FARMING THE SEA, COSTING THE EARTH

Why we must green the blue revolution

A report by the Environmental Justice Foundation

This report is one of a series documenting EJF's international investigations into the social, economic and environmental impacts resulting from shrimp production and consumption.

More information about EJF's shrimp campaign, and PDF versions of this and other reports in the series, can be found at:

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What's in a name?
Some people use the terms *shrimp* and *prawn* interchangeably – EJF makes no distinction between the two.

FARMING THE SEA, COSTING THE EARTH

Why we must green the blue revolution

Photo © Greenpeace

CONTENTS

EXECUTIVE SUMMARY

Shrimp farming has been heralded as part of a 'Blue Revolution', capable of providing food whilst allowing wild stocks to recover from over-fishing. The industry has experienced spectacular growth in recent years. Today, farmed shrimp account for about one third of global consumption of shrimp, having a retail value of US$50–60 billion. Mounting evidence raises serious concerns over the environmental and economic sustainability, as well as social equity, of large parts of the shrimp farming industry.

Shrimp are farmed in over 50 countries with 99% of production coming from developing nations. Of this, the vast majority is exported to the USA, EU and Japan. Environmental problems associated with shrimp farming have been reported from all major producers.

Concentrated mostly in developing countries in the tropics, export-oriented shrimp culture has been widely promoted by aid agencies, international financial institutions and governments as a means of reaching development targets and alleviating poverty. Much of this development has been unplanned and unregulated. Serious environmental and socio-economic concerns have been raised and the industry's expansion has been met with strong opposition from some sectors of society.

Shrimp aquaculture has led to the destruction of large tracts of valuable wetlands. In at least 12 countries, wetland Sites of International Importance listed under the Ramsar Convention face threats from shrimp farming. Evidence suggests that shrimp aquaculture has been a major contributor to global mangrove forest loss, and in a number of countries it is considered to be the biggest threat to these ecosystems. Globally, it has been estimated that as much as 38% of recent mangrove loss may be due to shrimp farm development.

Mangrove loss has left coastal areas more exposed to erosion, flooding and storm damage, removed critical habitats for marine and terrestrial species, and led to reduced biodiversity, declines in fisheries, and loss of forest products and ecological services vital to many subsistence economies.

Recently, legislation to protect mangroves has improved, and there have been efforts to promote better practice within the shrimp farming industry. However, in many countries, laws are inadequate or poorly enforced, and the destruction of mangroves for shrimp aquaculture continues.

Other important wetland habitats impacted by shrimp aquaculture include salt flats, salt marshes, mudflats and freshwater wetlands such as grasslands and *Melaleuca* forests. The loss of wetlands and increased levels of pollution from shrimp farm development also threaten adjacent coastal and marine ecosystems, such as seagrass beds and coral reefs. In a number of countries, large areas of agricultural land have been inundated with saline water to create shrimp ponds, directly affecting crop productivity and the health and livelihoods of rural communities.

Shrimp farming produces organic and inorganic waste that pollutes marine and terrestrial environments, and salt-water intrusion associated with shrimp aquaculture can change soil composition. Many chemical inputs used in shrimp farming, including antibiotics, fertilizers, disinfectants and pesticides, are known to have detrimental impacts on the environment and human health.

Shrimp farm productivity is heavily dependent on surrounding wetland goods and services. There is a clear conflict between the need for healthy ecological support systems and ecological degradation as a result of shrimp farming. Although a shrimp farm's ecological footprint will depend on the intensity of farming, for semi-intensive shrimp aquaculture systems it has been estimated to be 35–190 times the size of the farm area. Mounting evidence suggests that conversion of wetland and mangrove aquaculture can be economically detrimental. Recent analysis of a mangrove system in Thailand revealed that the total economic value of the intact mangrove exceeded that of shrimp farming by 70%.

The external economic, social and environmental costs commonly generated by shrimp farming have raised major concerns about the viability and desirability of the industry.

Degraded mangroves, Vietnam. Shrimp aquaculture has experienced spectacular growth over recent years, but has had serious negative environmental and social consequences.

© Thornton / EJF

Shrimp farming can impact wild fish and shrimp populations on a large scale. Habitat destruction, unsustainable bycatch during shrimp fry and broodstock collection, the introduction of non-native species, pathogens and pollutants can all be shown to have negative effects.

Globally, nearly two thirds of all fish harvested depend upon the health of wetlands, seagrasses and coral reefs at key stages in their life-cycle. Shrimp aquaculture is proven to directly threaten these environments. Bycatch rates of shrimp fry fisheries are among the highest of any fishery in the world, with as many as 1,000 non-target individuals harvested for every shrimp fry caught. In Bangladesh alone, an estimated 200 billion organisms of other species are caught during collection of tiger shrimp fry each year. Intensive or semi-intensive shrimp farming frequently requires fishmeal feed inputs derived from fish of more than double the weight of the farmed shrimp produced, increasing pressure on wild fish stocks.

This report concludes that it is imperative that new controls and management strategies are employed to remove the negative environmental impacts of shrimp farming. External costs must be included, taking into full account impacts on ecological and food security, and environmental and economic sustainability. Immediate action is necessary by all stakeholders and specifically governments, the shrimp farming industry, seafood producers, traders and retailers plus aid and development agencies, which together are promoting or indirectly supporting the unsustainable and unethical practices of this industry.

A small price to pay for environmental justice

£5 / $6 per month could help kids get out of the cotton fields, end pirate fishing, protect farmers from deadly pesticide exposure, guarantee a place for climate refugees

This report has been researched, written and published by the Environmental Justice Foundation (EJF), a UK Registered charity working internationally to protect the natural environment and human rights.

Our campaigns include action to resolve abuses and create ethical practice and environmental sustainability in cotton production, shrimp farming & aquaculture. We work to stop the devastating impacts of pirate fishing operators, prevent the use of unnecessary and dangerous pesticides and to secure vital international support for climate refugees.

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EJF ENVIRONMENTAL JUSTICE FOUNDATION

Protecting People and Planet

INTRODUCTION

This report provides detailed evidence gathered over the past three years to show that shrimp farming, as currently practised in many countries, is having serious and widespread negative impacts on environmental security, biodiversity, economic development and food security.

Perhaps most significant among the findings presented here is the fact that shrimp farming – by threatening the well-being of our natural environment – may be undermining long-term economic development and food security. The removal of vital mangrove forests and degradation of other wetland habitats has the potential to devastate marine biodiversity and commercial fish catches. Nearly two thirds of all fish harvested depend at some stage in their life cycle upon these habitats. Furthermore, shrimp farming can directly impact wild shrimp and fish populations through demand for fish-based feeds and wild broodstock and larvae for stocking ponds.

Around one billion people, most of whom live in developing countries, rely on fish and shellfish for their primary source of animal protein. Quite simply, our failure to protect marine and wetland ecosystems and ensure their ongoing health will result in a catastrophic decline in commercial and artisanal fisheries. To allow this to happen is wholly irresponsible – to do so when more than 70% of the world's fish stocks are already overfished or fully exploited[1] is surely madness.

The overriding conclusion EJF reaches in this report is that there is a compelling rationale for immediate action. Policy makers, global financial institutions, development agencies and above all the shrimp industry, retailers and consumers must act now to prohibit the unnecessary and unjustifiable damage that shrimp farming is causing to environments across the world.

Vastly improved management and monitoring are called for, along with an end to the 'get rich quick' approach, which has inspired such chronic short-sightedness and short-termism in the industry. Shrimp farming could provide income and food for local consumption, but only if it is well managed, taking into full account environmental costs and social needs. To achieve this, however, root-and-branch reform across much of the industry is essential.

As the vast majority of global production of farmed shrimp is destined for Western consumers, the major retailers and public who purchase their products have a unique opportunity to exert real influence: demanding products which are produced in an environmentally sustainable way, supporting local communities and the needs of the poor – those whom the Blue Revolution was originally intended to help most.

ABOVE: *Shrimp farms in Bangladesh. Most shrimp farming occurs in developing nations in the tropics. In Asia, the Black Tiger Shrimp (Penaeus monodon) is favoured whilst the White Shrimp (P. vannamei) dominates in Latin America. Shrimp farming is a relatively new phenomenon in Africa, where P. monodon is also farmed.*

© Trent / EJF

BELOW: *Penaeus monodon*, the Black Tiger Shrimp

© Shanahan / EJF

Shrimp Farming: the near history

For many years, the shrimp farming industry has been promoted as part of a 'Blue Revolution', offering 'food for the hungry' while reducing the pressure on wild shrimp populations and curbing the impacts of trawling[2]. Recently, shrimp farming has experienced spectacular growth. Annual production in 2000 was valued at over US$6.8 billion at the farm gate and US$50–60 billion at retail[3]. Today, farmed shrimp make up around one third of shrimp consumed[3], compared to just 5% in the early 1980s[4]. Shrimp are farmed in over 50 countries, with an estimated 99% of production coming from the developing world[5]. In a few countries, such as Malaysia and China[6], up to 50% of farmed shrimp are consumed domestically, but for most of the leading producers, shrimp are farmed for export, mainly to Europe, the USA and Japan.

Penaeus vannamei.

© Shanahan / EJF

Shrimp trawler.

© William B Folson, NMFS / NOAA

Trawling: an alternative to shrimp farming?

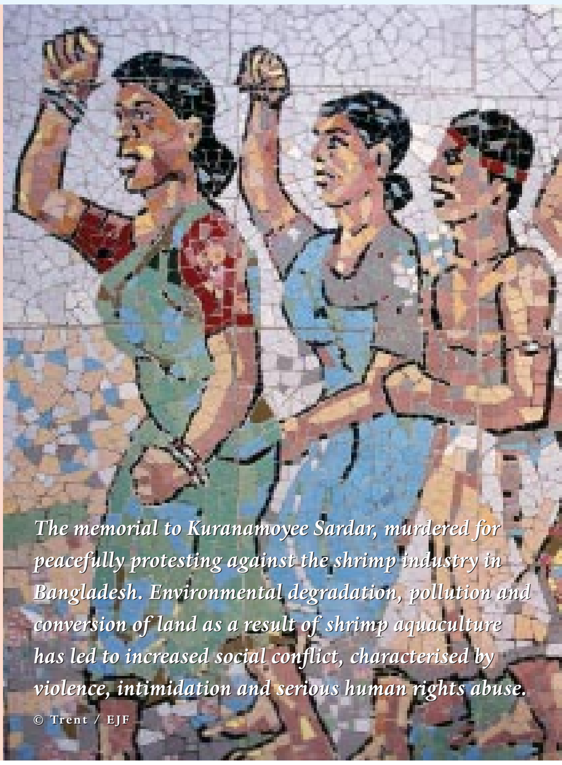
Demand for shrimp has traditionally been met by trawling, one of the world's most unselective and wasteful fishing methods.Shrimp fisheries produce only 2% of global seafood yet account for one third of the total discarded catch[7]. Apart from devastating ecological impacts, the capture of non-target species has also had serious effects on many commercial fish stocks, causing unemployment and deprivation in the fishing industry and coastal communities[8]. Scientists also believe that populations of endangered species such as seahorses[9] and sea turtles[10] are declining rapidly due to shrimp trawling: it is estimated that over 150,000 turtles are killed annually by shrimp trawlers[11]. The process of trawling for shrimp seriously disturbs seabeds, and has been compared to destruction and wholesale removal of the world's forests. Recent research has shown that the pass of a single trawl can remove up to 25% of seabed life, destroying marine habitats on which many species depend[12].

Impacts of trawling are discussed more fully in EJF's companion report, *Squandering the Seas: How shrimp trawling is threatening ecological integrity and food security around the world*[8], available online at http://www.ejfoundation.org.

Farmed Shrimp: the human cost

Shrimp farming offers a good example of the way that environmental security and human rights are inextricably linked. For many poor coastal communities, the advent of shrimp farming has led to loss of livelihoods and to other abuses. Shrimp farms can physically block access to coastal and estuarine resources, impacting fisherfolk and traditional harvesters of mangrove and wetland products; this may be exacerbated by the uncertainty of property rights in wetland areas, resulting in the loss of livelihoods for those who have used the land under *de-facto* or customary law[12]. Furthermore, mangrove deforestation reduces local food security as fish and shellfish catches decline. Pollution of land and water due to shrimp farming further impact lives and livelihoods. Other abuses associated with the industry include illegal land seizure, exploitative child labour and hazardous conditions in processing plants. Shrimp farming has been characterised by corruption, intimidation and violence, and there have been murders linked to the industry in at least 11 countries.

These social impacts, along with serious human rights abuses associated with shrimp farming, are detailed in EJF's companion report, *Smash and Grab: conflict, corruption and human rights abuses in the shrimp farming industry*[14], available online at http://www.ejfoundation.org.



The memorial to Kuranamoyee Sardar, murdered for peacefully protesting against the shrimp industry in Bangladesh. Environmental degradation, pollution and conversion of land as a result of shrimp aquaculture has led to increased social conflict, characterised by violence, intimidation and serious human rights abuse.

© Trent / EJF

BACKGROUND

Shrimp Production

Shrimp farming is a relatively new industry, one that has undergone tremendous growth with relatively little planning and regulation. As a consequence, the expansion of shrimp farming has come at a considerable cost to the natural environment. Indeed, there exist real concerns about the sustainability of shrimp farming as conducted under most current systems of production.

'Shrimp aquaculture in Vietnam is on the verge of wholeheartedly adopting the intensification and industrialisation model that Thailand has struggled with for the past decade; current practices in Thailand are not ecologically sustainable, and there is concern that the consequences of such a transformation in the Mekong River Delta and along the coasts and major deltas of the north of Vietnam would be even more serious'

Dr Louis Lebel *et al.*, Ambio, 2002[37].

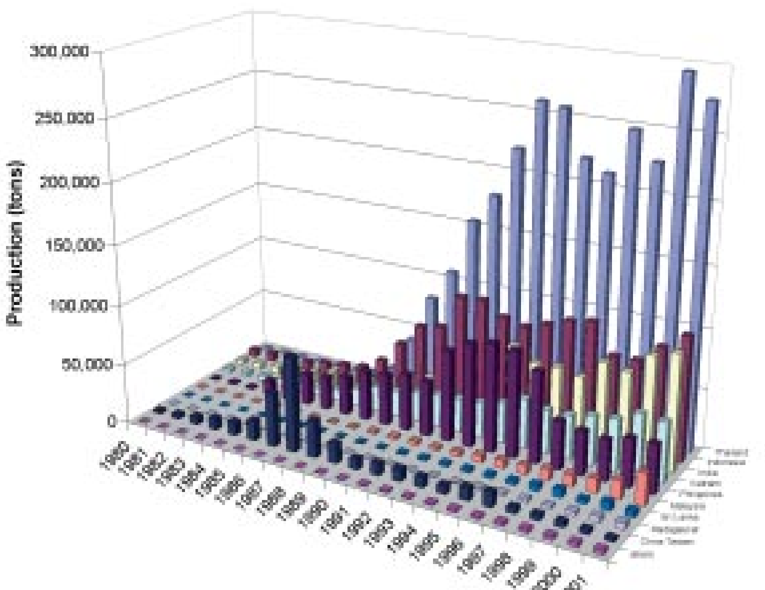
Boom and bust

More intensive forms of shrimp farming are characterised by high shrimp mortality risks due to disease, and 'boom and bust' cycles have been observed at the industry level. Major disease outbreaks occurred in the Philippines (1988), Taiwan Province of China (1987–88, 1993), Sri Lanka (1989), Thailand (1991), Ecuador (1989, 1994), China (1993), Vietnam (1993), Indonesia (1994) and Bangladesh (1994)[26,27,28] and a 1993–94 survey, led the Network of Aquaculture Centres in Asia to estimate losses in 12 Asian countries of US$143 billion[29]. Since then, additional serious disease outbreaks have occurred, including those in India (1995), Bangladesh (1996) Thailand (1996), and Ecuador (2000); in some cases such outbreaks have led to a localised collapse of shrimp farming[26]. A 1999 US Department of Agricul-ture report stated that shrimp disease outbreaks worldwide have had a total negative impact averaging US$1 billion annually since 1994[30]. At the farm level, operators face large risks because of high cash costs of seed stock and feed, and because of low survival rates[31]; these can vary greatly – in Vietnam one region had 15–20% survival whilst in another province only 1–5% sur-vival was recorded[32].

Top 15 producers of farmed shrimp (2000) by weight and value[24].

Country	Production (MT)	Production US$
Thailand	299,700	2,125,384,000
China	217,994	1,307,964,000
Indonesia	138,023	847,429,000
Vietnam	69,433	319,392,000
Bangladesh	58,183	199,901,000
India	52,771	393,938,000
Ecuador	50,110	300,660,000
Philippines	41,811	271,385,000
Mexico	33,480	194,184,000
Brazil	25,000	175,000,000
Malaysia	15,895	124,577,000
Colombia	11,390	91,120,000
Honduras	8,500	59,500,000
Taiwan Province of China	7,237	60,483,000
Sri Lanka	6,970	78,342,000

Aquaculture of Penaeus Monodon by country (1980–2001)



Data from http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp

Intensive or extensive?

Shrimp farming involves the use of ponds or enclosures where juveniles are reared until of harvestable size. Methods vary and can be loosely classified along an 'extensive-to-intensive' continuum according to pond area, feed and chemical use, and stocking densities. Terminology varies between sources and countries, but it is of value to introduce the following general definitions[26,33,34].

- **Extensive/traditional:** Mangroves and intertidal areas are enclosed by dikes in large ponds to allow polyculture of naturally stocked crab, shrimp and fish. Shrimp larvae densities are 1–3/m^2 and water exchange is by tidal action. Mangroves, if enclosed, usually die after 3–5 years. Supplemental feeding or fertilization is rare. Yields are low (50–500 kg/ha).

- **Semi-intensive:** Uses small (5–25 ha) ponds from which natural vegetation is cleared and in which supplementary stocking and feeding are routine. Shrimp densities are 5–8/m^2, and can occasionally reach 10–20/m^2. Ponds are often drained, dried and treated between flooding periods. Water exchange of 10–20% per day is effected by pumps, and aerators may be also be used. Yields vary from 500–10,000 kg/ha.

- **Intensive:** Uses small (< 0.1 to 5 ha) ponds, cleared of all natural vegetation and using artificial stocking with juvenile shrimp. Feeding and aeration to maintain oxygen levels are necessary. Stocking densities are high (over 20/m^2). Yields range from 5,000–20,000 kg/ha. Water exchange has conventionally been high (up to 30% per day) but lower water exchange systems are increasingly being adopted following successful implementation in Thailand.

According to a recent survey of a number of shrimp farming countries, 1.3 million hectares have been developed into 110,000 shrimp farms in the following ratio: extensive (59% of farms); semi-intensive (29.5%); intensive (11.5%)[26]. Between countries, however, these ratios vary considerably. For example, as many as 90% of the shrimp farms in Bangladesh are extensive[26].

Quantifying the environmental impacts of different production systems is not straightforward. Whereas intensive and semi-intensive ponds rely on artificial stocking of post-larvae, use potentially polluting chemicals and artificial water exchange systems, extensive farms must be considerably larger to produce similar yields and thus can have greater impacts on natural habitats. Simply put, the trade-off is that between one system reliant on high levels of inputs and another requiring a lot of space.

In many countries, faced with declining productivity and encouraged by high profit potential and government support, the trend is towards intensification of shrimp aquaculture systems. In Vietnam, when extensive systems are upgraded to 'improved-extensive' systems, production has been shown to be likely to fall after about 10–20 years[35]. Many of Vietnam's 'improved-extensive' farms were started about 10 years ago, and are now beginning to experience serious problems with pollution and disease, leading to reduced or negative profit margins[5]. For many of the farmers, the only real option if they are to keep their land is to upgrade to semi-intensive systems (currently being encouraged by the government), though this requires major investments for improved infrastructure, food, and seed. Even if the systems are upgraded, semi-intensive systems are predicted by academics to fail after 5–10 years[36], as occurs elsewhere. Those farmers who

ABOVE: Shrimp farms in Ecuador
© Greenpeace

'Shrimp farming ranks as one of the most resource-intensive food production systems, characterizing it as an ecologically unsustainable throughput system … inherently liable to collapse.'

JONAS LARSSON, PROFESSOR CARL FOLKE AND PROFESSOR NILS KAUTSKY[25].

can afford to are likely to have to upgrade again, those who can't, or who are unable to obtain loans, risk losing their land. It is estimated that after approximately five years, these intensive systems will also fail to be profitable[36].

Most farms in central Vietnam have now adopted intensified systems, while those in northern and southern Vietnam continue to practice a variety of semi-intensive systems[37]. A recent study found that 90% of shrimp farmers in northern Vietnam, and over 50% of farmers in southern Vietnam intended to further intensify their production systems[37]. In Bangladesh, while most farms are currently extensive, with few inputs in the way of feed or chemicals, the establishment of feed distribution centres and a likely trend for establishment of farms in supra-litoral areas (some of which are being part-funded by feed companies) are thought likely to lead to greater intensification of production[38,39]. Data from India and Indonesia show a similar pattern of declining productivity after 5–10 years in intensive and semi-intensive systems[7,40].

Rising land values have reduced the feasibility of new extensive farm developments and contribute to the general pattern of intensification. Without appropriate infrastructure, technology and planning, this trend may be a risky one. Under current methodologies used in most shrimp farming countries, intensive systems tend to be unsustainable, yet it would be incorrect to characterise intensification as inherently unsustainable. There exists potential for future developments to overcome the problems of sustainability in high intensity production, greatly extending pond life-spans. However, considerable capital investment will be necessary, as will time for research and development, and for the majority of shrimp farmers in developing countries these luxuries are simply not available. For example, it was recently concluded that establishment of such farms is too expensive for the type of small-scale pond operations found in much of Thailand, which are dependent on highly intensive and untreated systems through rapid conversion of mangrove and coastal resources[41].

BELOW: *Abandoned shrimp pond, Phuket, Thailand.*
© Williams / EJF

Shrimp Pond Abandonment

In Thailand, there has been a rapid shift from more extensive systems to smaller, more intensive, highly-productive farms. However, the unsustainable nature of these intensive and semi-intensive systems has contributed to the industry's expansion, as such farms have been routinely abandoned after just five to six years of production because of problems of disease and water quality, leading to new farms being established elsewhere[42]. This has given the industry in Thailand and other parts of the developing world a reputation as a destructive 'slash and burn' style of enterprise. Although Thai shrimp farm expansion has slowed in recent years, it continues nonetheless as new farms are developed to replace unproductive and abandoned ones[41]. As many as 70% of previously productive Thai ponds are reported to have been abandoned[43] and shrimp aquaculture there is becoming similar to shifting cultivation, with farms moving further and further south as harvests fail[36]. In 1996, 20,800 ha of shrimp farms in Thailand were abandoned with an economic loss of 5 billion baht (c. US$20 million)[44]. A report published in 2000 stated that, in the upper Gulf of Thailand, 40,000 ha were abandoned with 90% of shrimp farmers there out of business[45]. Pond abandonment has also been reported in Sri Lanka, Cambodia, the Philippines, Taiwan Province of China, Bangladesh, China, Malaysia, Colombia and Mexico[46]. This is of concern as conversion of extremely degraded pond areas to other agricultural uses is often not economically feasible[47].

