working on standard development for a number of other aquaculture species including salmon, trout, tilapia and catfish (WWF 2007b).

It is important to note that certification criteria alone will not ensure the sustainability of the aquaculture industry worldwide. In order to do so, a more fundamental rethink and restructuring of the industry is essential (see section 7).

7. RECOMENDATIONS

Any aquaculture that takes place needs to be sustainable and fair. For aquaculture systems to be sustainable, they must not lead to natural systems being subject to degradation caused by:

1. an increase in concentrations of naturally occurring substances

2. an increase in concentrations of substances, produced by society, such as persistent chemicals and carbon dioxide

3. physical disturbance.

In addition people should not be subject to conditions that systematically undermine their capacity to meet their basic needs for food, water and shelter.

In practical terms, these four conditions can be translated into the following recommendations.

Use of Fishmeal, Fish Oil and Trash Fish: To reduce the pressure on stocks caught for fishmeal and fish oil, there needs to be a continued move towards sustainably produced plant-based feeds. Cultivating fish that are lower down the food chain (herbivores and omnivores rather than top predators) that can be fed on plant-based diets is key to achieving sustainable aquaculture practices. Industry must expand its research and development on herbivorous and omnivorous fish which have strong market potential and suitability for farming.

In more general terms, there is an urgent need for fisheries management to shift towards an ecosystem-based approach wherein a global network of fully protected marine reserves covering 40% of the oceans is established, together with sustainable fisheries management outside of the reserves (Roberts *et al.* 2006). This is key to achieving sustainable fisheries.

Greenpeace considers the culture of species that require fishmeal or fish oil-based feeds derived from unsustainable fisheries and/or which yield conversion ratios of greater than one (i.e. represent a net loss in fish protein yield) as unsustainable. Plant-based feeds should originate from sustainable agriculture, and sources of omega 3 should be algal derivatives, grape seed oils, etc.

Nutrient Pollution and Chemical Pollution: To reduce nutrient wastes, there is great potential for the development of integrated multi-trophic aquaculture (IMTA) systems, aquaponics and integrated rice-fish culture.

Greenpeace considers aquaculture that results in negative environmental impacts in terms of discharges/effluents to the surrounding environment as unsustainable.

Escapes of Farmed Fish to the Wild: To overcome these problems it has been suggested that enclosed bag nets or closed wall sea pens should be used to prevent fish from escaping or that land-based tanks should be used (Naylor and Burke 2005). Ultimately, land-based tanks are the only option if the goal is to eliminate any risk of escapes which might otherwise occur as a result of hurricanes or other extreme weather events at sea. It is crucial to use native rather than exotic species (Pérez *et al.* 2003).

Greenpeace recommends that only species which are native should be cultivated in open water systems, and then only in bag nets, closed wall sea pens or equivalent closed systems. Cultivation of non-native species should be restricted to land-based tanks.

Protection of Local Habitat: Some aquaculture practices have had serious negative impacts on local habitat. Aquaculture practices must be set up in a way that provides for protection of coastal ecosystems and local habitats. In addition, no new aquaculture practices should be permitted in areas that are to be designated as marine reserves and any existing aquaculture operations within such areas should be phased out.

Greenpeace considers aquaculture which causes negative effects to local wildlife (plants as well as animals) or represents a risk to local wild populations as unsustainable.

Use of Wild Juveniles: The use of wild-caught juveniles to supply aquaculture practices, particularly some shrimp aquaculture, is destructive to marine ecosystems.

Greenpeace considers aquaculture which relies on wild-caught juveniles as unsustainable.

Transgenic Fish: The physical containment of genetically engineered fish cannot be guaranteed under commercial conditions and any escapes into the environment could have devastating effects on wild fish populations and biodiversity (Anderson 2004).

Greenpeace demands that genetic engineering of fish for commercial purposes should be prohibited.