Environmental Impacts of Shrimp Aquaculture

Mangrove degradation and loss

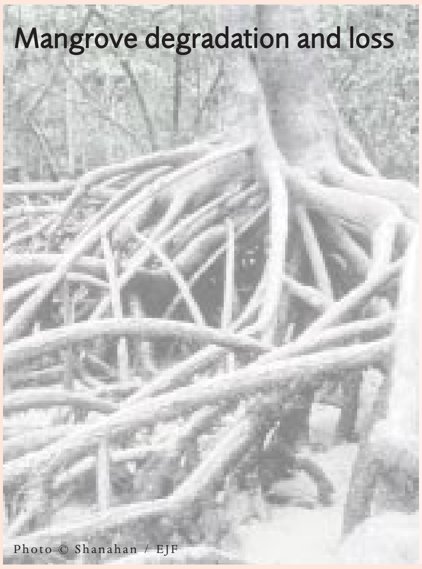


Photo © Shanahan / EJF

- Loss of critical ecological goods and services provided by mangrove ecosystems.
- Impacts on adjacent coastal and marine ecosystems.
- Threats to marine and terrestrial biodiversity.
- Serious implications for local communities, concerns over reduction in food security due to dependence of fisheries on mangroves, and loss of access to mangrove products.
- Loss of mangrove undermines the very basis of shrimp production raising issues of sustainability.
- Exacerbation of problems of pollution and disease with the loss of filtering actions and soil stabilisation that mangroves provide, and due to acid sulphate potential of soil.
- Conversion of mangroves for shrimp aquaculture development economically non-optimal and often unsustainable, with long-term negative socio-economic consequences.

(See pages 12–23)

Degradation of other habitats


Photo © Florida Keys National Marine Sanctuary / NOAA

- Conversion of other wetlands including salt marshes, mudflats and freshwater wetlands for shrimp aquaculture.
- Increased terrestrial run-off threatening coastal and marine ecosystems including seagrasses and coral reefs.
- Negative implications for biodiversity and conservation of a number of threatened species.
- Negative implications for food security.

(See pages 24–31)

Pollution


Photo © Ann Wahlstrom / Katrin Holstrom

- Pollution from nutrients and organic waste, antibiotics and other chemicals.
- Pollution increased by large water exchange rates of more intensive systems, this may be exacerbated where shrimp ponds are sited in mangroves and other wetlands.
- Concerns over the impacts on marine biodiversity and on coastal ecosystems.
- Concerns over health impacts for producers and consumers.
- Salinisation and depletion of ground and surface waters.
- Negative implications for food security and human health.

(See pages 32–43)

Depletion of wild fish and shrimp stocks

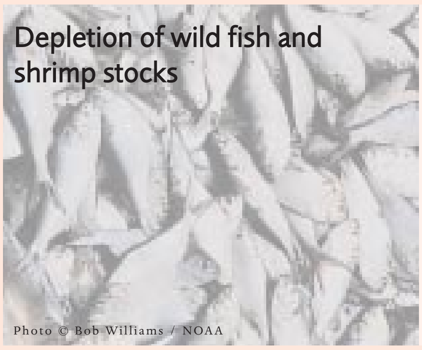


Photo © Bob Williams / NOAA

- Depletion of wild fish and shrimp stocks due to habitat degradation.
- High rates of bycatch during shrimp fry and broodstock collection
- Use of fish products in feed.
- Introduction of non-native species, pathogens and pollutants.
- Serious implications for marine biodiversity and food security.
- Present systems of shrimp aquaculture undermine the very basis of natural shrimp production.

(See pages 44–55)

From Wetlands to Wastelands

The primary environmental impacts associated with shrimp farm (aquaculture) development include degradation of vital coastal and wetland habitats, organic and inorganic pollution of the wider environment, salinisation of soil, and salinisation and depletion of water supplies. Rather than reducing pressure on wild populations, shrimp aquaculture can undermine the very basis of shrimp production, impacting wild fish and shrimp stocks through habitat destruction, very high rates of bycatch during collection of shrimp fry and broodstock to stock ponds, use of fish products in feeds, introduction of pollutants, and biological pollution of wild populations. Environmental degradation, declines in fisheries and loss of access for traditional users to coastal and estuarine resources associated with shrimp aquaculture have led to the deterioration of local livelihoods, marginalisation of local populations, and reduced food security. Farmed shrimp are produced for an export market and impacts associated with their production remain local externalities the costs of which are not incorporated into the market price.

BELOW: *The Sundarbans mangrove forest, Bangladesh. Over half of the world's wetlands and half of the world's mangroves have been lost over the past century.*
© Williams / EJF

Shrimp farms require substantial quantities of water, and are primarily located alongside rivers, estuaries and coastal areas. Consequently, the industry's rapid expansion is exacting a serious toll on wetland habitats found in these areas, and the communities and wildlife dependent on them.

The conversion of large tracts of wetlands in recent decades has been compounded by the long-standing trend of substantial under-valuation of these ecosystems, and the fact that such areas have often been used as open-access lands, lacking formalised or well-defined land rights[2,3,4,5,6]. Mangrove forests, which lie in the intertidal zone providing a natural habitat for many shrimp species, have been particularly impacted.

Mangroves have traditionally been used for shrimp farming[7,8,9], but with the expansion of commercial shrimp farming and the associated clearance of mangroves[8], these valuable ecosystems have been rapidly degraded. Today, mangroves are among the world's most threatened habitats. It is estimated that over half of the world's mangroves have been destroyed[10,11,12,13] and the remaining mangrove cover is declining at an alarming rate[4,9,11,14,15,16]. Much of this destruction has been recent: it has been estimated that 35% of the total area of mangrove forests has been lost in the last twenty years[15]. These losses exceed those for tropical rainforests and coral reefs[15]. The exact extent to which shrimp aquaculture has been responsible for mangrove loss is unclear, but evidence suggests shrimp farming has been a major contributor to global mangrove loss; it has been estimated that as much as 38% of recent global mangrove loss may have been due to shrimp aquaculture[15]. In some local watersheds and even in some countries, it is considered to be the greatest single threat to mangrove ecosystems[8,9,11,12,15,16,17,18,19,20,21].

Wetlands

Wetlands, including mangroves, salt marshes and tidal grasslands have been described as *'the kidneys of the landscape'* because of the functions they perform in the hydrological and chemical cycles, and as *'biological supermarkets'* because of the extensive food webs and rich biodiversity they support[22]. Wetlands occupy about 8.6 million km^2, or 6.4% of the world's land surface, of which approximately 56% lies in the tropics and sub-tropics[23]. They occupy transitional zones between permanently wet and generally dry environments – they are neither aquatic nor terrestrial, and the presence of water for a significant period influences the soils, micro-organisms, and plant and animal communities present[22].

Wetlands are dynamic systems, continually undergoing natural change due to subsidence, drought, rising sea-level, or infilling with sediment or organic material, but direct and indirect human activity have considerably altered the rate of change of wetlands, with loss now far exceeding growth[22]. Wetlands world-wide face a variety of anthropogenic threats. In addition to conversion to aquaculture ponds, other threats to wetlands from human activity include: human settlement; drainage for agriculture; disturbance from recreation; reclamation for urban and industrial development; pollution; fishing and associated disturbance; commercial logging and forestry; wood cutting for domestic use; catchment degradation, soil erosion and siltation; conversion to salt pans; diversion of water courses and over-grazing by domestic livestock[22].

IMPACTS ON MANGROVE ECOSYSTEMS

Mangrove forests are among the most productive[1] and complex ecosystems in the world[2], and occur at the interface of terrestrial, freshwater and marine environments[3]. They are also among the most threatened habitats in the world today, with rates of loss exceeding those of tropical rainforests and coral reefs[4].

Shrimp aquaculture is one of the major threats to mangroves. It has been estimated that as much as 38% of recent global mangrove loss may be due to shrimp farm development[4] and in some countries such conversion represents the major cause of mangrove deforestation in recent years.

Recent estimates of current global mangrove coverage have varied between 14 and 30 million ha, with an average estimate of approximately 17 million ha[8], around 40% of which occur in Asia[5,6]. However results from a 2003 study by the UN Food and Agriculture Organisation (FAO) – the most comprehensive assessment to date on the state of the world's mangrove forests – suggest that mangrove area worldwide had fallen below 15 million ha by the end of 2000, down from an estimated 19.8 million ha in 1980[7] – nearly 25% in 20 years. Other recent estimates place total mangrove loss as high as 35% over the last two decades[4].

Mangrove ecosystems, consisting of mangrove plants, their associated flora and fauna and associated abiotic factors line the coastlines of tropical and subtropical countries around the world[8]. Found in 112 countries and territories between latitudes of 32°N and 38°S, mangroves grow along the tropical coasts of Africa, Australia and Oceania, Asia and the Americas.

RIGHT: *Mangroves are among the most threatened habitats in the world today, and are declining at an alarming rate[4,5,8,11,12,13].*

© Jeremy Stafford-Deitsch

Based on historical records, individual countries have lost anywhere between 5–85% of original mangrove cover[5] and, overall, it is estimated that over half of the world's mangroves have been destroyed[1,5,9,10]. By far the most rapid losses have occurred in recent decades[5,132]. National rates of mangrove decline differ, but there is a dominant pattern of reduced mangrove area for nearly every country, particularly those with large mangrove forests[4].

Globally, mangrove losses have been estimated to be as high as 2.1% per year[4], though the 2003 study by the FAO estimates annual global loss at 1.1% between 1990–2000, down from 1.9% per year from 1980–1990[7]. In comparison, rates of annual loss of terrestrial tropical forests during the 1980s and first half of the 1990s were 0.8%[4]. Continental and national rates of mangrove loss may be much higher, with that in the Americas estimated to be over 1% per year[7] and as high as 3.6% per year[4]; annual rates of loss in South America were estimated at 5.3% from 1980–1990[7].

Losses between 1990–2000 have been estimated to be as high as 6.2% per year in China, and 4.5% per year in Vietnam[7]. Extensive losses, particularly over the last 50 years, include estimated losses of 83% of original mangrove cover in Thailand by 1993[14], of 70% in Guinea-Bissau by the 1980s, and a loss of 67% of mangrove cover in Panama between 1983 and 1990[15].

Causes of Mangrove Deforestation

Global mangrove destruction has been driven primarily by human activities[4], with some of the major anthropogenic threats including:

- Overexploitation of forest resources for fuel-wood, charcoal, timber, tannin and woodchip production[4,8].
- Conversion for aquaculture, agriculture (particularly rice cultivation[8]), salt production, coastal development and tourism[1,8,16,17].
- Pollution from industrial wastes, mining, and oil exploration. Oil accumulation on mangrove roots can lead to defoliation and death of mangroves trees[2,8] and may slow natural regeneration[2].
- Warfare – for example, use of napalm and herbicide defoliants during the American-Vietnamese war devastated Vietnam's mangroves, destroying an estimated 124,000 ha[17].
- Interception of freshwater for agriculture and irrigation, and prolonged flooding due to artificial dikes and causeways[8].

Threatened forests: the impact of shrimp farming

'Although the data are incomplete and often contested, there is no doubt that shrimp farming has been a significant cause of [mangrove] destruction in some areas'

FAO, World Bank, WWF, NACA Consortium Project, 2002[18].

Conflicting data reported by governments, the shrimp industry and environmental organisations regarding the impacts of shrimp aquaculture on mangroves has meant that accurate assessments of mangrove loss due to shrimp farming are difficult. However, it is clear that shrimp aquaculture is having a substantial negative impact, requiring urgent measures to prevent further damage to mangroves and other natural environments.

In the countries that are the largest producers of farmed shrimp, the Network of Aquaculture Centres in Asia-Pacific (NACA) report that 20–50% of all current mangrove deforestation is due to shrimp farming[19]. Professor Claude Boyd and Dr Jason Clay reported in 1998 that shrimp farming alone appears to be responsible for less than 10% of global mangrove loss[10], and an earlier paper by Dr Clay reported that globally, shrimp farming may be responsible for between 10–20% of mangrove clearance that has taken place since 1960[20].

Other estimates are considerably higher – for example, in a 2001 paper Professor Ivan Valiela and colleagues at the Boston University Marine Program report that conversion to shrimp aquaculture is responsible for 38% of total mangrove destruction, and that *'shrimp culture is, by a considerable margin, the greatest cause of mangrove loss'*[4].

Despite the varying estimates, it is clear is that the expanding, often unregulated shrimp aquaculture industry has been a significant contributor to mangrove loss[4,8,12,21,22,23,24,25,26,27].

'In many tropical countries of the world, shrimp aquaculture has been a major contributing factor in the recent losses of mangrove forests'

Professor Eric Wolanksi *et al.*, 2000[26].

A 2003 report by the Centre for Tropical Ecosystems Research (cenTER Aarhus), the International Society for Mangrove Ecosystems (ISME) and the World Bank states that the threat to mangroves from aquaculture in South and Southeast Asia, Africa and Central and South America is increasing[34].

Current and future threats to mangroves from aquaculture[34]

	South & Southeast Asia	*Africa*	*Central and South America*
Current:	High	Low	Medium-High
Future:	Increasing	Increasing	Increasing

Most damage is caused by direct conversion of mangrove land to shrimp ponds, while other impacts associated with hydrological changes or increased organic and inorganic pollution due to shrimp farming may also lead to, or exacerbate, mangrove degradation. For example, salinity may be altered by isolation of mangroves from brackish water, by freshwater flooding or through discharge of saline pond water into low salinity mangrove areas. Changes to estuarine flow and local hydrology can be caused by isolation from brackish water and normal tidal inundation by the construction of ponds, canals or access roads[25]. Salt tolerance differs between mangrove species, but chronic high salinity is always detrimental, and can lead to stunted growth or replacement of mangroves by salt marshes or barren soil[126]. Shrimp farming may lead to excessive sedimentation of mangrove ecosystems, organic pollution can lead to eutrophication, and chemical contaminants or disease from the farms can affect mangrove fauna[25,26]. Additionally, conversion of adjacent mudflats, and disturbances resulting from shrimp farm operations and fry collection can inhibit mangrove growth and regeneration (see Annex I, pages 64–72).

'Although conversion for agriculture, settlements and salt production have reduced mangrove cover, aquaculture remains the major causal factor at least in SE Asia'

Dr Jurgene Primavera[35]

RIGHT: *Degraded mangroves and shrimp farms in Vietnam. Shrimp aquaculture has been a major contributor to mangrove loss and, in a number of countries and local watersheds, conversion to shrimp farming represents the greatest threat to mangrove ecosystems.*

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Case Study: Bangladesh

Mangrove cover in Bangladesh's Chokoria Sundarban forest fell from 7,500 ha in 1976 to 973 ha in 1988, and just 411 ha in 1999[36], largely due to shrimp aquaculture development[24,37,38,39]. Destruction of these mangroves has left local communities vulnerable to the devastating impacts of cyclones[37,40], and has reportedly had socio-economic impacts on over 90% of the local community[38]. Following the loss of these mangroves, local fishermen have reported an 80% drop in catches[41].

Meanwhile, the ill-planned expansion of shrimp farming in areas adjacent to the Sundarbans has been considered by some to be one of the most significant causes of gradual loss of the forest[42,43,44]. Degradation of surrounding lands has depleted traditional fuel sources (such as cattle dung and hays), and communities are increasingly having to exploit the Sundarbans for fuel (such as leaf litter, fallen fruits and wood).

Shrimp culture has also been associated with unemployment in rural areas and, in the areas around the Sundarbans, many displaced farmers are reported to have resorted to the collection of honey, fuel-wood or other forest products, often illegally[45,46,47]. The ecologically damaging process of shrimp fry collection has had a severe impact on the aquatic ecology of the area, while the physical disturbance caused by hundreds of thousands of fry catchers is reported to be affecting mangrove growth and regeneration[48].

ABOVE: *The Chokoria Sundarban forest in Bangladesh has been almost completely destroyed by conversion to shrimp farms.*

© Philip Gain / SEHD

'Indiscriminate conversion of [Bangladesh's] mangrove forests into shrimp farms has resulted in the destruction of marine breeding grounds and the erosion of shorelines. The destruction of the mangroves has far-reaching ecological implications for the whole region. A large number of local varieties of fish have disappeared and nutrient content of the soil has diminished, resulting in drastic reductions in land productivity'

UNITED NATIONS ENVIRONMENT PROGRAMME[49]

LEFT: *Shrimp fry collection in the Sundarbans.*

© Williams / EJF

Case Study: Thailand

Thailand was the world's leading producer of farmed shrimp in 2001, producing shrimp with a value of approximately US$2.4 billion[51]. Aquaculture, charcoal production, logging, pollution, urban expansion and tourism have placed enormous pressure on Thailand's coastal ecosystems. The Thai Economic and Social Development Board estimated that 253,000 ha of the country's 380,000 ha of mangroves had been destroyed by the mid 1990s[52], while other authors have estimated that as much as 83% of original mangrove cover in Thailand had been lost by 1993[53].

Conversion to shrimp aquaculture is believed to have been a major cause of recent mangrove loss there[5,13,31,32,50,141]. Mangrove cover fell by nearly 50% from 1975 to 1993 (312,000 ha to 168,683 ha), reportedly largely due to conversion to shrimp aquaculture[5,32,58,60], with more than 17% of the country's mangrove forests being converted to shrimp ponds in just six years (1987–1993)[54]. In just two years (1986–1988), Chanthaburi Province in the Gulf of Thailand lost nearly 90% of its mangrove forests to shrimp ponds[31].

'Only 20% of mangrove forests recorded in 1961 in the Gulf of Thailand are left'

SONJAI HAVANOND, MARINE AND COASTAL RESOURCES DEPARTMENT[50].

'Since 1975, the area of mangroves in Thailand was virtually halved and the majority of this conversion is attributable to shrimp farming'

PROFESSOR EDWARD BARBIER & DR MARK COX, 2002[13].

Statistics released in 1998 by the Thai government, based on comparison of remote sensing images, indicated that about one third (31–32%) of reported mangrove forest lost became shrimp farms[55,56,57]. However, a paper released in 2002 suggests that as much as 50–65% of Thailand's mangroves have been lost to shrimp farm conversion since 1975[58].

Shrimp farm area expanded from 31,906 ha to 66,027 ha between 1983–1996, with the number of shrimp farms rocketing from 3,779 to 21,917 in this period[13]. The rate of mangrove destruction increased sharply with the growth of shrimp aquaculture, reaching 13,000 ha/year in 1980–1986[57,59]. The rate slowed after 1987, but in the mid-1990s annual loss was estimated to be around 3,000 ha/year and recent estimates have placed it as high as 6,037 ha/year[33].

Conversion for shrimp aquaculture is by no means the only cause of mangrove loss in Thailand, and other coastal economic activities are contributing to the destruction of mangroves. In addition, there have been welcome shifts in policy towards promoting the conservation of mangroves and the participation of local communities[13,60]. The government has implemented management plans geared toward the protection of remaining mangrove areas and has ceased granting land-use concessions in mangrove forests[61,62]. However, there have been reports of concessionaires in the south rushing to convert thousands of hectares into farms before introduction of this legislation[63], and of forged land-use documents being used to obtain deeds illegally[64]. Indeed, in 2003 it was reported that mangroves were being encroached in Prachaup Khiri Khan by local politicians in order to develop shrimp farms[65,66]. As stated in a recent paper by Professor Edward Barbier and Dr Mark Cox, *'It remains to be seen whether Thailand will become a model of sound management of coastal mangrove development and protection … or continue to be an example of how uncontrolled shrimp farm expansion can lead to extensive destruction of mangrove resources'*[13].

RIGHT: *1973 – This image from1973 shows the coastal area of southern Thailand with mangrove areas.*

LOWER RIGHT: *2002 – This 2002 image reveals a dramatic change in land use along the southern coast. Much of the coastal ecosystem has been converted to intensive shrimp cultivation, new infrastructure and construction of new dikes.*

Case Study: Vietnam

Over the last fifty years, Vietnam has lost at least 220,000 ha of mangrove forests[67] – more than 80% of original cover has been deforested[68]. In 2000, just 110,680 ha were thought to remain[69]. Following widespread replanting after the American-Vietnamese war, much of this destruction has been very recent, and today shrimp aquaculture is thought to represent the single greatest threat to Vietnam's mangroves[29,70]. In the Mekong Delta's Ca Mau province, the shrimp farming area trebled over the 12 months to mid-2001[71], reportedly covering 202,000 ha[72]. Mangrove cover in this area has fallen from over 200,000 ha prior to 1975 to 60,000–70,000 ha today, mainly due to shrimp aquaculture development[73]. In just four years (1983–1987), 102,000 ha of mangroves were converted to shrimp farms[74].

In many ways, Vietnam's government has been progressive in their protection of mangrove and other important wetland habitats. The government has called for the expansion of aquaculture to be carefully planned to protect the environment, promoting the development of integrated shrimp-mangrove farming systems and sandy-land aquaculture, and supporting mangrove replanting programmes and projects focused on defining sustainable land-uses in the brackish zone. There have also been public warnings about the risks of excessively intensive shrimp aquaculture and the fight against mangrove loss[70]. However, whilst these projects and the government's awareness of the environmental issues should be highlighted and welcomed, it appears that government plans for significant aquaculture expansion are placing incredible pressure on coastal areas, and there may be conflict between reforestation and shrimp cultivation expansion programmes[70,75].

In some areas shrimp farming in protected areas is being 'allowed' to continue, and even freshwater inland wetlands are now being developed. There are now many areas of small isolated patches (around 100 ha) of wetland left where, because they are considered to be too small to be of conservation value, a blind eye has effectively been turned to aquaculture development; 'illegal' shrimp farm development in areas of ecological importance is continuing at a rapid rate[70].

'For the last decade, the greatest threat to mangroves in Vietnam has been shrimp aquaculture'

Professor Phan Nguyen Hong, Vietnam National University, Hanoi[29].

'Analyses of the characteristics and changes of the soil and water, the behaviour of creatures in the ponds, as well as on the tidal flats have shown that the construction of chain embankments for shrimp ponds has led to severe degradation of the environment and a decrease in the natural resources of the entire Ca Mau Cape [Vietnam].'

Professor Phan Nguyen Hong, Vietnam National University, Hanoi[76].

BELOW LEFT: *The southern part of Ca Mau province, Vietnam in 1993.*
© NASA, Landsat image mosaic

BELOW RIGHT: *The same area in 2002. Shrimp farms appear as dark blue, mangrove forest as green and agriculture as pink/green[75a].*
© ASTER, image mosaic

'The continuing degradation and destruction of Ecuador's mangroves, principally from the construction of shrimp farms, is widely viewed as one of the most important symbols of environmental degradation along the coast… Despite [an] increasingly complex legal framework, mangrove destruction continues'.

Dr Stephen B. Olsen, Director, Coastal Resources Centre, University of Rhode Island, 2000[80].

Case Study: Ecuador

The decline of Ecuador's mangrove cover has occurred simultaneously with the arrival and explosive growth of shrimp farming. According to official data, Ecuador's total mangrove area fell from 362,802 ha in 1969 to 263,695 ha in 1991 and 146,938 ha in 1995[77]. Meanwhile, the National Aquaculture Chamber reported that, as of 2000, 207,000 hectares of shrimp ponds had been developed[78]. There is little reliable data on the extent to which shrimp aquaculture has been directly responsible for mangrove destruction, but most of the 50% loss of mangrove forests in the last 20 years has been attributed to shrimp farm development[8,31,40]. It has been reported that of the 26.5% mangrove loss Ecuador's Pacific coast experienced between 1969 and 1995, around 90% was due to shrimp farming[79,80].

In the last thirty years, 64,000 hectares of mangrove have been destroyed in Esmeraldas province alone, of which 50,000 ha were converted to shrimp ponds. Only 2% of the Chone Estuary's original mangroves now remain[78]. Significantly, many shrimp farms are illegal. Ecuador's Coordinadora Nacional para la Defensa del Manglar (Mangrove Defence Network)[81] states that only 58,000 hectares of shrimp ponds have legal status in the form of a legal mangrove concession[82].

Cayapas-Mataje Ecological Reserve

In July 2003, the Cayapas-Mataje Ecological Reserve became Ecuador's 11th Ramsar Site. The Reserve comprises sedge marshes, tidal brackish marshes, peatlands, humid tropical forest and some of the tallest mangroves in the world, over 60 metres high. Endangered species including Jaguar *(Panthera onca)*, Blue-fronted Parrotlet *(Touit dilectissima)* and American Crocodile *(Crocodylus acutus)* inhabit the reserve[83]. Though protected on paper, research by the Ecuadorian environmental organisation Fundecol and Greenpeace produced evidence that some 1,118 hectares of mangroves in the Cayapas-Mataje Reserve had been destroyed in one year to make way for illegal shrimp farms[84]. The development of shrimp farming has led to declines in local communities' fish and shellfish catches, with devastating impacts on livelihoods; one resident stated: *'God forbid that the mangrove ecosystem should disappear because nothing better awaits us in the cities'*[85].

BELOW: *Shrimp farms in Ecuador.*

© Trent / EJF

Case Study: Honduras

Shrimp farming is considered a major threat to mangroves in Honduras[5]. The area under cultivation currently stands at 16,200 ha, concentrated in extensive salt flats and mangrove areas of the Gulf of Fonseca[86]. Shrimp farms are reported to have been responsible for approximately one third of the mangrove loss, while other activities have together resulted in two thirds of the total mangrove decline[87].

Concern from local communities and NGOs prompted the Honduran Government to declare a moratorium on shrimp pond construction from 1997 until June 1998, involving prohibition on new concession contracts for public lands in the gulf. In October 1998, the Honduran Congress passed legislation designating nearly 75,000 ha of wetlands in the Gulf of Fonseca as protected areas to be developed under various categories developed by the World Conservation Union (IUCN)[88], and the Honduran portion of the gulf was declared a wetland site of international importance (under the Ramsar Convention) in July 1999[90].

However, it is widely believed that the moratorium was ineffective in halting shrimp farm expansion; 60 new farms were thought to have been established during this time[91]. CODDEFFAGOLF, a Honduran NGO, has recently claimed that Honduran laws and international treaties were broken by, amongst others, Natural Resources and Environment Ministers in the granting of licenses for shrimp farms to operate in protected areas[92]. Ironically, in November 2002, Honduras's sole official representative at the Ramsar Convention meeting in Valencia was an employee of the country's largest shrimp farm (Granjas Marinas San Bernardo – GMSB).

TOP: *1987 – This image shows the Gulf of Fonseca before the beginning of intensive shrimp cultivation.*

ABOVE: *2000 – Over 250 sq. km in the Gulf of Fonseca has been leased through concessions. The 2000 image documents the resulting conversion of wetlands. Estimates of mangrove loss due directly to the construction of shrimp farms range from about 20 to 40 sq. km. If conservation policies are not put in place, estimates suggest that all the mangroves will disappear within 20 years.*

Case Study: Indonesia

Indonesia has the largest mangrove area of any country, with approximately 23% of the world's mangroves[5]. However, between 1960 and 1990, 269,000 ha of Indonesia's mangroves were reportedly converted to shrimp ponds[95], and shrimp farming remains a major threat[5,96,97]. Mangrove cover reportedly fell from 3.2 million ha to 2.4 million ha between 1986 and 1996 in order to build aquaculture ponds[98]. Along the Mahakam River in Kalimantan (Borneo), 50% of Nypa stands have been lost to aquaculture in the last 10 years[99] and 17,429 ha of mangroves were lost between 1982 and 1996[98].

In Lampung Province (Sumatra), shrimp aquaculture has led to the loss of nearly 90% of mangrove cover; 27,000 ha of brackish water shrimp and fish ponds have been developed in mangroves in the province, some of which were nominally protected[100]. A 1998 study indicated that of 11,500 ha of mangrove originally found at the mouth of Lampung's Tulang Bawang River, less than 1000 ha remained, with most being highly degraded; an estimated 94% of mangrove cover had been lost in just 10 years, primarily due to conversion for shrimp ponds[100]. Many of these shrimp farms are thought to be operating without government permission and serious concerns have been raised over their sustainability; many of the farms have failed due to disease, resulting in bankruptcy and a pattern of shifting cultivation, increasing pressure on coastal resources[101]. This dramatic loss of mangroves in Lampung has been exacerbated by the conversion of mudflats to shrimp ponds, affecting mangrove regeneration and resulting in serious shoreline erosion[100].

In 2001, it was reported that 2000 ha of Karang Gadang Nature Reserve in North Sumatra were illegally cleared to create shrimp farms[102].

> *'Conversion to brackish water shrimp ponds is the prime – and currently the only – cause of mangrove loss in Lampung.'*
>
> COASTAL RESOURCES MANAGEMENT PROJECT – LAMPUNG REPORT, 1999[100]

Case Study: Burma (Myanmar)

Burma was estimated to have a mangrove forest area of 652,000 ha in 1983. By 1997, this area had reportedly decreased by 271,000 ha, leading to a decline in coastal fisheries production of 190,000 tonnes annually[103]. Burma's mangroves are protected under the Forest Law of 1992[104], and there have been some small-scale reforestation efforts. However, though much of the planned and existing shrimp farm area has been on land cleared of mangroves for other reasons, the scale of the planned development represents an impediment to ecological restoration of the earlier devastation. Additionally, enclosure of 20–40 hectare blocks of mangrove by shrimp farm embankments has isolated the forest from tidal flow and led to tree loss[105].

Case Study: India

'The rapid expansion of shrimp aquaculture on India's flat coastal lands has been an important cause of conversion of mangroves in the past decade'

Lars Hein, FAO, 2000[107].

Although much of India's shrimp farming is not in mangrove areas, shrimp farming was nonetheless an important cause of mangrove loss in the 1990s. For example, the State of Andhra Pradesh has experienced extensive expansion of shrimp aquaculture, from an estimated 6,000 ha in 1990 to as much as 84,000 ha in 1999[106]. In the Godavari delta, Andhra Pradesh, shrimp farms were responsible for approximately 80% of mangrove conversion in the decade to 2000[107]. The rate of conversion of mangroves into shrimp ponds in the delta increased in the period 1997–1999, despite policy regulations banning the conversion and the protected status of the Godavari forest[107].

Case Study: Philippines

Around half of the 279,000 ha of Philippine mangroves lost from 1951–1988 were developed into aquaculture ponds, with 95% of Philippine brackish water ponds in 1952–1987 being derived from mangroves[28]. In August 2003, it was reported that local fishermen were urging the government to recall lease agreements issued for the expansion of shrimp farms on 200 ha of old growth mangrove in Palawan[108].

BELOW: *Mechanised mangrove destruction for shrimp farm construction in Ecuador.*
© Greenpeace

SHRIMP FARMING IN AFRICA

According to the United Nations Environment Programme, 38% of Africa's coastline and 68% of its marine protected areas are under threat from unregulated development[109]. Of concern are poorly-planned or regulated shrimp farming operations. Relatively little shrimp farming took place in Africa until the early 1990s but the continent represents a potential new frontier for the industry and large mangrove areas are being targeted by developers, drawn by rich natural resources, cheap labour and low land prices[110,111].

In Mozambique, large-scale shrimp farms are reported to be planned near Maputo (7,500 ha), Beira (19,500 ha) and Quelimane (6,000 ha)[112]. Shrimp farms also operate in a variety of coastal and inland zones in Guinea, Gambia, Eritrea, Egypt, South Africa, the Seychelles, Kenya, and Madagascar, which leads African farmed shrimp production (3,486 MT in 1999)[112,113].

Deltas in Danger

Three biologically-rich and culturally important large river deltas are among areas that have been targeted for new aquaculture developments.

Niger Delta, Nigeria[114]

Nigeria's mangrove forests are the largest in Africa and the third largest in the world. Local communities rely on the forests for building materials and food, and it is estimated that 60% of fish caught between the Gulf of Guinea and Angola breed in the mangroves of the Niger Delta. Industrial shrimp farming supported by the Nigerian Government has been proposed in the delta.

Tana Delta, Kenya[115]

The Tana Delta is the largest wetland ecosystem in Kenya, comprising riverine forests, mangroves, flood plains and grasslands. Over 200 bird species have been recorded in the delta and it holds an important population of the Nile Crocodile *(Crocodylus niloticus)*[116]. Coastal Aquaculture Limited was allocated land in the Tana Delta in the early 1990s in order to develop shrimp farms. However, the local communities also claimed ancestral rights to the land. Following widespread protest, the Kenyan government used a Presidential decree and stopped the project. Litigation between CA Ltd and the government was unresolved, and the company is now reportedly lobbying the new government in order to restart the project and develop shrimp farms.

Rufiji Delta, Tanzania

The Rufiji Delta contains the largest estuarine mangrove forest on the east coast of Africa and is of considerable economic and conservation importance[117]. In the late 1990s, the African Fishing Company (AFC, run by an Irish arms dealer, R. J. Nolan) planned the world's largest shrimp farming project in the delta[118]. The project, a 10,000 ha shrimp farm, was to take up a 19,000 ha site, inclusive of feed plant, hatchery, processing plant, etc, in the largest continuous block of mangrove in East Africa (53,000 ha)[119]. The project was endorsed by the government in 1998 in a deal that also allowed Nolan to import over half a million dollars worth of arms into Tanzania annually[118]. However, a review of the Environmental Impact Assessment (EIA) found it to contain substantial errors, omissions and misrepresentations, including suppressed risks of the project[120]. Thirty-three thousand people resided in the proposed area in 19 registered villages and scattered sub-villages – the EIA claimed that the area was virtually uninhabited[121]. Following widespread opposition to the project by local communities, environmental organisations and academics, and as a result of legal action by villagers with support from the Lawyers Environmental Action Team and Professor Issa Shivji[118,112], this proposal was eventually rejected and the AFC went into liquidation in August 2001[123]. A moratorium was declared on all commercial aquaculture in Tanzania until the government has established proper guidelines. It was also declared that aquaculture should not be conducted in ecologically sensitive areas such as mangroves[124,125]. This laudable intervention is an example to other countries currently examining potential shrimp farm development or expansion.

> *'Local and foreign shrimp farm investors have major interests to expand in eastern Africa, which may have dire consequences for the mangroves in the region'*
>
> Dr Patrik Ronnback, Professor Ian Bryceson & Professor Nils Kautsky[112].

ABOVE: *Abandoned shrimp farm, Ruvu delta near Bagamoyo, Tanzania. After a single harvest, the subsequent attempts to culture shrimp failed, probably due to inappropriate design and water management*

© Ian Bryceson

THE RAMSAR CONVENTION ON WETLANDS

Adopted in 1971, and entering into force in 1975, this was the first global, inter-governmental conservation treaty dealing with one specific type of ecosystem. It provides the framework for international cooperation for the conservation of wetland habitats, and aims to stem the loss of wetlands and to ensure their conservation and wise use. The convention currently has 135 contracting parties; 1,235 wetlands have been designated for inclusion in Ramsar's List of Wetlands of International Importance, covering some 106 million hectares.

1 Any increase in shrimp farming in the *Reserva de la Biosfera La Encrucijada* (Mexico) might severely impact mangroves and reeds and reduce the populations of mammals, turtles, crocodiles and birds.

2 In the *Marismas Nacionales* site (Mexico) large areas of the San Blas creeks have been converted into shrimp farms, with similar developments planned.

3 At *Manchón-Guamuchal* (Guatemala) collection of shrimp larvae to stock farms is a threat, as is the further expansion of shrimp farming within the wetlands.

4 In Honduras, shrimp farms have been built in the S*istema de Humedales de la Zona Sur de Honduras* site in the Gulf of Fonseca.

5 Ecuador's *Cayapas-Mataje Ecological Reserve* Ramsar site comprises sedge marshes, tidal brackish marshes, peatlands, humid tropical forest and the tallest mangroves in the world but is threatened by illegal shrimp farms. Fish catches have declined following shrimp farm development.

6 In the *Manglares Churute* Ramsar site (also Ecuador), unauthorised shrimp farms have fragmented saline areas and vegetation in the North-west of the reserve.

7 In Peru's *Santuario Nacional Los Manglares de Tumbes*, mangroves have been cut for shrimp farming.

8 In the *Ciénaga de Los Olivitos* Ramsar site in Venezuela, increased shrimp farming and the industry's use of water resources are considered potential threats.

9 *Reentrancias Marânheses* (Brazil) is habitat for primates, turtles, manatees and over 200,000 shorebirds.

Honduras
Shrimp farms account for 64% of mangrove loss in the Gulf of Fonseca.

Ecuador
Nearly 50% of mangroves lost in the last 20 years, mainly to shrimp farming.

Sri Lanka
Over 50% of salt marshes in Mi Oya basin lost to shrimp farming.

Bangladesh
Chokoria Sundarban mangrove reduced from 7500 ha in 1967 to 973 ha in 1988, mainly for shrimp farming.

Indonesia
269,000 ha of mangrove converted to shrimp ponds (1960–1990).

OF INTERNATIONAL IMPORTANCE

During the 7th Conference of Contracting Parties in 1999, a resolution (V11.21 – 15) was passed concerning the establishment of a moratorium on shrimp farming: *'[The conference of the contracting parties] also urges all Contracting Parties to suspend the promotion, creation of new facilities, and expansion of unsustainable aquaculture activities harmful to coastal wetlands until such time as assessments of the environmental and social impact of such activities, together with appropriate studies, identify measures aimed at establishing a sustainable system of aquaculture that is in harmony both with the environment and with local communities.'* However, the moratorium has not been widely adopted or enforced.

RAMSAR SITES AT RISK

Source: Ramsar Sites Database Service [http://www.wetlands.org/RSDB/default.htm]

10 In Sri Lanka, shrimp farming has led to mangrove destruction in the *Annainilunduwa Tanks Sanctuary* Ramsar site, and farm effluent has caused eutrophication and pollution of aquatic habitats.

11 Wetlands of *Chilika Lake* (India) are under intense pressure because of shrimp farming.

12 *Khao Sam Roi Yot Marine National Park* contains Thailand's most important freshwater marshes, which are under threat by the pumping of brackish water from shrimp farms. The park's declaration as Thailand's second Ramsar Site is being opposed by shrimp farmers.

13 Mangrove cutting and adverse effects of shrimp farm effluent have impacted Cambodia's *Koh Kapik* Ramsar site.

14 In 2003, it was reported that Vietnam's *Xuan Thuy* Ramsar reserve's mangrove forest area was decreasing and being polluted by effluent from local shrimp farms

15 In *Shankou Mangrove Nature Reserve* Ramsar site (China) mangroves are being destroyed for shrimp ponds.

16 *Zhanjiang Mangrove Nature Reserve*, also in China, was reported in 2002 to be threatened by expanding shrimp farms.

Vietnam

Mangrove cover in Ca Mau estimated to have fallen from 200,000 (1975) to 60,000–70,000, largely due to shrimp farming.

Rapid loss of seasonally-inundated grasslands on Ha Tien Plain, due to shrimp farming.

Philippines

Half of the 279,000 ha of mangroves lost from 1951–1988 were developed into aquaculture ponds.

Malaysia

235,000 ha of mangrove lost to shrimp farms and other aquaculture 1980–1990.

Thailand

An estimated 253,000 ha out of 380,000 ha of mangroves destroyed, largely by shrimp farms. Shrimp farm effluent responsible for serious seagrass losses in the Gulf of Thailand.

IMPACTS ON OTHER HABITATS

Shrimp farm development has led to the degradation of other important wetland habitats, often in association with mangroves, such as salt flats, salt marshes, and even of freshwater wetlands. Loss of mangroves and other wetland habitats, and increased levels of pollution from shrimp farm development, threatens adjacent coastal and marine ecosystems, such as seagrass beds and coral reefs. In many countries, large areas of agricultural land have been converted for shrimp aquaculture. Loss and degradation of these habitats have severe implications for biodiversity, ecological integrity and food security.

ABOVE: *Seagrass beds are of great ecological value, providing habitat for a high diversity of plants and animals.*

Freshwater wetlands & Melaleuca forests in Vietnam

Although marine shrimp require brackish water, in some areas even freshwater wetlands are now being rapidly reduced by the expansion of marine shrimp farming, for example, in the wetlands of the Ha Tien-Kien Luong region of Vietnam's Mekong Delta. These wetlands harbour the last extensive remnants of seasonally-inundated grassland in the delta, with patches of *Melaleuca* forest[1]. The biodiversity is exceptional, with plant communities that are not present in any protected area, and many rare and endangered animal species such as the very rare Indochinese *davisoni* race of the Black Ibis (*Pseudibis papillosa*[2]). The area is thought to be Vietnam's only breeding site for the endangered Bengal Florican (*Houbaropsis bengalensis*), and flocks of up to 377 of the endangered Southeast Asian population of Sarus Crane *(Grus antigone sharpii)* the world's tallest flying bird have been reported[2,2a].

The wetlands are vitally important, and the seasonally-inundated grassland of the Ha Tien Plain was ranked the highest priority for wetland conservation in a 1999 Birdlife International assessment of key wetland sites. However, the area remains under tremendous threat from human activities. Of an estimated 25,000 hectares of grassland and forest on the plain in 1997, it was estimated that only 4,000 hectares of grassland remained in early 2003[2b]. Conversion of the remaining wetlands is happening extremely rapidly. Illegal shrimp ponds are being established and use of flood canals to fill them is causing salinisation of the land. Much of this area is true freshwater habitat and its loss due to shrimp farm development is likely to be irreversible[1,2]. In 2003, it was reported that the 2,200 ha *Melaleuca* reforestation project near Hon Chong mountain in this area was being encroached upon at a very fast pace, a process likely to wipe out the whole project area if no protection measures are put into effect[1]. Indeed by December 2003 it was reported that just 100 ha of habitat suitable for the endangered Sarus Crane remained, and the flock had shrunk to just 287 individuals[2c].

WETLANDS OF THE MEKONG DELTA

An estimated 80% of Vietnam's shrimp production takes place in the south of the country[3], and much of the development of shrimp farms has been around the Mekong Delta[4].

The Mekong Delta is one of the largest and most complex wetland systems in South-east Asia, and is one of the most productive and densely populated land areas in Vietnam, supporting over 14 million people[5]. With 736 km of coastline, 320,000 ha of brackish water bodies[6], and wetland covering 3.9 million ha, the Mekong Delta fulfils an important role in regional and global biodiversity conservation. Over 386 species and subspecies of birds and 260 species of fish are known from the delta, together with hundreds of other vertebrate species, including five species of dolphin and the vulnerable dugong (*Dugong dugon*)[7,8]. It is an important breeding area and migration route for waterbirds, including many globally threatened and near-threatened species[9]. Socially and economically, this is a vitally important region, accounting for approximately 52% of national rice production, 70% of fruit production and 56% of sugar production[6]. The delta includes some of the most productive agricultural land in South-east Asia, with average rice yields estimated at 2.3 tonnes/ha, and supports one of the largest inland fisheries in the world, with an average yield from the Vietnamese portion of the delta of about 400,000 metric tonnes of fish. However, yield has been reported to be declining in recent years, partly attributed to overexploitation and destruction of wetlands[7].

In the creation of shrimp farms, vast tracts of these vital wetland habitats have been destroyed and degraded[10].

BELOW: *Painted Stork* (Mycteria leucocephala).
© David Behrens

Low salinity aquaculture in Thailand

In Thailand, low salinity shrimp culture techniques have been developed to overcome seasonal limitations of brackish water shrimp farming, and shrimp farming expanded inland rapidly during the second half of the 1990s[11]. This expansion was further encouraged by increasing concern over mangrove destruction, along with recurring disease problems in coastal areas[12] (partly attributed to poor water quality induced by shrimp farming itself[13]). The low salinity culture systems spread from seasonally-brackish areas to freshwater areas, and low salinity shrimp farms that draw freshwater from existing rice irrigation infrastructure now exist over 100 km inland. By 1998, low salinity shrimp ponds were estimated to have occupied 11,200 to 22,455 ha in central Thailand, responsible for as much as 50–60% of Thailand's farmed shrimp exports[14]. However, detrimental effects on neighbouring rice fields[15] (with rice yields reportedly reduced by as much as 50% in some areas[16]), high incidences of conflicts between rice farmers and shrimp farmers[13] and the potential for serious environmental problems in the country's main rice production area[17] drove the National Environment Board to impose a ban on inland aquaculture in 1998. The ban resulted in protests, petitions and requests for compensation from shrimp farmers[18], and the government has come under significant pressure to lift the ban for economic reasons. At the time of writing, the ban still held, with the backing of many civil society groups and academics. However, some authors have expressed concerns that the ban could lead to renewed pressure on conversion of coastal areas for shrimp production[13].

ABOVE: *Floating Bazaar. Snail collection, Bangladesh.*

© Philip Gain / SEHD

Freshwater shrimp aquaculture in Bangladesh

In Bangladesh, farming of the freshwater prawn, *Macrobrachium rosenbergii* generally has fewer impacts than that of the brackish water species *Penaeus monodon* yet still impacts large areas of freshwater wetland habitats. Conversion of these wetlands has been linked to reduced biodiversity, reduced agricultural production, and population declines of ecologically important species (such as the 'farmer's friend', the Indian bullfrog *Rana tigrina*). The reduction in wetland habitats is also reported to have affected beel (shallow lake and swamp) fisheries; access to these fisheries has been reduced, and local fishermen have reported reduced catches and incomes. Additionally, canals used as common fishing grounds have been converted for shrimp ponds, while fishing around shrimp culture areas is reportedly prevented by shrimp farm guards in many areas. Feeding practices for the prawns have led to drastic falls in the populations of the ecologically-important freshwater snail, *Pila globosa*, a preferred source of feed – up to 66.5kg of the snail are used for each ha of pond every day. Snails are critically important in the freshwater aquatic *'beel'* systems, acting to filter the water and providing an important source of food for fish; removal of the snail is likely to result in an increase in aquatic macrophytes, which could lead to eutrophication of water bodies. The impacts of their loss are likely to be far-reaching, and the reduction in their numbers is believed to be one cause for pollution in inland waters[19].

Chilika lake

Chilika, connected by a narrow channel to the Bay of Bengal, is the largest brackish water lake (lagoon) in India[20] and has been designated a Wetland Site of International Importance under the Ramsar Convention. In addition to supporting some 60,000 fishermen[21], the lake provides important habitat for 118 fish species[21], over one million migratory birds[22] of 130 species[23], and the endangered Irrawaddy dolphin *(Orcaella brevirostris)*[20]. In 1996, India's Supreme Court ruled that no new shrimp aquaculture operations be allowed within 1,000 metres of Chilika Lake[24,25,26,46]. However, the ruling had little effect on shrimp industry practices[27,46]. Around Chilika Lake, 'mafias' remained undeterred and constructed shrimp farms, allegedly with the support of local politicians, in violation of this order[25]. In 2003, it was reported that continued collection of tiger prawn larvae in Chilika Lake has had serious impacts on 30 aquatic species whose juveniles are killed as bycatch when shrimp are targeted and that illegal shrimp farm embankments impede sediment flow and contribute to siltation of the lake[28]. Disease has caused mass mortality of farmed shrimp around the lake in 2003 and there are concerns that this may impact the ecology of the lake and wild shrimp populations[29].