Diseases: *Greenpeace recommends cultivation at stocking densities that minimise the risk of disease outbreaks and transmission and, therefore, minimise requirements for therapeutic treatments.*

Resources: *Greenpeace considers aquaculture that depletes local resources, for example, drinking water supplies and mangrove forests, as unsustainable.*

Human Health: *Greenpeace considers aquaculture that threatens human health as unfair and unsustainable.*

Human Rights: *Greenpeace considers aquaculture that does not support the long-term economic and social well-being of local communities as unfair and unsustainable.*

APPENDIX 1

Examples of IMTA Systems

- Research has been taking place since 2001 in the Bay of Fundy, Canada on an IMTA system co-cultivating salmon (*Salmo salar*), kelp (*Laminaria saccharina* and *Alaria esculenta*) and blue mussel (*Mytilus edulis*) (Chopin *et al.* 2007; Chopin and Robinson 2006). Waste products from the salmon production are utilized by the shellfish and seaweed for growth. Study of the system showed that the growth rate of kelp was increased by 46% when cultured in proximity to the fish farms, while the growth rate of mussels increased by 50%.The increased growth rates are indicative of the increase in food availability and energy next to the salmon farms. Research showed that, with proper management, the mussels and seaweeds from the IMTA system can be safely used for human consumption (Chopin *et al.* 2007). The next step in the operation is scaling up for commercial use, which is presently ongoing. It is expected that, by 2011, ten salmon farms will have been converted to IMTA systems for salmon, kelp and mussels (Chopin 2006a). Calculations show that 80% of the salmon farms in New Bruswick, Canada, are suitable for IMTA and that applying the system would generate extra revenue as well as creating more jobs. It is recognised by the researchers that the co-culture of salmon, kelp and mussels is a simplified system and there is space for including other species with different functions in the development of more advanced systems. Species such as sea cucumbers, polychaetes and sea urchins may also be included (Chopin 2006b).

- Research is being conducted into IMTA mariculture systems in open water in the UK by The Scottish Association of Marine Science (SAMS). Studies involve investigation of the growth of seaweed alongside fish farms and the culture of shellfish (scallops/oysters), sea urchins and abalone (SAMS 2007). Results to date on growth of seaweeds alongside salmon farms indicate that yields of *Laminaria saccharina* and *Palmaria palmata* were enhanced by 50% and 63% respectively when cultured in proximity of fish farms, compared to sites away from the farms (Sanderson 2006). Ecomonically, growth of *P. palmata* for the edible market may at worst, be cost neutral and could be used as feed for abalone and urchins. *L. saccharina* is being tested for use in the pharmaceutical industry.

- In Chile, research has demonstrated that at least two species of seaweed (*Gracilaria chilensis* and *Macrocystis pyrifera*) can be successfully grown in proximity to salmon farms (Buschmann *et al.* 2007). The demand for *Macrocystis* is increasing for abalone feeding, but the market value for *Gracilaria* does not yet permit its commercial scaling.

- In north China, no seaweed is commercially cultivated in coastal waters in the warm season from late spring to early autumn. In order to fill this gap, research was carried out to test the feasibility of growing seaweed commercially alongside open-water coastal marine fish culture in an IMTA system (Zhou *et al.* 2006). The seaweed *Gracilaria lemaneiformis* was co-cultivated with rockfish (*Sebastodes fuscescens*). The seaweed effectively reduced nutrient wastes from fish culture and grew fast enough to be of considerable market value.

  SEAPURA, or “Species Diversification and Improvement of Aquatic Production In Seaweeds Purifying Effluents from Integrated Fish Farms”, is a European Union project. It has involved the testing of many seaweed species alongside fish farms to determine their suitability in IMTA systems (Santos 2006; SEAPURA 2007)

- Acccording to Neori *et al.* (2007), commercial pond farms for seaweed–abalone, or, micro-algae–shellfish presently exist in Australia, China, Israel, South Africa, and Thailand and some utilize waste from fish farms.

- Research has been carried out in a number of countries on the use of effluent from shrimp farms to grow seaweed. For example, in Hawaii, Nelson *et al.* (2001) devised a successful system of growing red seaweed (*Gracilaria parvispora*) using effluent from a commercial shrimp farm. The seaweed was grown in ditches filled with the effluent and later transferred to a lagoon for the finishing stages of growth. The system was in commercial use for several years but ended after some disagreements between people involved (S. Nelson, personal communication).

- 'Sealand Sole' is the name given to a pilot project on IMTA in the Netherlands. The project is investigating the land-based production of sole (*Solea solea*) in a system which co-cultures ragworms (*Nereis virens*), shellfish and saline crops. The intention is to farm the sole and ragworms in outdoor ponds in which the ragworms provide a live food source for the fish as well as being harvested as an high-value ingredient for aquaculture feeds. The feed supplied to the ragworms will also promote algal growth which, in turn, will be used as feed for both ragwoms and shellfish. Resulting nutrients in the pond will serve as a fertilizer for saline crops (Ketelaars 2007).

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