'There is food – luxury food – being grown everywhere: in the shrimp ponds, in Chilika Lake itself, in the nearby fields which once grew rice. But the fisher community is devastated, and the daily catch is reduced to almost nothing'

FARIS AHMED, IN DEFENCE OF LAND AND LIVELIHOOD[30].

Shrimp Aquaculture and Legislation in India

Shrimp farming has experienced rapid growth in India where its impacts have led to serious environmental concerns and violent social conflict. A World Bank funded report cited mangrove loss, salinisation and pollution of land and flooding of crops among the environmental problems 'threatening the long term sustainability' of shrimp farming in India[31].

Following years of social conflict resulting in a number of deaths, in 1996 India's Supreme Court issued a landmark ruling against the shrimp farming industry. It required industrial shrimp aquaculture operations acting within the coastal regulation zone (500 m from the shore) or within 1,000 m of Chilika Lake and Pulicat Lake to cease all operations, and that local farmers and workers adversely affected by the industry be compensated. It also ruled that no new shrimp aquaculture operations be permitted in this zone[24,25,26,46]. Whilst an important legal victory on paper, the ruling had limited real impact[27,46]. It was followed by the 1997 Aquaculture Bill, which allowed existing farms to continue operations and introduced a farm licensing system. However, many farms failed to acquire licenses and few unlicensed farms closed[32].

In 2003, it was reported that 848 ha of shrimp farms ordered to be destroyed by the Supreme Court in Jatasinghpur district were still in existence[33]. In July 2003, 26 arrest warrants were issued relating to conversions of agricultural land in Kujang, Ersama and Balikuda areas after shrimp farms earlier demolished by authorities had been rebuilt and agricultural land polluted and rendered barren[34]. In November 2003, villagers' protests against illegal shrimp farms in Cuddalore district were reported to have been met with police brutality which included 'mercilessly' beating women with lathis (truncheons)[34a].

ABOVE: *Villagers around Chilika Lake re-enact a peaceful protest against the shrimp industry in 1994 during which they blocked the key train route between Madras and Calcutta. Their peaceful action brought widespread media attention to the plight of Chilika's fisher community*[30].

Salt marshes

In Sri Lanka, approximately 76% of shrimp farms have been developed in intertidal areas that were previously classified as mangroves, salt-marshes and intertidal mudflats[35]. The salt marshes in the Puttalam / Mundal estuarine system, and in particular those on the Mi Oya flood plains, have been severely threatened by the advent of shrimp farming in the area, with over 200 ha of salt marshes around the Puttalam lagoon, and over 50% of the salt marshes in the Mi Oya basin lost to shrimp aquaculture[36,37]. Similarly, Ecuador reportedly lost a considerable area of salt marshes associated with mangroves between 1969–1998, mostly due to conversion to commercial shrimp ponds[38].

Tam Giang Lagoon

Seventy kilometres long and with an area of 22,000 ha, Tam Giang Lagoon in Vietnam is the one of the largest lagoons in Southeast Asia. It is an important aquatic environment, supporting a rich fish and invertebrate fauna, is a major staging and wintering area for migratory waterfowl, and an important source of natural resources for human utilisation. 300,000 people have settled around the lagoon and earn their livelihood by directly or indirectly exploiting its resources[39], which include molluscs, crustaceans and over a hundred fish species. Annual finfish production alone was estimated to be 3,600 metric tonnes in 1997[40]. Disease has ravaged large areas under aquaculture development, and many shrimp ponds are now polluted and abandoned[39]. Salinisation of agricultural land following dike destruction has led to conflicts around Tam Giang Lagoon[39]. Shrimp aquaculture development around the lagoon has also led to conflict over land allocation between fishers and shrimp farmers – much of the land has now been enclosed, and local fishers, especially the very poor, are unable to access resources on which many of them depend for their livelihoods[41]. This has led to intentional damage of aquaculture structures, presumably by angry fisher-folk[39].

ABOVE: *Net enclosure shrimp farming in Tam Giang Lagoon, Vietnam.*
© Thornton / EJF

Enclosure of Open Access Areas

Being in the tidal zone, many wetlands lack a history of ownership, clear tenure rights or any official delineation of property rights[42], and have traditionally been used as open-access lands, a factor which has contributed to their loss as a result of shrimp farm development. Enclosure of, and loss of access to, such areas and their resources has resulted in households increasingly being excluded from previously available livelihood sources. On the other hand, the spread (and in some cases subsequent failure) of shrimp farming operations has in some cases caused an increased reliance on open-access resources[42].

Impacts on agricultural land

Large tracts of agricultural land have been converted to shrimp farms because of the latter's high profit potential (for example three times that of rice cultivation in Bangladesh[43,44]), and, in a number of countries, active government support (in the form of subsidies, tax breaks or preferential loans). For example, in Thailand it has been estimated that nearly 50% of land used for shrimp pond production may have formerly been used as rice fields[45]. Furthermore, because of declines in crop yields on land adjacent to shrimp farms or, in some cases, deliberate inundation of land, poor farmers are often forced to sell land at deflated prices or turn to shrimp farming themselves[46,51]. As a result, previously productive agricultural land is increasingly used to farm shrimp for export, impacting local food security.

In Bangladesh, increased soil salinity due primarily to shrimp farming was recently implicated in a 68% decline in tree cover between 1985 and 2000 in one area of Satkhira District[47], while in Rampal, Bagerhat District, such salinisation is believed by local communities to have led to the loss of half of the 32 crops traditionally grown[48]. In other areas of Bangladesh there are numerous reports of declines in crops, fruit trees and rice yields and of impacts on livestock following the onset of shrimp aquaculture[19].

In Vettapalem, India, 1,000 ha of rice fields that previously fed 10,000 families were reportedly lost to shrimp farm development and associated salt pollution[49]. In Vietnam's Ca Mau Province, a reported 125,000 ha of rice fields were converted to shrimp ponds in 2001; rice production that year fell by 460,000 tonnes[50].

Conversion of agricultural land has had significant impacts upon crop and livestock production, and on the health, income and employment of rural communities. The consequences for the poorest and most vulnerable members of society, and especially those who rely on access to government owned land or common resources, have been particularly profound, with landlessness and indebtedness on the increase. The social and economic impacts of shrimp production, and impacts of agricultural productivity, are discussed in greater detail in EJF's companion reports, *Smash & Grab*[51], *Risky Business*[10] and *Desert in the Delta*[19].

For some, the conversion to shrimp production can bring increased income and improvements in living conditions. However, shrimp farming is characterised by very high levels of risk, which exposes poor farmers to financial ruin and can promote increased socio-economic disparity.

BELOW: *The conversion of agricultural land for shrimp aquaculture has affected the health, income and employment opportunities of local communities in shrimp producing areas.*
© Trent / EJF

Integrated shrimp farming systems

While conversion to commercial monoculture shrimp farming can impact agricultural productivity, in some cases conversion to integrated shrimp or polyculture farming systems can bring benefits for small-scale farmers and may represent more ecologically sustainable approaches to shrimp farming.

Polyculture incorporates several species occupying different ecological niches into a single farming system[52]. This can improve resource-use efficiency, and, on a farm level, can help to insure against risks of disease or changes in market conditions. Such systems can be closed and relatively self-sufficient[53] and integrated farming technologies where resources and wastes are re-circulated within the farm may be one way of reducing the ecological footprint of shrimp farming[54]. Some traditional coastal systems incorporating polyculture include: Indian *pokkali* combining rainy season rice and fish culture with dry season extensive fish and shrimp culture; Indonesian *tambak* ponds of integrated mangrove, fish and shrimp culture, and Philippine *tumpang sari* ponds integrating mangroves, fish, shrimp and molluscs[52,55].

In Hong Kong, *gei wai* ponds integrate shrimp production (primarily *Metapenaeus ensis*) with the culture of fish (such as Grey mullet, *Mugil cephalus*), oysters, algae and brackish water sedges[56]. At the Mai Po Nature Reserve, the 240 ha of traditional *gei wai* ponds exist around large areas of mangroves, reed-beds and sedges, and have been highlighted as an example of sustainable wetland management. The ponds are naturally stocked and, after harvesting, non-commercial species left in the ponds provide a food source for large numbers of birds, including the endangered Black-faced spoonbill (*Platalea minor*). Over 400 invertebrate species have been recorded in the Reserve's 46 ha of reed-beds (one of the largest remaining stands in Guangdong Province), and over 500 pairs of herons and egrets were recorded nesting in one *gei wai* mangrove stand[56].

ABOVE: *Gei wai shrimp ponds at Mai Po Nature Reserve showing reedbeds (brown) and mangroves (dark green).*

Recirculating integrated systems can offset costs with revenues from hydroponic vegetables and seaweeds produced in the treatment of wastewater[53,57], and recirculating systems that produce high-quality fish, shrimp and hydroponic produce without the need for energy intensive waste treatment are currently being developed in the USA[53]. Applied research into such systems, and into the adaptation of traditional polyculture models should be supported.

In Vietnam, alternative cropping of wet season rice and dry season shrimp is widely practiced throughout areas of the Mekong Delta coastal provinces affected by salinity[58]. Recent research showed that the diversification of income within this system can reduce the financial risks associated with shrimp aquaculture whilst providing staple foods for household consumption, and found that in general farmers using this system managed to achieve financial sustainability[58]. However, the study found that the practice of 'free' natural shrimp recruitment during water exchange was not environmentally sustainable, with sedimentation of the ponds leading to loss of both rice and shrimp land. The study recommended low-water exchange and artificial stocking with hatchery reared post-larvae to improve sustainability, though widespread adoption of this system is constrained by shortages in the supply of post-larvae and high incidence of viral disease in the shrimp stock[58]. A further concern is a trend towards intensification of rice-shrimp systems[58], with some farmers abandoning the rice crop cycle entirely, increasing environmental and financial risks[10].

Integration has also been beneficial in Bangladesh, where seasonal waterlogging in some areas limits farmers to a single rice crop per year and harvests are significantly lower than in other parts of the country. In such areas, some small-scale farmers have benefited from exchanging a rice-only cropping system to rotational cropping with prawn (freshwater), whitefish and vegetables[59]. However, in some areas there have been reports of reduced crop yields and reduced soil fertility (linked to pollution, sedimentation and delayed draining of ponds) and increased prevalence of 'stem root' virus following development of rotational shrimp farming systems (both freshwater and brackishwater)[43,44,60,61,62,63,64].

In Vietnam, promotion of mangrove-shrimp farming systems has been a positive development in many ways[10]. However, concerns have been expressed over the actual models being used. With current systems, both shrimp harvests and mangrove survival and ecology are reportedly affected[65]. The integrated systems also alter an area's suitability for mangrove growth, and accelerate succession from mangrove to terrestrial/inland species[66]. Further research into sustainable models for these systems should be supported.

Seagrass beds and coral reefs

In many areas, the typical coastal profile moves from mangroves to shallow waters with seagrass beds, to offshore coral reefs. Mangroves, seagrasses and coral reefs can all occur in isolation, but research has shown substantial physical and biological interaction between the ecosystems where they coexist[67].

Shrimp farms directly pollute coastal waters, releasing effluent containing both chemical and organic waste, which can lead to nutrient enrichment (and in some cases eutrophication) of coastal waters. In addition, shrimp aquaculture development has caused widespread mangrove and wetland destruction in tropical areas, removing the natural filters for terrestrial pollutants and sediments. Increased erosion, siltation and pollution that can occur following mangrove and wetland destruction can lead to degradation of coral reef and seagrass habitats[67,73,75,76,77,89].

Seagrasses require high levels of light due to their complex below-ground tissues[78]. Most seagrass losses are attributed to reduced light intensity due to sedimentation and/or increased epiphytic algal growth caused by nutrient enrichment[68,70]. In a number of areas, this may be linked to increased terrestrial runoff associated with shrimp aquaculture development[70,79]; for example, effluent from shrimp farms has led to serious seagrass losses in the Gulf of Thailand[70].

Corals require nutrient-poor waters of low turbidity for vigorous growth[82]. It is estimated that nearly 50% of reefs in Vietnam and Taiwan Province of China, and 35% of reefs in the Philippines are threatened by sedimentation, while studies at various sites in Indonesia have shown a 30–60% decrease in coral diversity as a result of pol-lution and sedimentation[67]. Aquaculture, along with other coastal development, and the destruction of mangroves, wetlands and seagrasses which act as sed-iment traps and filters, are of significant concern[67,82].

(See Annex II: Seagrasses and Coral Reefs, page 73.)

ABOVE: *Mangrove root, soft coral and seagrass.*

BELOW RIGHT: *Dugong* (Dugong dugon)*: highly dependent on seagrass beds.*

'Habitat loss is serious in the Gulf of Thailand as a result of effluent from shrimp farms'

United Nations Environment Programme Dugong Early Warning and Assessment Report[70].

'The impact on water quality, particularly nutrient run-off on to seagrass beds and near-shore corals is the primary threat from prawn farming on the coast.'

Great Barrier Reef Marine Park Authority, Australia[73a].

POLLUTION

ABOVE: *Outflow from shrimp ponds, Ecuador.*

'Shrimp farming will be Vietnam's final choice, because it is so damaging to the environment, and so polluting to the soil, trees and water; that it will be the last form of agriculture. After it, you can do nothing'

DR DUONG VAN NI, HYDROLOGIST AT CAN THO UNIVERSITY[18].

Shrimp aquaculture both causes pollution and is affected by it. In many non-extensive commercial shrimp aquaculture systems, farmers use high stocking densities, and high levels of feed, pesticides, antibiotics and other chemicals in efforts to maximise profits and combat disease. However, there is concern over the ecological and health impacts of some chemicals used, and both chemical and organic waste produced from shrimp farms pollutes the marine environment. This pollution, together with increased salinisation from shrimp ponds and high levels of exploitation of freshwater resources, can leave agricultural land and drinking water unusable. Pollution may be exacerbated by the location of shrimp farms in mangrove and other wetland areas, due to acidity of soils and the loss of natural filtering services provided by these habitats.

Shrimp farming often requires relatively high capital inputs and consequently requires commensurate financial rewards. In order to maximise profits many intensive and semi-intensive commercial farms stock shrimp at very high densities. Purchase of post-larvae to stock ponds is typically a very large investment, and shrimp survival is crucial if a farm is to be economically viable. In many cases, this leads to the use of high levels of feeds, pesticides, antibiotics and other chemicals to combat the stress and susceptibility to disease caused by overcrowding. This can be exacerbated when shrimp farms are located in mangroves, where soils often have high acid sulphate potential, and elevated acidity can stress the shrimp.

Shrimp are sensitive to environmental change and low oxygen concentrations, and in more intensive systems large water exchange rates are often required to maintain oxygen levels and discharge of wastes, though this has been reduced in recent years due to risks of disease spreading (particularly in Thailand). Water exchange typically involves pumping water in from surrounding rivers or groundwater supplies (which can deplete fresh water sources), and then pumping out waste water from the ponds into canals, rivers and near-shore waters to remove unwanted nutrients, dissolved gases, phytoplankton and pathogens. This can lead to contamination of fresh ground and surface-water supplies; contamination of surrounding land by polluted, saline and sometimes acidic pond-waters which can leach into the surrounding soils; and coastal pollution, which can deplete wild fish and shrimp stocks. Resultant deterioration in water quality can promote disease outbreaks and subsequent declines in farm productivity[1].

Such impacts, combined with increased levels of pollutants from agriculture and coastal development, are exacerbated further by the removal of mangroves and wetlands for shrimp ponds. These ecosystems and associated seagrasses maintain water quality by filtering or degrading toxic pollutants and may be capable of absorbing excess nutrients and sediments discharged by shrimp farms[10], and helping to control pathogen populations[11,12].

In more intensive systems, as much as 30% of pond water may be flushed out each day; in Thailand alone, shrimp ponds have been reported to discharge approximately 1.3 billion cubic metres of effluent annually[13]. More recently, the shrimp aquaculture industry has been developing closed shrimp production systems, with low or zero water-exchange or circulation systems, to reduce disease and control effluents[14]. However, these systems are expensive and many farms still use high water exchange rates; in many countries, few of the smaller-scale operations treat effluent prior to release. Additionally, even if effluent from individual ponds falls within reasonable quality standards, the high concentration of farms in many areas can eventually lead to pollutants exceeding the carrying capacity of nearby coastal waters[15]; shrimp pond abandonment in a number of countries has been attributed to the proliferation of initially successful farms that ultimately overwhelm the system, triggering disease outbreaks[16]. Coastal waters and estuaries have high pollutant retention, so pollution may continue to harm the ecosystem for some time after discharges have stopped or farms have been abandoned[17].

BOTTOM: *Shrimp farm effluent pipe, Guayas Province, Ecuador.*

Credit: Shanahan / EJF.

Contributory factors

In many countries where shrimp farming has developed rapidly, shrimp farmers' lack experience of, or access to information on, appropriate aquatic health management measures[2] is a key problem. For example, antibiotics are often used against viral diseases, upon which they have no effect[3]. In addition, in some countries, misleading advertising claims occur[4,5] and private companies promoting their products may encourage overuse[6]. Some antibiotic products available for shrimp farmers in Thailand are wrongly marketed as cures for viral diseases[7].

Although some chemicals have been banned in major shrimp producing countries because of health concerns (e.g., chloramphenicol in Thailand and Vietnam), enforcement remains an issue and in a number of cases these chemicals remain available illegally.

In many countries quality assurance of aquaculture chemicals can be a problem, making appropriate use much more difficult. A survey in Thailand found that labels often lacked vital information such as the active ingredient name and percentage by volume, or instructions for safe and efficient use[6], and many chemicals are sold with inconsistent drug concentrations. In Asia, the practice of re-packaging can be widespread, in some cases resulting in the complete loss of label information[2]. During repackaging, products may also be contaminated, diluted or 'improved', making correct dosing even more difficult[2].

Assessing risks posed by aquaculture chemicals is constrained by lack of data on environmental fate and effects. When chemicals have not been developed specifically for aquatic use, predicting synergistic, additive or antagonistic effects is difficult and sometimes impossible[2]. In addition, lack of studies from tropical and marine systems often makes it necessary to refer to data from temperate and freshwater climates, while temperature and salinity may influence effects[8].

Poor pond design, and particularly design of water exchange systems, also contributes to increased pollution from shrimp farms. In some countries (such as Vietnam), many small-scale shrimp ponds have been constructed by shrimp farmers with limited resources and experience[9]. In such cases, effluent discharge and water uptake are often to and from the same water body, through the same canal, with no water treatment either prior to pond filling or before discharge, and with exchange of water between neighbouring farms[9].

Pollutants associated with discharge from more intensive shrimp ponds can include organic waste such as faeces and unused food, soil and water treatments, fertilisers, disinfectants, antibacterial agents, other therapeutants, pesticides, herbicides, algaecides and feed additives. Concerns surrounding such pollutants include: their persistence in aquatic environments; the possibility of residues in non-cultured organisms; their toxicity to non-target species; promotion of resistance in both target and non-target species; possible effects on sediment bio-geochemistry; problems associated with nutrient enrichment; as well as possible effects on the health of farm workers and consumers[2].

There is no clear distinction between the different groups of substances. For example chlorine, which is used as a disinfectant to kill bacteria and viruses, can also be used as an algaecide, a herbicide, or to regulate the pH of the water[8]. Generally, there is very little reliable information about the quantities of the various chemicals used in shrimp aquaculture[2,8] but there are reports of high levels of use in some cases/countries. For example, a report published in 2001 included an estimate that around 50,000 tonnes of chlorine were used annually in Thai shrimp farms alone[8]. Current figures are unavailable, but are thought to be substantially lower today.

Nutrients and organic waste

In the absence of published information on shrimp nutrient requirements in pond-based farming systems, almost all commercial feeds used are usually over-formulated and meet a standard of providing nutritionally complete diets, regardless of different stocking densities and natural food availability in farm systems[14].

Consequently, significant amounts of waste can accumulate in the form of uneaten food, faeces, ammonia, phosphorus and carbon dioxide[15,19]. Nutrient balance estimates for intensive Thai shrimp farms indicated that only 23% of total pond nitrogen input and 12% of total phosphorus input were incorporated into new shrimp biomass over the production cycle;

BELOW: *Shrimp farm ponds with effluent receiving channel in foreground, Khao Sam Roi Yot National Park, Thailand.*

© Williams / EJF

22% and 7% of these, respectively, were released from the pond through routine water exchange[20]. Overfeeding is also a significant problem: where feed supply exceeds both consumption and the inherent ability of the pond ecosystem to remove material via remineralisation, excess feed can pose a threat to the integrity of pond bottoms and can encourage disease[21].

Shrimp pond effluent high in organic matter can have a high biological oxygen demand (BOD), resulting in oxygen depletion in receiving waters[22]. Shrimp farms have been implicated in a number of cases of fish deaths, eutrophication of coastal waters[10,23] and harmful algal blooms[22,24], which can have severe impacts on associated seagrass beds and coral reefs[25], and on fisheries and livelihoods dependent on them[11].

Increased levels of dissolved organic nitrogen and phosphorus, total dissolved nitrogen, suspended solids and chlorophyll-*a* have been reported in creeks receiving shrimp farm effluent compared to those in pristine mangroves[8]. Brackish water shrimp farming was shown to contribute 90% of organic matter entering the Tulang Bawang River in Lampung, Indonesia, and red tides – growth of harmful algae – have been reported for the area south of a PT Central Pertiwi Bratasena shrimp farm in Lampung[26].

Of particular concern is pollution associated with pond sludge removed after harvest. The sludge has higher concentrations of organic matter accumulated during shrimp development and pollutants may be actively flushed out of ponds with high-pressure hoses or passively discharged to the environment following re-suspension during harvest[27].

'[Research in Thailand] estimated that the 40,000 ha of intensive shrimp ponds operated in 1994 produced the waste equivalent of 3.1–3.6 million people for nitrogen and 4.6–7.3 million people for phosphorus. This is equivalent to increasing the population of the coastal zone by 50–100% without any sewage treatment'

Swedish University of Agricultural Science Research Report Funded by Swedish Government[31].

In Texas, USA, poorly sited coastal shrimp ponds have damaged shallow, environmentally sensitive lagoons through siltation and eutrophication[28]. For example, discharges of solids from shrimp farms are thought to have contributed to the creation of a 15-acre sediment delta in the Laguna Madre[28]. The environmental degradation caused by shrimp farming has spurred lawsuits by grassroots organisations, and a coalition of coastal residents, environmentalists and recreational fishermen have been working to achieve major changes in the way shrimp farms are operated and regulated[29]. Following the enactment of environmental regulations in Texas, several shrimp farms have changed management practices and built retention ponds, reportedly reducing discharged solids and ammonia levels by 98%[30].

Antibiotics

In an interview study undertaken in Thailand in 2000, it was shown that more than 60% of the farmers used antibiotics prophylactically[7]. Additionally, 20% of all the interviewed farmers used antibiotics against viral diseases[7].

The high risk of disease within intensive and semi-intensive systems, and the enormous potential financial losses, have led to widespread intensive antibiotic use during shrimp production and during the sterilisation of ponds between harvests. Prophylactic use is particularly common in shrimp hatcheries, and can make shrimp larvae more susceptible to disease once released, further promoting use of antibiotics and other chemicals in ponds[2].

High therapeutic and prophylactic antibiotic use increases risks of resistant strains of pathogens emerging and the possible loss of efficacy of these

ABOVE: *New Hope? Shrimp farm antibiotic packaging in Vietnam. Antibiotics are widely used in shrimp aquaculture, often incorrectly, raising concerns for the health of consumers and local people and for the wider environment.*

© Shanahan / EJF

'Antibiotic residues in food is not only a threat to shrimp consumers in importing countries, but also a threat to people living in shrimp farming areas'

DR SARA GRÄSLUND, DR KARIN KARLSSON & DR JANENUJ WONGTAVATCHAI, 2002[7].

drugs, both for shrimp farming and for wider medicinal uses. There is also the possibility of antibiotic build up in shrimp, with concerns for the health of consumers, and as antibiotics can enter the systems of non-cultivated animals, other food products (such as mussels, which are often collected and eaten by local people[7]) may be affected. Many of the antibiotics used in shrimp farming are, to a degree, persistent in the environment, where they can affect ecosystem's bacterial assemblages and where they can have acute toxic effects on aquatic animals and plants[7].

Antibiotics may be administered as baths or feed supplements. Even where given with feed, a large proportion is released to the surrounding environment. This is true in particular with oxytetracycline, one of the most widely used antibiotics in aquaculture. Because of feed waste and limited absorption by the shrimp gut, it is probable that over 95% of oxytetracycline provided is not assimilated, has no therapeutic value and leaves the pond via the effluent[32]. Oxytetracycline is among the most persistent of antibiotics in sediments; it is not microbially degraded, and under conditions of rapid sedimentation, as would be expected near many aquaculture facilities, may persist indefinitely[32].

Of particular concern for human health are the use of both chloramphenicol and nitrofurans in shrimp aquaculture. Chloramphenicol is a broad spectrum antibiotic also used to treat bacterial meningitis and typhoid. Its use in food is banned in the EU, USA and Japan due to perceived health risks to consumers, including a dose-independent link between chloramphenicol and aplastic anaemia, a rare and often fatal disease[2]. The chemical also poses an occupational health hazard to those handling it. Nitrofurans (a group including nitrofurazone and furazolidone) are considered to be potential carcinogens[33] and are also banned for use in food-producing animals in the EU and USA[2,34].

Use of these antibiotics in shrimp production has led to trade restrictions and suspension of imports for a number of producer countries in recent years, and their continued use makes future bans likely. In addition to the economic impacts of these controls, such actions also risk leading to products that have failed to meet standards being released onto domestic markets[2].

The risk of development of resistant bacteria is a serious cause for concern and is considered to be one of the most important reasons to control the use of antibiotics in aquaculture[7]. A 1995 report by the American Society of Microbiology singled out the use of antibiotics in aquaculture (not just shrimp) as potentially one of the most important factors leading to the evolution of antibiotic-resistant bacteria[35].

A recent analysis of the development of resistant bacteria in shrimp farms in Thailand found that 77% of bacteria tested from farmed shrimp were resistant to one particular type of antibiotic (sulfonamides), while more than one third of the bacterial strains tested carried multiple resistance[36]. Antibiotic-resistant bacteria have reportedly been found in ready-to-eat shrimp in the USA[37], and resistance to some antibiotics commonly used in southeast Asian shrimp farming is already reportedly developing in human as well as shrimp pathogens[8]. Furthermore, some antibiotics can cause bacteria to develop resistance not only to that specific antibiotic, but also to other antibiotics[7]. Resistance-encoding elements can also be transferred between bacterial species, meaning that bacteria can become indirectly resistant to an antibiotic without being directly exposed to it[7].

Other chemicals

The most common products used in shrimp aquaculture are liming materials and fertilisers promoting phytoplanktonic ('micro-algal') growth[8]. Others include pesticides, disinfectants, other soil and water treatments, probiotics and feed additives. Liming materials are used globally to neutralise soil and water acidity, particularly to neutralise acid sulphate resulting from oxidation of pyrites in ponds constructed in mangrove areas. Fertilisers are widely used to increase growth of natural food, but may also cause soil and water conditions to deteriorate if applied indiscriminately[2,8]. Along with artificial feed, these contribute to the high nutrient content of effluent.

The term 'pesticides' can be used in a broad sense to include disinfectants, or chemicals targeting a certain group of organisms – the more specific pesticides can be used in shrimp ponds to kill fish, crustaceans, snails, fungi and algae. Disinfection, or elimination of pathogens, can be obtained by heating, UV-radiation and a large number of chemical compounds. These are used in large quantities to disinfect equipment, prepare ponds, control phytoplankton and sometimes to treat disease[8]. For example, in Vietnam, chlorine and formaldehyde use is widespread for pond preparation and sterilisation, and some farmers wash shrimp in formaldehyde (1–2 ppm concentration) to reduce risks of disease and parasites[38].

A number of the pesticides and disinfectants used have been implicated in the deaths of shorebirds and finfish, affecting local wildlife populations and communities dependent on these[39]. Toxic levels of formalin and tea-seed (a plant-derived toxin) can occur in adjacent waters during drainage of pond water soon after application[40] and the discharge of tea-seed has been associated with mass fish deaths in associated mangrove areas[41].

By-products from chemicals used in disinfection can also have environmental impacts. For example, chlorine added to natural waters can react with organic substances and ions such as bromides, resulting in significant concentrations of halogenated hydrocarbons, several of which are known to be carcinogens and some of which have a high acute toxicity[8]. Chlorate, an inorganic by-product found in water disinfected with chlorine dioxide or hypochlorite, is highly toxic to marine macro brown algae. All oxidising agents that are effective in water treatment will create oxidant by-products that are potentially toxic, and even though oxidising agents themselves may disappear within hours of disinfection, these by-products may be persistent[8].

Environmentally, chemical persistence is of major importance. Persistent chemicals and their by-products can affect organisms within ponds, and in different ecosystems, through bio-accumulation, bio-magnification and physical transport[8]. Persistence of residues strongly depends on environmental conditions, and the persistence of aquaculture chemicals in tropical environments has not been thoroughly studied[8]. However, it is thought that chlorpyrifos (an organophosphate pesticide) originating from aquaculture in a tropical environment can be sufficiently stable to contaminate marine sediments, and several antibiotics, such as oxytetracycline and oxolinic acid, have been found in sediments six months after treatment[41]. It has also been reported that organotin pesticides are persistent enough to be present in fish 6–12 months after application, at levels that could have a negative effect on humans consuming the fish[41].

Insecticides, heavy metals, fuels and lubricants can be present in the ponds, while structural materials such as plastic can contain additives such as stabilisers, antioxidants, fungicides and disinfectants which can have an adverse affect on aquatic life if leached[8].

ABOVE: *Endosulfan, a pesticide used in Asian aquaculture. Persistent chemicals and their by-products can affect organisms both within shrimp ponds and in different ecosystems through bio-accumulation, bio-magnification and physical transport*[8].

Some chemicals used in shrimp aquaculture[2,6,8,27,42,43,44,45]

Liming materials

E.g.

Calcium oxide (CaO), Calcium hydroxide ($Ca(OH)_2$), Agricultural limestone ($CaCO_3$), Dolomite ($CaMg(CO_3)_2$).

Why?

To increase pH, especially in acid mangrove soils. Some also used to kill fish before stocking.

Risks:

High pH can be a risk if spilled. Corrosive to eyes, skin, respiratory tract. May cause dermatitis.

Coagulants

E.g.

Alum (aluminium potassium sulphate), Gypsum (calcium sulphate), Aluminium sulphate, Zeolite (an aluminosilicate clay), EDTA (disodium ethylene diamine tetraacetic acid).

Why?

Used to settle suspended particles, reducing turbidity. EDTA can reduce availability of heavy metal ions.

Risks:

EDTA and aluminium sulphate are irritants and toxic to aquatic organisms.

Fertilizers

E.g.

Organic (chicken, cow and pig manure and urea) and inorganic (ammonium phosphate, diammonium phosphate, ammonium sulphate, calcium nitrate, calcium sulphate).

Why?

To promote algal growth.

Risks:

Can promote oxygen depletion, eutrophication, and nitrification. Nitrogen, phosphorus and potassium fertilizers can irritate skin. Prolonged KNO_3 exposure linked to anaemia.

Disinfectants

E.g.

Potassium permanganate, hydrogen peroxide, iodophores (stabilised iodine), formalin, glutaraldehyde, Quaternary ammonium compounds (e.g., benzalkonium chloride) bleaches (calcium/sodium hypochlorite), malachite green (banned in EU & USA), ozone.

Why?

To disinfect water and equipment (e.g., to control viruses and bacteria).

Risks:

Spills can cause mortality of aquatic organisms due to high toxicity. Release of chlorinated water without neutralisation may have local impacts. Most are irritants and pose human health threats.

Pesticides

E.g.

Organophosphates (e.g., azinphos ethyl, dichlorvos, trichlorfon, malathion, diazinon, chlorpyrifos, monocrotophos, parathion), Organochlorines (e.g., endosulfan), Carbamates (e.g., carbaryl), nicotine (tobacco dust), rotenone, paraquat, copper sulphate, butachlor, Azuntol (cumaphos) trifluralin, formalin.

Why?

To kill fish, snails, parasitic worms, ectoparasites, and other shrimp disease agents (in ponds and hatcheries)

Risks:

Many are toxic or highly toxic to aquatic organisms, some are persistent in soil, water and bioaccumulate in food chain. Some classed as highly or extremely hazardous to human health by World Health Organisation. Some carcinogenic pesticides used.

Antibiotics

E.g.

Oxytetracycline, tetracycline, oxolinic acid, erythromycin, quinolones, sulfonamides, rifampicin, chloramphenicol, nitrofurans (furaltadone, nitrofurazone, furazolidone).

Why?

To treat shrimp disease in ponds and hatcheries.

Risks:

Promotion of antibiotic resistance in pathogens, threats to benthic microbial communities and natural bacterial decomposition in bottom sediments, health risks to humans, e.g., hypersensitivity. Some antibiotics used are banned by EU / USA in food production, e.g. chloramphenicol (link to aplastic anaemia & leukaemia) and nitrofurans (suspected carcinogens). In 2002, alerts were circulated about 43 separate consignments of shrimp entering Europe because of detection of these antibiotics .

Other inputs

Probiotics

E.g., Bacillus bacteria or living yeasts. Used to aid digestion, to increase rate of organic decomposition, or compete with pathogens.

Feed attractants

A 'start eating' stimulant for larvae

Steroid Hormones

Not common but may be used in hatcheries to make larvae appear healthy

Anaesthetics

E.g., benzocaine, quinaldine – small quantities used in broodstock transport.

Immunostimulants

E.g., yeast glucan, peptidoglycans, lipo-polysaccharides, Vibrio bacteria. Used to boost shrimp immune system.

Photo © Ann Wahlstrom / Katrin Holstrom

Chemical effects on micro-organisms, sediments & water

Antibiotic residues in bottom sediments can affect natural bacterial composition and activity, changing the ecology of these communities[7,8]. Resultant increased or decreased microbial activity can lead to anaerobic conditions, which in turn can result in more toxic by-products such as sulfides, and can reduce rates of organic matter degradation, leading to reduced water quality[8]. Chloramphenicol may also disturb denitrification, further reducing water quality. Persistent residues from chemicals that accumulate in sediments may be present after ponds have been abandoned, a factor that should be considered in pond management.

'Only the rich make money, the big outside investors, who come because they have already polluted their own land and they need virgin territory. Then when it goes wrong here, they move on.'

Anonymous, Vietnam National University, Ho Chi Minh City[18]

Salinisation of soils and water

Water exchange from shrimp aquaculture, seepage through ponds, mangrove and wetland loss, changes in the hydrology of local watersheds and the inundation of land associated with shrimp aquaculture can lead to ground and surface water supplies being subjected to salt water intrusion. The impact of this can be very variable, depending on local hydrology and salinity, soil properties and pond management practices[27], but it can result in irreversible changes in soil composition of ponds and surrounding areas, which can reduce the productivity of land or render it infertile. In many areas, saline intrusion occurs naturally and can affect land productivity in the absence of shrimp culture[49]; however, in a number of cases shrimp aquaculture is reported to have exacerbated saline intrusion. Problems of salinisation and depletion of groundwater have been reported from many major shrimp farming nations (including Thailand, Taiwan Province of China, Ecuador, India, Sri Lanka, Indonesia, the Philippines)[27,50,51].

In Bangladesh over the past few decades, ecological damage due to salt intrusion has increasingly been reported in shrimp farming areas and many

'Shrimp farming in southeast Asia arguably has caused the greatest water-use conflicts of any form of aquaculture'

Environmental Defense Fund report on the Effects of Aquaculture[24].

below: *Water intake at an Ecuadorian shrimp farm.*

© Trent / EJF

believe that shrimp farming is at least a contributing factor, if not the major cause[51]. A study of the impacts of shrimp farming undertaken by the Research and Development Collective in Bangladesh found that, following the introduction of shrimp farming, soil salinity in experimental (i.e., shrimp farming) compared to control sites increased significantly – in some areas the mean increase was as high as 500% – to a level at which the growth of many crops was seriously affected[52]. The study also found that the soil pH in shrimp farm sites was high compared to control sites, which can affect the productivity of soil, and that there was a significant difference in water quality between control and experimental sites, in particular with respect to salinity, pH, dissolved oxygen content, free carbon dioxide and ammonia-nitrogen. The study stated that *'the main constraint in the crop production is the increase in soil salinity levels due to prolonged inundation of the land by saline water'*[52].

Increases in soil salinity together with the fact that vast areas of farmland have been inundated with saline water has affected the variety and abundance of crops grown and affected livestock production in shrimp farming areas, further reducing food security and opportunities for income generation for rural communities. Water use and salinisation and pollution of land and water supplies due to shrimp aquaculture have also led to resource use conflicts in a number of countries. These impacts are discussed in greater detail in EJF's companion report *Smash & Grab*[50].

Semi-intensive and intensive farms can use large quantities of freshwater to compensate for evaporation or to obtain preferred salinity within

Case study: Self pollution in Sri Lanka's shrimp farms[21]

In Sri Lanka, pollution caused by shrimp farming activities has resulted in environmental degradation that, in turn, has caused major problems for the shrimp farming industry. The Dutch Canal Mundel lagoon system, a shallow semi-enclosed coastal water system with very limited tidal mixing, acts as the major brackish water source and a receiving body for 70% of Sri Lanka's shrimp farms. 68% of farms were found to be overfeeding. As a result, water quality in the system has rapidly deteriorated, thereby affecting associated farms and their production. Water exchange was carried out daily during the final month of cultivation in 60% of farms, with the mean volume of water released estimated at 3000m^3 per hectare.

A 1998 study found that none of the area's farms used any method of water treatment prior to release, and effluent was found to directly contaminate intake waters. Ammonium concentrations, BOD, sulfides, suspended solids and pH all fell outside the acceptable range on various occasions; effluent waters were also found to contain high levels of manganese and iron, which in excess can be toxic for many organisms, including shrimp. Further studies are needed to assess the long-term impact on the estuary but it is estimated that continued increase in nutrient levels and suspended material could lead to a benthos with very low dissolved oxygen levels, and a change in the constituent benthic communities.

the ponds[27], which can lead to saltwater intrusion of groundwater. Salinisation of ground and surface water has affected drinking and irrigation wells and caused skin irritations in local communities in Sri Lanka, India, Taiwan Province of China, Thailand, Malaysia, Ecuador and the Philippines[19], and in parts of Sri Lanka and Bangladesh, women are reported to have to walk as far as 5–6 km a day for fresh water supplies due to pollution of their local wells[50,53,54].

Over-exploitation of groundwater supplies by shrimp farms can also lead to a fall in water level. Pumping fresh-water from groundwater aquifers into ponds can lower the water table, which in turn can cause salt-water intrusion. Where high densities of shrimp farms have been present in Taiwan Province of China and the Philippines, sinking water tables have been linked to land sub-sidence, destruction of agricultural lands, and collapse of buildings[19].

Awareness of the impacts of groundwater depletion and of salinisation associated with shrimp farming are increasing. Water demands of intensive shrimp farms have been estimated at 50–60 million litres per metric tonne of shrimp produced[55] and moves are now being made to reduce this water demand through improved pond design and management. However, in many areas, particularly where existing pond infrastructure and water supply systems are inappropriate (such as in Bangladesh, where many of the shallow polders used for shrimp farming were built for agricultural production and suffer from significant water loss due to evaporation[56]), water management remains a serious concern. Intensive shrimp farm systems can reduce water use and salinisation greatly through re-circulation of water flow but this is expensive to achieve.

Destruction of mangroves and salt-marshes for shrimp farms has led to changes in soil pH in and around the ponds, and enhanced siltation, which further decreases water circulation and may increase the wet season flood frequency. In November 1995, floods affected 87% of farms as well as surrounding rice fields and villages. The study reported that 75% of local villagers were against the shrimp farms due to flooding, 2% of locals complained of skin diseases due to poor water quality, and 92% of lagoon fishers complained of low catches after the development of shrimp farming.

Some 99% of the farms studied had been affected by disease, and 40% of small and medium scale shrimp farmers were experiencing financial problems with expenditures exceeding the often low returns. The conditions found in the farms studied, together with the environmental deterioration, led to predictions of another major outbreak in the near future. However, 60% of the shrimp farming community did not understand the potential environmental impact of their actions, or the effect it would have on their own production. Seventy percent of the medium and large-scale shrimp farmers were foreign to the district, and had purchased the land solely for shrimp aquaculture.

OPPOSITE: *Pond intake from Chilaw Lagoon.*
© Jim Enright / Mangrove Action Project

BELOW: *Removing sludge from shrimp ponds in Sri Lanka.*
© Jim Enright / Mangrove Action Project

ABOVE: *Water collection, Bangladesh. Depletion of groundwater and salinisation of wells due to shrimp farming can have serious impacts on the daily lives of poor communities.*

© Williams / EJF

'Water management is probably one of the most contentious subjects in coastal shrimp aquaculture [in Bangladesh]'[56].

TIM HUNTINGDON, POSEIDON CONSULTING.

Reducing pollution

Pollution can be reduced by the use of various technologies and practices: the preferred method being reduction or prevention of pollution in the first instance. Other approaches are to re-cycle and re-use waste, treat waste, or to dispose of waste properly[24]. Further, wise shrimp farm siting can substantially reduce pollution. Key to this is that mangroves and tidal wetlands are generally not suitable sites for shrimp aquaculture[10,15].

Other pollution reduction methods include improved pond design, construction of waste-water oxidation-sedimentation ponds, pond sludge removal, reduced water exchange, a combination of semi-closed farming systems with settling ponds and biological treatment, and use of mangroves as biofilters for pond discharge prior to release of effluent[2,24,57]. The importance of appropriate water systems cannot be understated. However, even when aware of these issues, many farmers lack the ability to invest in the equipment necessary to tackle pollution.

In Thailand, there has been a significant trend in recent years in favour of semi-closed or closed systems with very little water exchange[58], which may help to reduce the discharge of waste and the spread of disease[10]. Recirculation technologies, developed in Thailand primarily to exclude viral pathogens from the culture system, can reduce effluent released to the external environment[2]. However, recirculation systems are capital-intensive, with relatively high investment and operating costs, and it seems unlikely that they will be used globally on a large scale until profitability is similar to that of other aquaculture systems[2,24].

Settlement ponds can be used to encourage denitrification and remove other pollutants bound to suspended solids and can be enhanced through stocking shrimp at lower densities in the ponds[15]. Their utility may be further enhanced through sediment ploughing after pond drainage to increase aerobic degradation, and the introduction of filter-feeders, macrophytes and/or other aquatic organisms into effluent ponds to bioconcentrate and/or metabolise residual chemotherapeutants, which may then be harvested and incinerated[2]. Other waste treatment approaches include mechanical filtration and the construction of wetlands. However, sedimentation and mechanical filtration both result in the accumulation of nutrient rich sludge that requires proper disposal[24].

As the industry develops new approaches and technologies, pollution will be considerably reduced. Yet for many small-scale shrimp farmers in developing countries, the adoption of best practices is, at present, simply not a financial reality.

Belize Aquaculture Ltd: A Superintensive Shrimp Aquaculture System[59].

Belize Aquaculture, Ltd., has developed a unique superintensive shrimp aquaculture system that has achieved production of over 20,000 kg/ha for some shrimp crops. This is the first commercial enterprise to incorporate a number of innovations into a system that allows superintensive shrimp production. Through a combination of lined ponds, low-protein feeds, heavy mechanical aeration and sludge removal, the system appears to address a number of the environmental impacts of conventional shrimp aquaculture systems.

The system is reported to be more than five times more efficient in land-use than semi-intensive systems, and due to water recirculation is 20–40 times more efficient in total water requirements. Feed protein and fishmeal use within the system is also more efficient – the nitrogen recovery rate (39%) is much higher than that of conventional aquaculture operations (15–25%), and the ratio of wild fish (converted to fishmeal) to shrimp produced in the system is reported to be less than 1:1. There is no effluent or seepage due to the water reuse and the lined pond bottoms, which significantly reduces the potential for pollution of coastal waters or salinisation of groundwater supplies.

However, the cost of constructing such a system is considerable and, for the entire operation (including hatcheries, power generation facilities and processing plants), may be as high as US$250,000 per hectare; for small-scale producers the cost of constructing a one-hectare operation is thought unlikely to be much less than US$80,000, even when energy, local hatcheries and processing plants are available. Such high costs are clearly prohibitive for the majority of small-scale shrimp farmers. Other concerns include uncertainty about how disease would affect the system and the likely dependence on highly skilled labour. Additionally, the production system is best suited to species such as *Penaeus vannamei*, which tend to be more omnivorous; at present it is unclear whether production with more carnivorous species such as *Penaeus monodon* would be economically feasible.

While this system may represent an important model for future aquaculture development, it should be recognised that all superintensive shrimp aquaculture production systems have failed in the past, and there remain a number of issues that still need to be addressed.

Organic shrimp farming

The best pollution reduction technique available is the elimination of potentially harmful chemicals and replacing them with organic alternatives. Specialist companies have begun producing aquaculture products (e.g., feed, growth stimulators, preservatives, and solutions that combat bacteria, fungi and viruses) derived from local minerals, medicinal plants, herbs, roots and tropical fruits.

By 2003, there were certified organic shrimp farms in Ecuador, Brazil, Thailand, Peru, one small-scale farmers' group in Java (with 156 members) and another in Vietnam (with 1,022 members)[60]. Additionally, there is one fully certified organic shrimp hatchery (for the production of shrimp larvae to stock ponds) in Ecuador, and two more are in the process of obtaining certification[60].

If rigorously devised and implemented, there is a potential for organic shrimp certification to achieve benefits beyond those of zero harmful-chemical use. Organic producers typically incorporate a more holistic view and have tended to take into account issues such as farm siting, mangrove and biodiversity conservation, and impacts on soils or other water bodies etc.

ABOVE: *Organic shrimp farm in Ecuador.*

DEPLETION OF WILD FISH AND SHRIMP STOCKS

'The potential of coastal aquaculture to improve the income and assure the availability of affordable protein to the poor in developing countries has been impeded by the emphasis on the industrial-scale cultivation of high-valued carnivorous species destined for export markets in Europe, USA and Japan. The primary motives are generating high profits for investors and input suppliers and enhancing export earnings for national treasuries. This is particularly true for intensive shrimp farming'

Dr Patrik Rönnbäck, Professor Ian Bryceson & Professor Nils Kautsky[66]

ABOVE: *Child collecting shrimp fry in Bangladesh.*

Shrimp farming was initially heralded as a mechanism to produce food in a way that would reduce the pressures of overfishing on wild populations, and limit the collateral damage shrimp trawling caused to other marine species (see EJF's companion report *Squandering The Seas*[74]). However, through habitat destruction, devastating rates of bycatch during shrimp fry and broodstock collection, use of fish products in feed, and the introduction of non-native species, pathogens and pollutants, shrimp aquaculture can undermine the very basis of shrimp production and impact wild fish and shrimp stocks, with serious potential consequences for biodiversity conservation and food security.

Around one billion people, most of whom live in developing countries, rely on fish and shellfish as their primary animal protein source[2], with fish providing 21% of total animal protein in Africa, and 28% in Asia[3]. In countries such as Ghana, Indonesia and Bangladesh, fish supplies as much as half of all animal protein[4]. Fish production is also a vital component in the global economy, and is particularly important in developing countries where more than 50% of the export trade in fish products originates[5]. Currently, the stocks of commercial fish species are drastically declining[6] and 35% of the most important commercial fish stocks are exhibiting a pattern of declining yields[7]. Up to one third of all known fish species are threatened[8].

The social repercussions of a further decline in marine fisheries are expected to be severe – the fishing industry directly or indirectly supports some 200 million people[9], and any shortfall in fish supplies is likely to affect developing nations disproportionately[7]. Not only will subsistence fishing communities experience reduced catches, but as demand and prices increase, exports of fish products from developing nations to wealthy nations is likely to rise as well, leaving fewer fish for local consumption and putting this protein source increasingly out of reach for low-income families[7]. In many ways, this is already the case with shrimp.

Habitat destruction

Mangrove forests provide nursery grounds and refuges for a great variety of fish, crustacean and mollusc species, many of which are of commercial or subsistence value, and are harvested as adults in coastal and offshore fisheries[10]. As discussed, shrimp aquaculture is considered to have been a significant contributor to global mangrove loss. The loss of these critical habitats, and degradation of other wetland and marine ecosystems associated with shrimp farm development, have been linked to declines in capture fisheries.

A close association between shrimp fisheries and mangroves has been clearly illustrated in the Asia-Pacific region[11,12]; with similar relationships suggested from Africa and Latin America[13,14]. Though there is some debate due to different methodologies used, a positive correlation between mangrove area and near-shore yields of fish or shrimp has been documented in Australia, the Philippines, Indonesia and Malaysia[15,16,17,18].

'Rapid growth in shrimp and salmon farming has clearly caused environmental degradation while contributing little to world food security. These industries provide food mainly for industrialised countries, consume vast quantities of wild fish as feed, and generally do not generate long-term income growth in impoverished communities. Promotion of shrimp and salmon farming in both rich and poor countries is being driven largely by short-run economic motives and, in the case of shrimp farming, without regard to collapses of local production systems… So long as the full environmental costs of feed and stock inputs, effluent assimilation, and coastal land conversion are not recognized in the market, ocean resources – including fisheries – will deteriorate further'

A statement from 'Nature's Subsidies to Shrimp and Salmon Farming' published in leading journal *Science*[1].

LEFT: *Snappers in mangroves at high tide.*

© Jeremy Stafford-Deitsch

'Our data suggest that the current rate of mangrove deforestation, which is greatest in the Americas at 2,251 km²/year and exceeds that of tropical rainforests, will have a significant deleterious consequence for the funtioning, fisheries, biodiversity and resilience of Caribbean coral reefs.'

Conclusion of paper published by Dr Peter Mumby *et al.* in *Nature*, February 2004[20a].

'The loss in wild fisheries stocks due to habitat conversion associated with shrimp farming is large'.

A statement from 'Effect of Aquaculture on World Fish Supplies' published in the journal *Nature*, 2000[10].

Seafood production supported by mangroves shows spatio-temporal variations, and there are significant differences in mangroves' structure and function both between regions and within individual systems[11,19] but some indication of the dependence of fisheries on mangroves is given below:

- In Southeast Asia, mangrove-dependent species account for about one third of annual wild fish landings excluding trash fish[20].

- In Malaysia, at least 65% of fish and shellfish harvested are associated with mangroves, over 30% of shell and finfish landed by commercial operators each year (approximately 200,000 metric tonnes) are mangrove-dependent[21,22], and in some regions the figure may be as high as 50%[23]. An estimated 600 kg each of finfish and shrimp are produced annually in Malaysia from every hectare of mangrove[10].

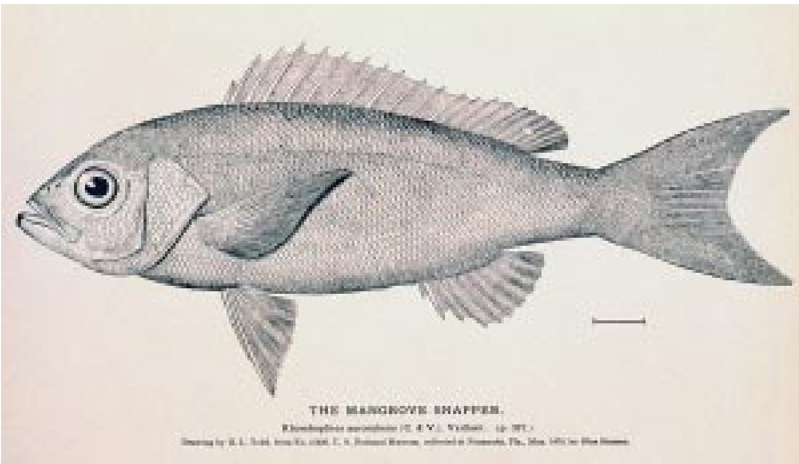
- 80% of the Indian fish catch from the lower delta region of the Ganges and Brahmaputra Rivers comes from the Sundarbans mangroves[21].

- On Fiji's islands, approximately half of all fish and shellfish caught by commercial and artisanal fishermen are dependent on mangroves for at least one stage of their development[21].

- In Tanzania, the mangroves of the Rufiji Delta make its surroundings the most important shrimp fishing grounds in the country, contributing around 80% of commercial catch[24], and in Tanzania, Madagascar and Mozambique there is a high correlation between extent of nearby mangrove areas and shrimp catches[24].

- 60% of the total shrimp fishery in Panama is based on species that depend on mangroves[13].

- The state of Campeche is responsible for one sixth of Mexico's total shrimp output, and the shrimp fishery there employs about 13% of the state's economically active population. The mangroves in the Laguna de Terminos are considered to be the main breeding ground and nursery habitat for the shrimp fry of the Campeche fishery, but future threats are expected to come from the expansion of shrimp aquaculture[14].



RIGHT: *Mangrove snapper,* Rhomboplites aurorubens. *Commercially valuable species which utilise mangrove habitats include mullets, groupers, snappers, tarpons, sea-perch and catfish.*

© NOAA

The loss in wild fisheries due to habitat conversion associated with shrimp farming is thought to be considerable[10,23]. In Thailand, an estimated 434g of fish and shrimp are lost from capture fisheries per kg of shrimp farmed in mangrove areas due to habitat conversion alone, indicating a potentially significant loss in wild fish production[10]. Additionally, uncertainty about the relationships between mangrove area and the goods and services that these ecosystems support, including fisheries, highlights the need for the precautionary approach to be adopted[25,26].

Globally, nearly two thirds of all fish harvested depend on the health of wetlands, seagrasses and coral reefs for various stages in their life cycle[21]. Mangrove and wetland degradation can also exacerbate impacts of pollution, both from shrimp aquaculture and from other coastal developments. Increased terrestrial runoff (including nutrient pollutants, toxic chemicals and increased siltation) due to shrimp aquaculture and associated wetland degradation may affect fisheries directly, and/or impact other coastal environments on which they depend, including seagrasses and coral reefs. Fisheries capture from coral reefs alone contributes about 10% of global human fish consumption, and much more in developing countries[10]: in tropical Asia, 70–90% of all fish caught by coastal fisheries are reef-dependent for at least one stage in their life-cycle[21]. Environmental degradation of coastal areas may represent an even greater long-term threat to aquatic productivity than over-fishing[27,28], and welfare impacts associated with destruction of coastal habitats are of great concern[29,35].

- In Thailand, the welfare losses from reduced fisheries catch estimated for mangrove deforestation of 3000 ha/year is thought to be close to the upper limit of the range US$12,000–408,000, depending on elasticity of demand[29].

- In Burma, the decrease in mangrove area from 1983 to 1997 of approximately 271,000 ha is estimated to have led to a loss of coastal fisheries production of almost 190,000 tonnes annually, including 41,000–47,000 tonnes of shrimp[30].

- In the Chokoria Sundarbans region of Bangladesh, fishermen have reported an 80% drop in fish capture since the large-scale destruction of mangroves for shrimp aquaculture development[31].

- In Sri Lanka, 92% of lagoon fishermen complained of low catch rates following shrimp farm development[32].

- Conversion of mangroves for shrimp ponds has been associated with decreasing supplies of wild shrimp post-larvae for stocking ponds in Ecuador[33,34], and a shortage of broodstock to supply hatcheries[11].

Impacts of the loss of access to resources to coastal communities are discussed in more detail in EJF's companion report, *Smash & Grab*[35].

'Environmental degradation of coastal areas … perhaps represents an even greater long-term threat to aquatic productivity [than over-fishing]'.

World Resources Institute[27].

'Expansion of shrimp exports has caused much devastation to Thailand's coastline, and had knock-on effects in other valuable commercial sectors, such as fisheries' .

Professor Edward Barbier & Dr Mark Cox, 2002[36].

'Collection of one tiger shrimp larva involves the removal of 1,400 other macrozooplankton individuals'

Report of the Ad Hoc Technical Expert Group on Mariculture, Subsidiary Body on Scientific, Technical and Technological Advice, Convention on Biological Diversity, 2002[45].

'The amount of shrimp fry bycatch destroyed globally is staggering and could have major consequences for biodiversity and capture fisheries production'

Dr Patrik Rönnbäck, Professor Ian Bryceson & Professor Nils Kautsky[66].

Shrimp fry & broodstock fisheries

Most shrimp farmers still rely on wild shrimp for the production of seed[38]. Fisheries for broodstock to supply hatcheries and wild shrimp larvae for ponds can have serious negative impacts on wild fish and shrimp stocks, which in turn can lead to reduced genetic diversity and reduced availability of breeding stocks and shrimp fry for aquaculture[10].

Hatcheries are increasingly being used to stock shrimp ponds (for example in much of Southeast Asia), and it has been estimated that 65–75% of all shrimp post-larvae are currently hatchery-produced[39]. However, in a number of areas (such as in Bangladesh, India and in many parts of Latin America) hatchery-produced fry are either not yet widely available or less preferable to wild-caught post-larvae, which are thought to have better survival rates[40]. Where hatchery-reared post-larvae are used, although captive breeding programs are improving[39], most are produced from the spawning of wild-caught broodstock[38,39].

The bycatch (non-target species caught and often discarded) rates associated with shrimp fry (post-larvae) fisheries are among the highest of any fishery in the world. Typically, shrimp fry are harvested with very fine mesh nets, which catch most of the organisms in their path. The favoured species for shrimp culture generally constitute a very small proportion of juvenile and adult populations in the wild[41], and typically constitute a very small proportion of fish and invertebrate larvae in a seed collector's catch[17].

For every fry of the tiger shrimp P*enaeus monodon* collected in India, it has been estimated that up to 160 fish and shrimp fry are discarded[10]. Other estimates for bycatch rates in India and Bangladesh indicate that as many as a thousand organisms are discarded for each *P. monodon* collected[42]; in the Bagerhat region of Bangladesh, a 2001 study reported that an average of 371 other shrimp, 274 finfish and 938 zooplankton were discarded for every *P. monodon*[43]. In Honduras, the annual collection of 3.3 billion *P. vannamei* and *P. stylirostris* post-larvae is reported to cause the destruction of some 15–20 billion fry of other species[44].

Many of the other species that are trapped are juveniles of commercially and ecologically important species, which utilise the mangrove habitats in which shrimp fry are typically found. While the full impacts of shrimp fry collection on biodiversity and capture fisheries production are not yet fully understood, they could be very significant[11,66] with serious ecological and social repercussions. Faced with a lack of sufficient data, the precautionary principle should be applied.

RIGHT: *The bycatch (non-target species caught and often discarded) rates associated with shrimp fry (post-larvae) fisheries are among the highest of any fishery in the world.*

Shrimp fry collection in Bangladesh

In Bangladesh, both brackish and freshwater shrimp production rely heavily on wild-caught fry, and hatchery production fulfils just 10% of the demand for freshwater prawn *(Machrobrachium rosenbergii)* fry[46]. The high demand for fry is further driven by a number of inefficiencies in the supply and use of fry – for example an estimated 40% of fry are lost from the time they are caught to the time they are stocked in a farmer's pond[47].

The total annual catch of more than two billion larvae of *P. monodon* along the coastline is thought to represent less than 2% of the total seed catch[48]. In 1989–1990, the total catch of just over two billion *P. monodon* reportedly resulted in the discard of 200 billion other organisms (including other shrimp, finfish and zooplankton)[48]; a more recent estimate suggests that 3 billion *P. monodon* are caught annually, indicating that the number of discarded organisms is likely to be significantly higher[49].

Wild post-larvae collection is thought to significantly impact wild shrimp stocks – for example, fisheries are thought to remove as much as 90% of the *P. monodon* stock[47], and recent indications are that the average number of post-larvae collected per person is falling drastically[50]. The substantial bycatch from shrimp fry fisheries is also likely to have serious impacts on coastal biodiversity and capture fisheries production[11,47,50,51]. Farmers interviewed in Khulna and Bagerhat districts for a recent study reported scarcity and decline of many indigenous fish, turtles and molluscs, which they attributed to the significant bycatch associated with shrimp fry fisheries[52].

Much of this collection (approximately 80% of the effort) takes place in southwestern Bangladesh, largely in and around the Sundarbans forest, and there are concerns that the removal of juveniles of commercially or ecologically important species may lead to serious problems for the fisheries in the Bay of Bengal. Additionally, disturbance to banks and topsoil by fry collectors can affect mangrove growth and regeneration[53], impacting important nursery grounds for many species. In India, diminishing yields in the more accessible areas of the Sundarbans are reported to have led to shrimp fry being illegally collected from the Sundarbans Tiger Reserve[54]. In 2002, the southwest region of Bangladesh was responsible for just 20% of total catch of *P. monodon* target species, but 90% of the bycatch; 80% of the target species was caught in the southeast, which was responsible for just 5% of the bycatch[49].

In a bid to reduce the impacts of fry fisheries on the coastal ecosystem and its dependent communities, the Department of Fisheries announced a complete ban on the collection of wild shrimp fry in September 2000[47]. Following an abeyance and review period, the ban has subsequently come back into force. However, the Government does not have sufficient resources to properly enforce this ban, and wild shrimp fry collection continues in the coastal region[55]. Meanwhile, serious concerns over the socio-economic impacts of the ban on shrimp fry collectors remain; as many as 400,000 people work as fry collectors in Bangladesh[49], many of whom are among the poorest members of society.

ABOVE: *Two hundred billion other organisms were reportedly discarded as a result of shrimp fry fisheries in Bangladesh in 1989–1990. More recent estimates indicate that this figure is now likely to be significantly higher*[48,49].

Socio-economic considerations of fry collection (such as provision of jobs by wild fry fisheries) are of great importance, but it should also be recognised that in some areas, paradoxically, those who rely on shrimp fry collection have in some cases been deprived of any alternative following shrimp aquaculture's onset and impact on traditional livelihoods. Where shrimp production relies on wild caught fry, spatial and temporal gear restrictions to reduce the negative environmental impacts should be formulated and enforced (such as bans on fry catching in ecologically sensitive areas such as migration routes, restrictions on the use of destructive fishing gears, and the introduction of methods to separate and return bycatch); any such restrictions should be tied to aid and alternative livelihood programmes for fishers.

From an ecological viewpoint, hatchery-produced fry are preferable. However, in many countries hatchery systems need improvement and regulation. For example, in Bangladesh, hatchery-produced survival rates are low, farmer perceptions of hatchery fry quality are poor and while the majority of shrimp farms are in the Southwest of the country, the majority of shrimp hatcheries are in the Southeast; efforts are currently being made to rationalise the sector and introduce independent certification schemes[56]. In Vietnam, only one third to one half of the demand is met by post-larvae produced in the country, the remainder being imported[57]. Breeding shrimp are also in short supply, and prices of broodstock have skyrocketed accordingly (reportedly reaching up to $1,000 each)[58]. High demands with limited supplies have led to quality control systems, where present, being inadequate[59]. It has recently been estimated that only 10% of breeding shrimp in the central region meet quality standards, and low quality of broodstock has been blamed for high numbers of recent shrimp deaths in the Mekong Delta[60]. These problems particularly affect the poorest farmers, often forced to buy on credit to be settled upon harvest through middlemen at the farm-gate[61,62,70].

Additionally, almost all hatcheries rely on wild-caught broodstock[38], which is associated with very high rates of bycatch, and, due to high levels of stress, can lead to poor quality fry. In Southeast Asia, most *Penaeus monodon* broodstock are caught in the wild by offshore trawlers equipped to hold live shrimp[38]. Shrimp trawling is one of the world's most wasteful and destructive fisheries, with up to 20 kg of discarded catch for every 1 kg of shrimp caught in tropical waters and with serious impacts on benthic envi-

ABOVE: *Trawlers collecting broodstock.*
© RUG Artemia Reference Centre

RIGHT: *Hatchery fry in bowls, Vietnam.*
© Thornton / EJF

ronments – the impacts of shrimp trawling are discussed in greater detail in EJF's companion report *Squandering the Seas: How shrimp trawling is threatening ecological integrity and food security around the world*[74]. There is an urgent need for improved methods of harvesting broodstock, but the use of farm-raised broodstock is preferred.

Closure of the hatchery cycle by breeding and domestication programs would reduce the demand for fry and broodstock, reducing concerns associated with these fisheries, and would also minimize the risk of introducing alien species and disease through the worldwide transfer of fry and broodstock[66]. However, although most of the commonly grown shrimp species can be matured and spawned in captivity, current production and quality of eggs and larvae is usually lower than from wild-caught spawners[38]. Applied research into techniques for rearing farm-raised broodstock should be supported.

Production of fishmeal

It has been estimated that fish catches from 14.5 ha of sea area are needed to produce food for just one hectare of semi-intensive shrimp pond in Colombia[71,72].

Farming omnivorous species like shrimp intensively or semi-intensively can require feed inputs of more than double the weight of the farmed species produced[10], leading to a net loss of protein. For shrimp fed on compound feeds, this is primarily in the form of fishmeal and fish oil, which supply essential amino acids that are deficient in plant proteins, and fatty acids not found in vegetable oils.

At present, the shrimp farming industry is dependent on marine capture fisheries for sourcing its dietary animal protein and lipid inputs[63]. Twenty-five to fifty percent of ingredients in most commercial shrimp 'aquafeeds' are derived from marine capture fisheries, including fishmeal, fish oil, shrimp / crustacean meal, squidmeal, krillmeal, and other miscellaneous products such as fish solubles, fish silages / hydrolysates, fish / squid livermeals, and seaweed extracts[63].

The relative feed efficiency of aquaculture is complex, and has not yet been fully analysed, but the ratio of wild fish used for fishmeal to farmed shrimp produced using compound feeds has been estimated to be as high as 2.25[64]. Other estimates have placed the feed conversion ratio (FCR) at 2.08 – i.e., the consumption of 2.08 kg of fish (pelagic, wet weight basis) for the production of 1.0 kg of shrimp (wet weight basis)[63].

Currently, the shrimp-farming sector is a net consumer of aquatic products rather than a net producer[63]. This means that additional pressure is placed on marine stocks, and that a valuable source of dietary protein to coastal communities is lost. The Global Aquaculture Alliance, the shrimp farming industry body whose slogan is 'feeding the world through aquaculture', contends that small oily fish used to make fishmeal are unfit for human consumption[65]. However, some of the fish used for fishmeal production can potentially be consumed directly (for example, small pelagic fishes such as mackerel and sardines provide an important protein source for people in Southeast Asia)[10], while the depletion of pelagic fisheries for the production of fishmeal is also thought to reduce available food supplies for marine predators, including valuable species consumed by humans such as tuna, as well as seals, dolphins and seabirds[10,66,67].

Some of the fish bycatch used for human consumption in India and cheap raw fish used for the salted fish industry in Malaysia have reportedly been diverted to shrimp farming, while high fishmeal prices due to shrimp farming have led to increased prices of poultry feed and chicken in Thailand[68]. In Vietnam, much of the feed used for shrimp ponds is rudimentary, containing small boiled fish, shrimp, crab, rice and egg yolk; not only

'As practiced today, aquaculture is a mixed blessing for the sustainability of ocean fisheries. The diversity of production systems leads to an underlying paradox: aquaculture is a possible solution, but may also be a contributing factor, to the collapse of fisheries stocks worldwide'.

Dr Patrik Rönnbäck, Professor Ian Bryceson & Professor Nils Kautsky[66].

'About 30% of the global harvest of capture fisheries is used for fishmeal production, one third of which is used by the aquaculture industry.'

From 'Shrimp aquaculture – State of the art' published by Swedish University of Agricultural Sciences, 2001[75].

does this have a poor conversion ratio, exacerbating pollution problems, but the use of locally-sourced fish can reduce local food security[69,70].

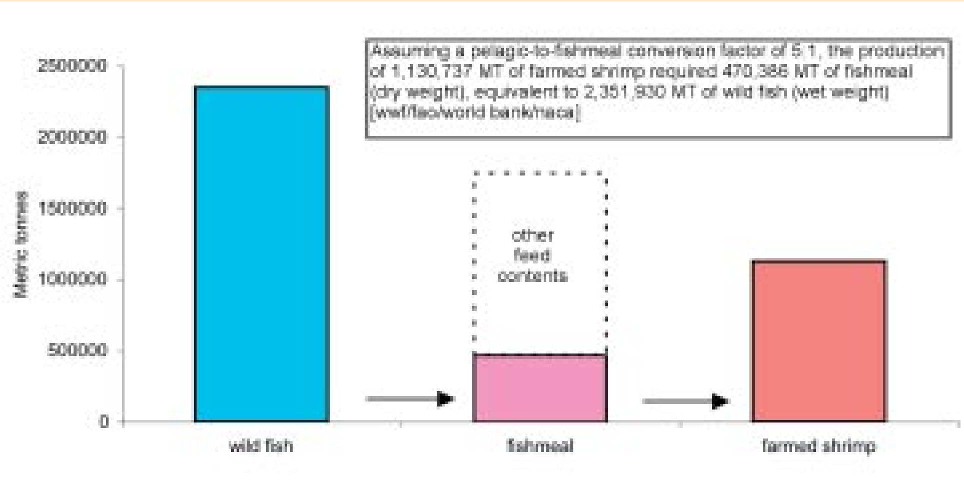
There are growing concerns over the ethics of processing potentially food-grade fishery resources to produce high-value farmed aquatic species[63], and it is clear that the growing aquaculture industry cannot continue to rely on finite stocks of wild-caught fish, many of which are drastically declining[10].

A recent report prepared for the World Bank, NACA, FAO and WWF consortium program on shrimp aquaculture estimates that the shrimp farming industry would have to lower its farm Feed Conversion Ratio (FCR) from 2 to 0.8, reduce mean dietary fishmeal level from 25 to 15% *and* FCR from 2 to 1.4, or reduce mean dietary fishmeal level from 25 to 10% to reach a point where the weight of pelagics consumed is even equivalent to the shrimp produced on a wet basis[63].

Due to the high costs involved in feeding shrimp (which may represent the largest production cost in some commercial shrimp aquaculture systems)[10] and impacts associated with nutrient pollution, improving feed efficiency is vitally important. Because of the severe ecological and social consequences of over-exploitation of pelagic fisheries, developing a strategy to replace fishmeal and fish oil in aquaculture feeds should become a priority[10] and research into alternatives should be encouraged and funded as a matter of urgency. However, such research must be specifically targeted towards sustainable, environmentally benign feed sources – reliance on genetically modified vegetable crops, for example, is entirely inappropriate at a time when the implications of genetic modification are still unclear to science. Equally, the fishmeal industry has proposed that fishing vessels be encouraged to retain bycatch, now discarded, for sale to producers of fishmeal and fish oil; however, sale of bycatch could prove undesirable if it undermines efforts to reduce bycatch rates or decreases *in situ* recycling of bycatch[10,74].

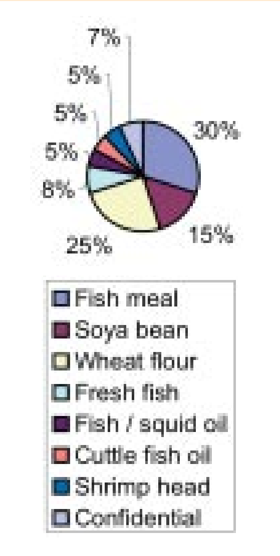
A net loss: Converting wild fish into farmed shrimp

An estimated 75% to 80% of all farmed shrimp are grown with industrially compounded aquafeeds in one form or another[73]. Based on global shrimp production figures of 1.13 million metric tonnes (MT) in 1999, and the global average feed conversion ration (FCR) of 2.0, it has been estimated that total global production of compound aquafeeds for shrimp approximated to 1.7–1.8 million MT in 1999. Assuming average global proportions of fishmeal and oil in shrimp feeds as 16% and 2%, a recent study estimated that the shrimp farming sector consumed 470,386 MT of fishmeal (21.2% of the total used in all compound aquafeeds that year), and 36,184 MT of fish oil (5.8% of total). Using a pelagic-to-fishmeal conversion factor of 5:1, the study estimated that it would have taken 2,351,930 MT of fish (wet basis) to produce the 1,130,737 MT of farmed shrimp[63].



Shrimp feed composition

The Thai conglomerate Charoen Pokphand (CP) dominates shrimp feed production and sales. Recent research funded by the Swedish government reported CP shrimp feed to have the following composition[76]:



Lessons from Salmon

Coastal aquaculture production has been increasing rapidly over the past decades[77]. In both developed and developing countries, market demand has led to increased intensification of aquaculture production, including a shift to the monoculture of high-value species for affluent markets and the use of fishmeal and fish oil in feeds[4]. Many of the environmental and socio-economic problems described in this report are not unique to shrimp farming, and other aquaculture activities, in particular farming of carnivorous finfish such as salmon, have raised similar concerns.

In 1998, farmed production of salmon in coastal waters surpassed production from wild capture fisheries[4]. However, the industry has caused a number of environmental and social concerns. Escaped farmed salmon are considered to represent a major threat to wild populations, and adult salmon of farmed origin reportedly now make up more than half of the salmon entering rivers in Maine, USA from the sea[4]. There is increasing evidence that escaped farmed salmon may hybridise with wild salmon populations[84], and recent research suggests that male farm-reared salmon may mate more aggressively than their wild counterparts, posing an even greater threat to native species than previously thought[78]. Transmission of disease from farmed salmon has also been a major concern, and diseases have decimated both wild and farmed populations[4]. Additionally, as salmon farming methods have become more intensive, employment opportunities have declined, and declining prices caused by the growing glut of farmed salmon has had negative socio-economic impacts on rural fishing communties[4].

One of the most critical issues to address for aquaculture systems is the net loss or gain of animal protein. About one third of the total harvest of capture fisheries is used to produce fishmeal, one third of which is used by the aquaculture industry[10].

'Only increased production of largely herbivorous fish … really have the potential to reduce pressure on wild fisheries'.

ENVIRONMENTAL DEFENSE FUND, USA[67].

RIGHT: *Shrimp feed mill, Ecuador. Farming shrimp intensively or semi-intensively can require fish inputs as feed of more than double the weight of end product, leading to a net loss of protein.*

© Shanahan / EJF

In 2000, aquaculture consumed 35% of the world's annual production of fishmeal and 57% of fish oil[79]. If the current rate of growth in consumption continues, it has been estimated that aquaculture will account for 56% of the world's annual production of fishmeal and 98% of fish oil by 2010[79].

Between 1986 and 1997, four of the top five and eight of the top twenty wild fish species harvested were small pelagic fish used in the production of feed for the aquaculture and livestock industries – anchoveta, Chilean jack mackerel, Atlantic herring, chub mackerel, Japanese anchovy, round sardinella, Atlantic mackerel and European anchovy[80]. Although a few pelagic fish species used for fishmeal do not make palatable human food, some of the species used provide an important protein source; furthermore given expected increases in worldwide demand for protein with population growth in the developing world, the demand for small pelagic fish for human consumption is likely to increase[4,10,67]. In addition, there are serious concerns over the ecological effects of massive harvests of small pelagic fishes[67]; for example over-exploitation of pelagic fisheries primarily for fishmeal have been implicated in declines of other wild fish, such as cod in the North Sea, and changes in seal and seabird populations[84].

ABOVE: *Harvest of fish for fishmeal production.*

Estimated 2000 Fishmeal and Fish oil use in World Aquaculture[81]

Fish	Production (million pounds)	Production Using Compound Feeds (million pounds)	Wild Fish Used in Compound Feeds (million pounds)	Ratio of Wild Fish to Fed Farmed Fish Produced
Marine Finfish	2,038	1,250	5,157	4.13
Eel	492	392	1,843	4.69
Salmon	1,953	1,953	4,762	2.44
Marine Shrimp	2,707	2,220	4,996	2.25
Trout	1,168	1,168	1,709	1.46
Tilapia	2,363	970	545	0.56
Milkfish	829	331	311	0.94
Catfish	1,060	913	273	0.30
Fed Carp	22,167	8,201	3,075	0.38
Filter-feeding Carp	12,169	0	0	0
Molluscs	20,150	0	0	0

Due to the potential impacts on ocean and coastal resources through large requirements for fishmeal and fish oil, and through habitat destruction, pollution, seed collection and the introduction of pathogens and exotic species, rather than contributing to fisheries production some types of aquaculture, including shrimp and high value carnivorous species such as salmon, can act to deplete wild fish stocks[10]. However, farming of herbivorous or filter feeding species (such as carp, tilapia or molluscs) can make a large contribution to local, regional and global fish supplies and food security[4,10].

While improvements in the management of aquaculture systems and adoption of integrated systems can certainly help to reduce the environmental impacts of shrimp aquaculture, in terms of food security the promotion of production and marketing of lower trophic level species is likely to be a more sustainable development strategy, particularly in the developing world.

At a November 2002 meeting of the UK Seafish Aquaculture Advisory Committee, Dr. Ian Pike (UK Association of Fishmeal Manufacturers) warned that China was using 3–4 million tonnes of 'trash' fish for aquaculture (not just shrimp) and was heading for an ecological disaster[84b].

'Although the frequency and impact of diseases in wild populations is poorly understood, concentrated outbreaks of an infectious disease in shrimp farms are likely to increase the risk of infecting wild stocks locally, as well as farther away from the farms. This could cause increased mortality in wild stocks, resulting in alterations to the ecosystem and reduced production of shrimp biomass'

World Bank, NACA, WWF & FAO consortium 2002[38].

Disease in Ecuador

Outbreaks of viral diseases have threatened to wipe out Ecuador's shrimp industry, and production and revenues have crashed in recent years. According to the National Aquaculture Chamber, the first large dive in production was in 1989; production plummeted from almost 60,000 tonnes to 45,000 tonnes. In 1994, Taura Syndrome Virus saw production fall to 75,000 tonnes from 90,000 tonnes in 1992. In 2000, the industry suffered losses of approximately 70,000 tonnes, to 40,000 tonnes, due to an outbreak of White-spot disease. The White-spot virus is estimated to have led to losses of approximately US$600 million for the industry between 1988 and 2000; export losses were even steeper, amounting to US$900 million[89]. Disease and increasing costs of aquaculture have led to abandonment of farms and suspension of activities. In 1991, it was reported that 40% of shrimp ponds in Ecuador were abandoned due to ecological damage or shortage of larvae[90]; in 2000, the Executive Director of the National Aquaculture Chamber reportedly said that of the existing 180,000 ha, only 50,000 ha were under cultivation[91].

Introduction of non-native species and pathogens

Accidental escapes and even intentional releases from aquaculture systems create 'biological pollution' with irreversible and unpredictable ecological impacts, and can result in genetic contamination of wild stock, reduction in biodiversity, competition for territory, genetic drift, spread of disease, and excess demands on available resources[17,82]. In America, non-native Pacific white shrimp *(Penaeus vannamei)* farmed in the Gulf coast of Texas and the Atlantic coast have been captured off the coast of South Carolina[67].

Development of hatcheries for cultured shrimp has reduced the dependence on mangroves to produce seed, but has increased demand for wild caught female broodstock or spawners[11]. Shortages of broodstock (linked in some areas to habitat destruction) have resulted in increased movements of animals (including exotic strains and species) within and between countries, with implications for the spread of disease and dilution of wild genetic material[83].

Shrimp viral diseases, including those caused by White-Spot and Taura Syndrome viruses, have caused catastrophic, multimillion dollar crop losses in shrimp farms in Asia[10,17] (e.g., US$750 million losses in China in 1993) and South America, and have led to a 'boom and bust' trend in shrimp aquaculture production. Both pathogens have now been reported in farmed and wild shrimp populations in the United States, and the White-spot virus has been reported in some Central and South American countries[84]. Taura Syndrome Virus, endemic to Central and South America, caused devastating losses to the Texas shrimp farming industry in 1995, with farms losing 95% of their *P. vannamei* stocks[67]. The White-Spot virus has also led to high mortalities in Texan shrimp farms, and may be killing wild crustaceans[67,84]. The virus is thought to have been introduced by release into nearby coastal waters of untreated waste from plants processing imported Asian tiger shrimp, and by shipping of contaminated white shrimp *P. vannamei* larvae through the Americas[84]. International trade of hatchery-produced young has also been implicated in the increased spread of shrimp disease.

In addition to ecological concerns, disease outbreaks have seriously undermined the sustainability and profitability of shrimp farming operations[38]. Disease outbreaks have caused the collapse of shrimp farming in parts of China, Thailand and India. The risk of crop failure from disease creates serious difficulties for small investors and, after just one harvest failure, many farmers have insufficient capital to recover[85]. In Vietnam, failure rates in some districts were as high as 70% in 2001[86]. Many small-scale Vietnamese shrimp farmers were bankrupted in 1994 when a disease epidemic spread throughout the southern provinces covering an area of 84,858 ha and resulting in US$26.7 million of damage[87]; in Duyen Hai, 100% of shrimp farms failed that year[88]. In many cases, ponds do not recover productivity following disease outbreaks[1].

There appears to be a clear link between environmental conditions and disease outbreak[75], with high stocking densities and physiological stress associated with many shrimp farms resulting in elevated incidences of disease[64]. The development of shrimp farms on acid sulphate soils (as found in mangroves) or fluctuations in normal environmental conditions (e.g., oxygen, temperature and salinity) can increase physiological stresses and lower the immune response of shrimp. Resistance to disease in shrimp may also be decreasing due to use of antibiotics and chemicals.

By the end of 2001, the White-spot virus is believed to have caused a cumulative global loss of production in the order of one million metric tonnes or more[39].

CONCLUSIONS & RECOMMENDATIONS

The rapid growth of shrimp farming has had serious negative environmental impacts, with direct human consequences. Worldwide, shrimp farming has been associated with environmental degradation, increased social and economic disparities, and, in some countries, serious human rights abuses.

Shrimp aquaculture has been responsible for destruction of large areas of ecologically and economically important mangrove and wetland habitats and the degradation of adjacent coastal and marine ecosystems, with implications for biodiversity conservation and ecosystem integrity. These same factors also undermine the very basis of shrimp production. Food security is further threatened through use of fish products to feed shrimp, capture of broodstock and shrimp fry to stock ponds, loss of access to coastal resources, pollution of nearshore waters, and conversion, pollution and salinisation of agricultural land.

An estimated 99% of farmed shrimp are produced in developing countries (mainly in Asia and Latin America) and the majority of farmed shrimp are exported, primarily to consumers in Europe, Japan and the USA. However, the high environmental and social costs of this industry are rarely internalised in the cost to the consumer.

Intensification and the rapid spread of unplanned and unregulated shrimp farming has led to widespread use of chemicals in aquaculture, including antibiotics and pesticides, some of which are known to have detrimental environmental impacts and to affect human health. Producers and sellers of chemical products do not provide farmers with adequate information and government authorities often do not have the resources to implement existing legislation designed to control sale and use of chemicals.

Evidence from shrimp farming regions suggests that many intensive and semi-intensive shrimp farms are currently unsustainable, and data for a number of countries indicates that the more intensive systems often suffer productivity declines and an increased risk of disease outbreak after just 5–10 years (and in some cases sooner).

Guidelines for responsible and sustainable aquaculture are embodied in the FAO Code of Conduct for Responsible Fisheries, the Declaration on the Sustainable Contribution of Fisheries to Food Security, the Convention on Biological Diversity, and other international agreements, policies, and voluntary codes of conduct[1]. While the adoption of these codes and policies are welcome, and represent recognition of the need to address some of the problems associated with aquaculture, there is an urgent need for greater scrutiny of the environmental impacts of shrimp farming and far greater accountability and social responsibility.

High-calibre strategic planning within the industry, reflecting an integrated, cross-sectoral and multi-disciplinary approach, is essential. Understanding and awareness of the interconnectedness of the social, economic and environmental factors is crucial. Involvement of, and increased co-ordination between governments of both producer and consumer nations, international financial institutions, aid and development agencies, members of the seafood industry, communities affected by shrimp aquaculture and the consumers of farmed shrimp is needed to ensure ecologically sustainable shrimp aquaculture, conservation and rehabilitation of wetlands and degraded habitats, and effective regulatory and economic policies.

Efforts by the industry to improve management practices and reduce the impacts associated with shrimp aquaculture should be highlighted and welcomed. However, governments and development agencies should be encouraged to consider the effects of aquaculture within the broader context of its impacts on coastal and marine ecosystems[2].

Finally, while the development of improved regulatory frameworks and management practices for shrimp aquaculture should be encouraged, it should be recognised that in some cases the promotion of alternatives to shrimp farming offer a far more environmentally sustainable future.

Mangrove (collared) kingfisher, Halcyon chloris.

General Recommendations

In light of the information presented in this report, all relevant parties should:

- Acknowledge that shrimp aquaculture can have serious negative environmental and socio-economic impacts, with implications for biodiversity conservation and the integrity of natural ecosystems, sustainable development and food security, social well-being and human rights.

- Recognise that large areas of wetland and agricultural land have been converted for use as shrimp ponds, and that this has had direct impacts on the health and livelihoods of local farming and fishing communities.

- Recognise that there are serious concerns over the sustainability of industrial shrimp aquaculture as currently practised; initial profits are unlikely to last, and conversion back to agricultural land or restoration of wetlands is likely to be a lengthy and prohibitively expensive process.

- Recognise that the environmental and social costs of shrimp farming have not been internalised within the industry, that the full costs of aquaculture remain unquantified, and that there is an urgent need for a full economic analysis of this industry.

- Recognise that alternative livelihoods, including those that existed prior to the onset of shrimp farming, can provide significant employment and income opportunities and make a substantial contribution to rural development. As such, the development and promotion of alternative livelihoods should be prioritised.

ABOVE: *Previously a luxury, shrimp is becoming a more affordable foodstuff in industrialised nations. The true cost of shrimp is that paid by the rural poor in producer countries.*

- Ensure the protection of mangroves, wetlands and other ecologically sensitive coastal areas, and ensure the rehabilitation of degraded aquaculture sites

- Encourage the use of less-intensive and/or traditional shrimp aquaculture systems, which include an emphasis on the carrying capacity of the environment, where these are better suited to local conditions.

- Ensure the development of aquaculture in a manner that is compatible with the social, cultural and economic interests of coastal communities, and ensure that such developments are sustainable, socially equitable and ecologically sound. The precautionary principle must be applied to every step in the development of shrimp production systems, from breeding of larvae or capture of shrimp to the processing of the end product.

- Ensure that artisanal fisheries and dependent coastal communities are not affected adversely by aquaculture development or operations. Integrated coastal management planning, with meaningful participation of all coastal user groups, should be central to any future shrimp farm development. Where possible, shrimp production should be centred on community based natural resources management or co-management. Recognising the importance of local communities, fishers and shrimp farmers in understanding the conservation and management of the natural resources on which they depend, all parties should promote awareness of responsible shrimp production through education and training.

- Reiterate and abide by commitments to implement the FAO Code of Conduct for Responsible Fisheries (Article 9), urging responsible aquaculture development.

- Actively seek greatly improved communication and collaborative mechanisms – both nationally and internationally – aimed at reducing the adverse impacts of shrimp farming.

- Ensure that multilateral development banks, bilateral aid agencies, and other relevant national and international organisations or institutions do not fund or otherwise promote aquaculture development that is inconsistent with criteria to reduce environmental and social impacts, and maximise benefits.

- Support appropriate trade-related initiatives to remove negative environmental and social impacts of shrimp farming. Specifically, these should include fully independent and transparent environmental certification, product labelling and Fair Trade schemes that maximise benefits accruing to local communities and protect social and human rights, as well as the environment.

Governments of Producer Nations

Governments of producer nations should:

- Reiterate commitments to implement the FAO Code of Conduct for Responsible Fisheries (Article 9) by the adoption of robust and effective national legislation, policies, and codes of conduct for sustainable aquaculture.

- Formulate and enforce legislation and policies relating to protection of wetlands and other ecologically sensitive coastal areas. These should include the following principles:

  a) Shrimp aquaculture development in, or negatively affecting, mangroves, wetlands and other ecologically sensitive coastal areas, or involving the wholesale conversion of productive agricultural land, should be prohibited, and such prohibitions enforced with clear penalties for infractions. National obligations under the Ramsar Convention on Wetlands and other international treaties should be enforced.

  b) Pollution and salinisation of surrounding water bodies and land, and the use of freshwater for marine and brackish water aquaculture should be prohibited.

  c) The licensing of shrimp farms and processing facilities should be mandatory, and should be conditional on favourable independent environmental and social impact assessments for farms above a certain size; in areas where there are numerous small farms, the scope for sector environmental and social impact assessment should be explored.

  d) Develop and implement coordinated national policies encompassing all aspects of shrimp production (both wild caught and farmed) in light of full consultation with stakeholders and civil society groups.

- Identify and clearly demarcate suitable – and unsuitable – areas for shrimp cultivation to improve land use planning, protect ecologically sensitive areas, and reduce conflicts over land tenure and usage. This should be done following extensive surveys of the geographical and environmental features of the coastal zone (including topography, tidal fluctuations, salinity, soils, existing land use and social needs), together with a comprehensive and transparent dialogue with local communities. Such a comprehensive overview will assist with clear decision making and dialogue between governments and stakeholders. Land-use zones based on this data must have full legal protection and should be tied to educational and awareness programmes amongst stakeholders.

- Recognise the full economic value of natural ecosystem goods and services (particularly those afforded by mangroves and other wetland ecosystems) during land-use decisions and encourage the incorporation of ecological considerations into economic analyses and land-use decisions. Such an assessment should give full consideration to the economic costs of shrimp production.

- Implement and enforce stringent regulations regarding the use of chemicals in shrimp aquaculture, and collect accurate data on usage of chemicals, particularly those of greatest environmental and health concern. Collaboration between manufacturers, suppliers and users of chemicals in aquaculture should be encouraged, and training and / or expert advice should be supported. All aquaculture chemicals must be sold with accurate and full labelling and / or data sheets in the principal local languages. The potential for schemes such as certification systems (or blacklists) for suppliers should be explored.

- Regulate the use of commercial feeds in aquaculture, and act to reduce the use of feeds based on fish products. The production of alternative (non-GM) feeds should be supported.

- Regulate the collection of shrimp used for stocking ponds, including the collection of shrimp fry and the collection of broodstock for use in hatcheries. The use of hatchery fry should be encouraged and the development of farm-reared broodstock supported. Transition for fry collectors to alternative livelihoods must be supported as a priority. Stringent regulations on the importation of shrimp and on quarantining imported stock should be enforced.

- Formulate (or clarify) and enforce property and land use rights (incorporating traditional user rights).

- Increase stakeholder consultation with regard to the shrimp industry; in particular, affected communities need to be given greater opportunity for participation in management decisions, and transparency in decision-making must be promoted (for example by making public all plans for the development or expansion of shrimp farms).

- Establish and support a complaints resolution mechanism to enable communities to report on problems and gain peaceful resolution to concerns.

- Implement education and awareness programmes for local communities and for shrimp producers to ensure that regulations are adhered to, better practices adopted and alternative livelihoods promoted. Awareness raising of the importance of natural resources (particularly wetland ecosystems), together with education on better practice and alternative livelihoods should be carried out in collaboration with the media, civil society groups, government institutions and schools.

- Explore mechanisms (such as economic instruments and fiscal incentives / disincentives) to encourage better practice. These could include land use taxes for shrimp farms, effluent charges on pollutants and soil conservation funds that will better reflect the true economic costs of shrimp cultivation.

- Withdraw subsidies, tax breaks and other incentives used to encourage industry expansion, and require environmental planning and performance as preconditions to the approval of loans, credits, subsidies and access to resources[5]. The potential for introducing performance bonds as mandatory tools for all farms over a certain size should be considered.

- Explore the potential for establishing eco-restoration funds with contributions from fees and taxes on earnings of shrimp producers, processors and traders, from downpayments made as a prerequisite of licensing agreements or from performance bond funds.

- Promote increased co-ordination among policy makers, industry, civil society, primary resource users and research institutions.

The Shrimp Aquaculture Industry

The shrimp aquaculture industry should:

- Fully and publicly acknowledge its obligation and responsibility to use best practice, specifically ensuring environmental sustainability, economic viability and social equity.

- Respect all national and international laws and treaties aimed at protecting the environment and human rights.

- Ensure that all operations adhere to existing and forthcoming government regulations, and ensure that both new and existing farms are assessed to ensure full compliance with national land use policies, strategies and legislation.

- Commit to reducing the environmental and social impacts of shrimp aquaculture operations through stock selection, improved site selection, pond design and farm management.

- Support the regulation of wild shrimp fry and broodstock collection, and the development of farm-produced broodstock for use in hatcheries.

- Support the regulation of commercial feeds used in aquaculture and promote improved on-farm feed management practices that take advantage of natural food availability, reducing nutrient input levels and consequent feed wastage. Fishmeal and fish oil in shrimp feeds should be replaced with more sustainable protein and lipid sources, and research into the development of alternative (non-GM) feeds should be promoted.

- Support the regulation of drug and chemical use in aquaculture and promote holistic shrimp health management. Farmers should be encouraged to avoid the use of prophylactic treatment, and to avoid the use of chemicals where alternatives are available.

- Encourage the development of organic production and set targets and deadlines for its achievement.

- Provide technical support for efforts to improve pond design to reduce water use and exchange, and to reduce pollution of the surrounding environment.

- Ensure that shrimp farms do not lead to salinisation or other pollution of water supplies or land.

- Provide direct financial assistance for the restoration of mangrove and wetland ecosystems, and for habitat protection. Shrimp farms sited in illegally-cleared mangrove areas should provide immediate funds for reforestation and should compensate local communities for losses. Any mangrove afforestation must not negatively impact ecosystems which are ecologically valuable in their own right.

In many areas, particularly in Asia, small-scale shrimp farms have developed rapidly, often with little planning or regulation. Considered in isolation, the environmental impacts of each farm may not be great, but the cumulative impacts can be significant. Project environmental impact assessment (EIA) in such areas may not be feasible, and sector environmental assessments, particularly within the context of broader integrated resource or coastal zone management plans, may be more useful . Within this context, the potential for formation of farmer co-operatives for certification or licensing should be explored. Integrated resource management plans should address issues of land zoning, chemical use, nutrient enrichment, hydrology, salinization, environmental capacity, habitat protection, equity and social issues, disease prevention and management, farmer organisation and product marketing[6].

- Ensure that the human rights, including resource rights, of all people affected by shrimp production are respected, and that future operations are only developed following full consultation and support of local stakeholders. Farms must not block or interfere with traditional user access to critical resources, and specific commitments to fully respect coastal communities' traditional access to natural resources are required.

- Ensure that all shrimp farmers have clear legal title or rights to land use, water use, construction and operation. All decision making regarding leases and rental of public land or licensing permits should be transparent, and the terms of all leases respected. Lands that have previously been illegally occupied by the shrimp industry must be returned to local communities and restored.

- Ensure that shrimp ponds do not lead to reduced productivity of farmland or reduced livelihood opportunities for local communities.

- Encourage the development of schemes whereby local communities can benefit from shrimp farms, and assess the potential for using a percentage of profits generated by the industry to fund local community initiatives focused on education and health provision.

- Encourage, support and abide by independently developed and monitored certification schemes and trade related mechanisms aimed at ensuring social equity and environmental security. Unrestricted access should be given for third-party monitoring of all aspects of production and initiatives to register and approve all producers, processors and exporters adhering to credible, third-party certification schemes should be supported.

- Ensure that every effort is taken to introduce transparency into the industry (such as by allowing public access to assessments of operation performance).

- Participate in the promotion of responsible shrimp production through increased information exchange, education and training.

- Expose producing companies that are shown to flout national environmental legislation or that demonstrate a disregard for environmental protection. Industry associations and other professional bodies should publicly demonstrate their commitment to sustainable shrimp aquaculture and reject producers that fail to attain high standards.

- Industry associations and individual producers should make a commitment not to use political influence to amend or introduce laws or policies that will undermine or have other negative impacts on environmental protection.

The International Donor Community

The international donor community should:

- Provide increased financial assistance directly tied to improved governance and regulation of the shrimp industry and natural resource management. Improved environmental, social and land-use legislation, and appropriate mechanisms for implementation and enforcement, should be encouraged.

- Employ substantially improved standards (relating to environmental sustainability and security, economic viability, social equity and human rights) in the design, distribution and monitoring of lending and aid packages. These conditionalities should be communicated to all stakeholders.

- Provide financial assistance for mangrove and wetland conservation, protection and restoration, and for the protection of coastal livelihoods.

- Research and promote alternative land uses for abandoned shrimp aquaculture ponds. Care should be taken that mangrove and wetland afforestation should not affect other important habitats such as mudflats.

- Provide financial support and technical assistance for the rehabilitation of abandoned shrimp ponds. This must be undertaken with the full participation of local communities and must prioritise their needs.

ABOVE: *Low impact, traditional methods of shrimp culture such as these freshwater prawn traps on the Mada river, Sri Lanka, have been joined by a range of more intensive prawn-rearing methods, of concern because of their environmental impacts and lack of sustainability.*

- Give greater recognition and support to the livelihoods that were pursued before shrimp farming became established. Specifically, develop and facilitate transition to alternative livelihoods for individuals involved in shrimp fry collection, and those who have been displaced due to shrimp farming. Provide support and raise awareness of co-operatives and enhanced means to market products.

- Facilitate an independent review of lending and aid to the shrimp sector. Priority within the review should be given to a cost-benefit analysis that takes full account of environmental, social and economic factors and the impacts on local communities. Further research into the value of wetlands and agricultural land, and full economic analyses of shrimp aquaculture in relation to alternative land uses should be undertaken as priority. Such a review must incorporate comprehensive stakeholder input and dialogue with affected communities.

- Support greater governance of the industry via direct, targeted support to civil society organisations who can raise awareness of issues and alternatives and also serve to disseminate information relating to regulations, rights and responsibilities.

- Support the development of independent monitoring and reporting of practices by the communities that are affected by shrimp aquaculture to help ensure compliance with environmental and social laws and regulations, and support the development of an independent complaints procedure to resolve conflicts.

- Encourage best practice through the free exchange of technical information and through community education programmes (for example on the safe and effective use of chemicals in aquaculture, and the potential dangers of misapplication, improved pond design, feeding practices, site selection etc.)

Shrimp producers must act to reduce the environmental and social impacts of the industry through improved site selection, species selection, pond design and management, including:

a) Encourage the use of hatchery-produced fry, and support efforts to produce farm-reared broodstock and to regulate the use of wild shrimp fry. Native species should be stocked where possible (particularly in tidal areas and other areas prone to flooding), and guidelines for disease inspection and quarantine must be followed.

b) Comply with land zoning and environmental regulations to ensure protection of critical ecosystems, and for larger operations ensure that development and continued operation is conditional on environmental and social impact assessment. No new shrimp farms should be developed in, nor divert essential water flows to or from, mangroves, wetlands or other ecologically sensitive areas, or areas of productive farmland. Shrimp farms sited in mangroves must ensure that a proportion of the land is reforested, and in these areas integrated shrimp-mangrove systems should be encouraged.

c) Encourage traditional aquaculture systems, with an emphasis on the carrying capacity of the environment and the real and effective participation of all groups that benefit from coastal resources.

d) Encourage diversification within shrimp culture areas, supporting polyculture and rotation with agriculture.

e) Promote organic systems of shrimp production. Holistic shrimp health management with a focus on disease prevention should be encouraged, and drug and pesticide use discouraged. Pesticides listed by the World Health Organisation in class Ia, Ib or II should not be used in any systems.

f) Ensure that pond design is site-specific, and that design and management act to minimise the risk of pollution to the surrounding environment and the risk of spread of disease between farm stocks and from farm stocks to natural stocks. Brackish water or effluents must not be discharged into freshwater bodies or agricultural land. Discharged water should be of equal or better quality than intake water, and where possible, the quality of effluent water should be monitored before discharge.

g) Ensure that water use and exchange is minimised, and that groundwater and freshwater (for marine/brackish water systems) are not used.

h) Avoid and discourage the use of shrimp feeds that impact the environment and local food security, and promote the design of ponds to ensure that natural foraging behaviour of shrimp is supported. The use of external feeds should be reduced as far as possible, whilst the development and use of alternative (non-GM) feeds that are not based on fish products should be supported.

- Support environmental education at all levels, with an emphasis on community based natural resource management.

- Support efforts to increase coordination among public agencies, and assist in the development of communication and information sharing between agencies, civil society, governments, industry and stakeholders.

- Redirect aid and development funds currently targeted to shrimp aquaculture towards maximising local poverty alleviation and long-term environmental and social benefits at local levels. Avoid channelling overseas development aid into projects that promote unregulated, unsustainable or inequitable expansion of shrimp farming.

- Prioritise the full participation of all stakeholders in any development and subsequent monitoring of shrimp farming.

- Support the development of independent, third-party certification, labelling and Fair Trade schemes, and support the introduction and promotion of market-based mechanisms such as performance bonds that can promote better practice within the industry. Press for the removal of trade-distorting subsidies that have led to the rapid expansion of aquaculture and processing.

Research Institutions

Research institutions should undertake further research into the following:

- The economic, social and cultural value of mangrove and wetland goods and services.

- The ecological impacts of shrimp farming, including damage to mangrove and wetland habitats – satellite and GIS images should be used to monitor change over time and made publicly available.

- Full cost-benefit analysis of the environmental, social and economic impacts of shrimp aquaculture and alternative land uses.

- The potential and cost of large-scale habitat restoration in abandoned shrimp-ponds.

- The effects of chemicals used in shrimp aquaculture in aquatic tropical environments (including the impacts of these chemicals on the environment, consumers, and farmers/local communities). Further research into alternatives to antibiotics and other chemotherapeutants, such as probitoics, bioremediation, immunostimulants and vaccines should also be undertaken.

- Alternative (non-GM) feeds that reduce the need for feeds based on fish products (such as those from oilseeds, microbial proteins etc.), more water-stable shrimp feeds, and ways to minimize nutrient loss through leaching and feed disintegration.

- Improved methods of broodstock collection, and the development of farm-reared broodstock for use in hatcheries.

- Sustainable models for integrated/polyculture and rotational systems. Applied research in this area should be supported and the implementation of sustainable models promoted.

Consumers & Retailers in Consumer Countries

Consumers and retailers in consumer countries should:

- Acknowledge the existence of widespread negative impacts, including environmental problems and serious human rights abuses, associated with the shrimp industry.

- Lend active support to the swift development and implementation of independent certification of shrimp products based on robust social and environmental criteria.

- Refuse to buy, sell, distribute or eat shrimp products without certain knowledge that they have been produced without causing environmental destruction, social hardship or human rights abuses. Buy only products with recognised, credible environmental, Fair Trade and organic labels.

- Support independent monitoring and investigation of shrimp production methods and their environmental, economic and social impact on communities.

- Call upon international aid and development agencies and multi-lateral institutions to fund the effective monitoring and reporting of shrimp production techniques in major producing countries.

ANNEX I: THE ECOLOGY AND IMPORTANCE OF MANGROVES

Mangrove forests: life at the interface of land and sea

Mangroves are comprised of a diversity of plant species that thrive in intertidal zones, 'overwash islands' and estuaries. They display highly-developed adaptations enabling them to exist in conditions of high salinity, extreme tides, strong winds, high temperatures and muddy, anaerobic soils[24]. These adaptations include aerial roots and specialised mechanisms for gas exchange; mechanisms for salt exclusion and/or secretion; and seeds that germinate before separating from the parent plant (viviparous reproduction – see box below)[24,25,26].

Globally there are estimated to be approximately 54–74 'true' mangrove species[1,24,27] ranging from ferns and shrubs to trees over 60 metres high[28], with the greatest diversity of mangrove species being found in Southeast Asia[4]. In addition to the 'true' mangrove species, mangrove ecosystems provide a unique habitat for diverse bacterial, fungal, and algal communities, and a firm substrate upon which other plants can grow.

LEFT: *Aerial roots play an important role in mangrove plants' gas exchange. Examples of specialised root systems include stilt roots (e.g.,* Rhizophora *spp.), pneumatophores, or spike roots (e.g.,* Sonneratia *and* Avicennia *spp.) knee roots (e.g.,* Bruguiera *spp.) and buttress roots (e.g.,* Xylocarpus *and* Heritiera*)[26]. Root architecture differs according to species, but also depends to some extent on prevailing conditions[1].*

Adaptations to the Coastal Environment

Aerial roots play an important part in the gas exchange of mangrove plants[24,25]. The profuse lateral root systems of many mangroves also mechanically anchor the plants in fluid, often unstable soils; they play an important role in protecting young trees and germinating seeds from wave action, and trapping sediment and organic material[1,26].

Mangroves are physiologically tolerant of high salt levels, and the primary mechanisms for salt regulation include salt excretion through specialised glands in the leaves (e.g., *Avicennia, Acanthus*); salt exclusion (e.g., *Rhizophora, Bruguiera* and *Ceriops*); and salt accumulation (e.g., *Excoecaria* and *Lumnitzera*). Some mangrove plants may achieve greater tolerance through increasingly conservative water use and reduced stomatal transpiration, others may also accumulate or synthesise other solutes to regulate osmotic balance[24].

Most mangrove species exhibit high reproductive rates and 'viviparity', an adaptation to shallow marine habitats which may allow seedlings to develop some salinity tolerance before being released from the parent tree[24,26], and to avoid delays associated with germination on reaching a suitable sediment for growth[29].

Servicing biodiversity and environmental health

Mangrove forests support a wide variety of marine and terrestrial animal life through food web interactions (directly through detritus and indirectly through planktonic food chains). The shallow inter-tidal reaches that characterise mangroves act as refuges and nursery grounds for many species of fish, crustaceans and molluscs[30], many of which are of commercial value and are harvested as adults in coastal and offshore fisheries[31,32] (see Depletion, page 44). Mangroves often show tight ecological linkages to adjacent coastal and wetland ecosystems, including seagrasses and coral reefs[3,32,33,34], which are vitally important for marine productivity and biodiversity (see Annex II, page 73).

These important ecosystems perform a range of critical ecological functions (or services) – summarised in the table below. They act to stabilise coastlines, in many cases promoting coastal accretion; through retention of nutrients, chemicals and fixation of heavy metals, they act as barriers preventing pollution of near-shore waters from terrestrial run-off; can play a key role in coastal protection, dissipating the energy of storms and providing a natural barrier against cyclones and floods; act as carbon sinks, and can play a role in controlling the salinity of sediments[36]. In addition to these important regulatory ecological values, many of which indirectly support economic activities, mangroves also provide numerous direct uses to local communities through provision of fuel-wood, food, medicine and construction materials. These products and services, and in particular the support of fisheries, are vital to many subsistence economies and provide a commercial base to local and national economies[32,37].

NATURAL PRODUCTS AND ECOLOGICAL SERVICES OF MANGROVE ECOSYSTEMS[24,32,38,39]

Natural Products

- Fuel (wood, charcoal, alcohol)
- Construction materials (timber, beams, poles, thatch and matting)
- Fishing materials (poles for traps, fish poison, tannins, floats)
- Food (fisheries, other fauna, vegetables from mangrove plants, honey, alcohol, cooking oils, sugar, fermented drinks, teas)
- Household items (furniture, glues, waxes)
- Textiles (fibres, dyes, tannins for leather)
- Natural insect repellents
- Fertilisers
- Traditional medicines (see page 72)
- Anti-viral drugs (e.g., against Human-immuno deficiency virus and Hepatitis B virus) anti-tumour drugs and other pharmaceutical agents (see page 72)
- UV screening compounds
- Dyes
- Agar
- Fodder for livestock

Ecological Services

- Protection against floods, hurricanes, tidal waves
- Control of shoreline and riverbank erosion
- Support and protection of other ecosystems (including seagrasses and coral reefs)
- Provision of nursery, breeding and feeding grounds – support of coastal and off-shore fisheries
- Maintenance of biodiversity and genetic resources
- Storage and recycling of organic matter, nutrients and pollutants, including human waste
- Export of organic matter and nutrients
- Biological regulation of ecosystem processes and functions
- Production of oxygen
- Sink for carbon dioxide
- Protection of coastal zone fresh water aquifers from salt water intrusion

ABOVE: *Mudskippers, relatives of the gobies, are amphibious fish characteristic of many mangroves. They 'skip' across the surface of the mud using their tail, and their pectoral fins, which serve almost as legs. Some even climb up aerial roots, where they cling on partly by grasping the root with their pectoral fins – in many species the pelvic fins are fused together to form a sucker*[1].

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Mangrove – an oasis for endangered wildlife

Mangrove ecosystems provide an important habitat for a great diversity of mammal, reptile and bird species, including many classed as globally threatened and near threatened by the World Conservation Union (IUCN). Reptiles can be common in mangroves, and many display adaptations enabling them to survive in this saline environment[1,5]. Endangered Nile and American Crocodiles *(Crocodylus niloticus & C. acutus)* and endangered and critically endangered sea-turtles, turtles and terrapins utilise mangroves. Marine mammals include vulnerable Dugongs *(Dugong dugon)* and Manatees (three *Trichechus* species), and a number of species of dolphin and porpoise, while terrestrial mammals include otters, Fishing Cats *(Felis viverrinus)*, Clouded Leopards *(Neofelis nebulosa)*, endangered Tigers *(Panthera tigris)* and monkeys, including the endangered Proboscis Monkey *(Nasalis larvatus)*[40].

Mangroves and wetlands provide vital breeding, migratory and over-wintering sites for many threatened bird species, such as the vulnerable Masked Finfoot *(Heliopais personata)*[41], as well as land-based species, such as the critically endangered Madagascar Fish Eagle *(Haliaeetus vociferoides)*. Many vertebrates found in mangroves also occur in other coastal ecosystems, but there are some mangrove endemics such as the Mangrove Finch *(Cactospiza heliobates)* of the Galapagos Islands[42]; the Rufous-tailed Hummingbird *(Amazilia tzacatl)* and the critically endangered Sapphire-bellied hummingbird *(Lepidopyga lilliae)* of Colombia[5]. The remnant population of this species is estimated at just 50–249 individuals and is thought to be decreasing[43]. The endangered Mangrove Hummingbird *(Amazilia boucardi)* of Costa Rica has a population estimate of just 2,500–10,000, which again is thought to be decreasing; destruction of mangrove habitat, partly caused by conversion to shrimp ponds, is reducing and severely fragmenting the naturally very small and disjunct range of this endangered species[43,44].

RIGHT: *The Rufous-tailed Hummingbird (*Amazilia tzacatl*) is endemic to mangroves, and responsible for pollination of* Pelliciera *flowers*[5].

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Impacts of mangrove destruction

Destruction of mangroves has left coastal areas exposed to erosion, flooding and storm damage, altered natural drainage patterns, increased salt intrusion and removed critical habitats for many aquatic and terrestrial species[95], with serious implications for both biodiversity conservation and food security.

As mangroves are not only influenced by the chemical and physical conditions in their environment, but also help to create these conditions, perturbations to the system can have cascading long-term effects[24]. In 1997 it was reported that mangrove deforestation in the Southeastern side of the Mekong Delta led to coastal erosion, with 70 m of land being lost per year, and subsequent flooding and salt water intrusion[52].

Erosion, siltation and increased coastal pollution that occurs where there has been heavy mangrove destruction can lead to degradation of other coastal habitats, such as coral reefs and seagrasses, and eroded sediments can lead to further damage to the mangroves themselves[24].

In many areas, mangrove loss has led to reduced biodiversity, reduced fish catches[7,12,18,39], coastal erosion[12,52], acidification, loss of detrital foods, and loss of forest products. In Vietnam for example, mangrove loss and aquaculture development have been linked to local extinctions of monkfish, mullet and starfish species[53].

The ecological damage and reduction in direct benefits associated with mangrove loss have had significant effects on local communities. Reduction in fisheries may affect local, regional and international fishing communities and social impacts associated with destruction of mangroves are of serious concern (see EJF's companion report, *Smash and Grab*[96]).

The relationships between mangrove ecosystems and the goods and services that they support are not linear; the exact relationships are complex and likely to be context specific, and it is possible that the loss of mangroves beyond a certain threshold can lead to a collapse in the whole system[11,55]. Given the uncertainties about the relationships between mangrove areas and associated ecological and environmental functions[11], it is critically important that a precautionary approach is adopted.

Damage to mangroves can compromise their ability to retain nutrients, and disturbances to mangroves such as changes in frequency and duration of tidal flooding can affect the chemical properties of mangrove soils, causing them to lose their metal-binding capacity. This may result in the mobilisation of heavy metals[24,35], which can accumulate in invertebrate fauna. Certain heavy metals, specifically the highly toxic mercury and (under certain circumstances) lead, can undergo bio-magnification[63] (a build up of metal concentrations up the food chain), with implications for vertebrates and ultimately top predators, including humans.

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Swimming tigers of the Sundarbans

Straddling the border between India and Southwestern Bangladesh, the Sundarbans ('beautiful forest'), at approximately one million hectares[46], is the world's largest, and one of the richest, contiguous mangrove ecosystems. The forest is of great socio-economic importance, and provides a critical buffer against the devastating cyclones and tidal surges that periodically strike the region[47].

Both the Indian and Bangladeshi Sundarbans are Natural World Heritage Sites, providing an important habitat for a high diversity of fauna and flora, many species of which are threatened. Examples include the Ganges River Dolphin *(Platanista gangetica)*, Irrawaddy Dolphin *(Orcaella brevirostris)*, Olive Ridley Turtle *(Lepidochelys olivavea)*, critically endangered Hawksbill Turtle *(Eretmochelys imbricata)*, Estuarine Crocodile *(Crocodylus porosus)*, Spot-billed Pelican *(Pelacanus philippinensis)* and Black-headed Ibis *(Threskiornis melanogaster)*, among others. However, its most charismatic inhabitant is the Royal Bengal Tiger *(Panthera tigris tigris)*. Tigers are classified by the World Conservation Union (IUCN) as endangered, meaning that they face a very high risk of extinction in the wild in the near future; there are currently estimated to be only 5,000–7,500 left on the planet[40] and numbers are declining rapidly due to poaching, habitat loss, and prey depletion. The Sundarbans supports the world's largest remaining wild population of tigers (around 600), and its preservation is considered to be critical to their long term survival[44,48,49,50].

This vital habitat is facing a variety of anthropogenic threats, and the expansion of commercial shrimp farming in areas around the Sundarbans is a serious cause for concern[51].

'Mangroves are forests that give life to human beings, protect them from natural disasters, give life to other beings that live within them. They are natural industries created by our God and therefore they must be respected. They are not idle lands, as some would like to think, or useless swampy places; on the contrary, they are resources of incalculable value and difficult to restore. Let's not forget, then, that mangroves are life, are fire, are pure environment, are blood.'

Camilo de Leon, a community leader in Champerico, Guatemala, speaking out against the impacts of shrimp farms[71].

Storm Protection

Many mangroves play a critical role in coastal protection, reducing shoreline erosion and acting as very effective storm breaks. Mangrove trees both shield the land from waves and trap sediments in their roots, maintaining a shallow slope on the seabed that absorbs the energy of tidal surges[56]. In countries prone to typhoons, hurricanes and severe floods, the costs of mangrove loss, both financial and in terms of human life and livelihoods, can be devastating. In the Indian state of Orissa, where the low-lying coastline has been stripped of mangroves to make way for shrimp farms[56], a cyclone in 1999 left approximately 10,000 people dead[57] and around 7.5 million homeless; areas with intact mangrove forests were reported to be largely unaffected[58]. Mangroves protected villagers in the Chokoria Sundarbans of Bangladesh from a 1960 tidal surge[16], but widespread mangrove loss for shrimp pond construction has left the area highly vulnerable to the impacts of cyclones[17] and another cyclone of comparable magnitude in 1991 caused an estimated 140,000 deaths and serious property damage[16,59]. In Vietnam, when the biggest typhoon for a hundred years claimed 3,000 lives along the southern coast[60], damage was less in areas with mangroves[61]. Decimation of mangroves along the Philippine coastline is reported to have exacerbated great losses to life and property inflicted by an average of 20 typhoons and tsunamis each year[62].

Shrimp farm site selection

Evidence from shrimp farming regions suggests that many intensive and semi-intensive shrimp farms are not currently sustainable[7,8,21,62,64,65,66,67,68]. In Indonesia[22], Vietnam[20] and Thailand[15,93] for example, productivity declines and risks of disease outbreaks increase after 5–10 years of operation. Such problems may be increased where farms are located in mangroves, and it is increasingly being recognised that mangroves are unsuitable sites for commercial shrimp farming[94].

Many mangrove ecosystems have 'potential acid sulphate' soils; when the soil is exposed to air following mangrove loss and degradation, iron pyrite can be oxidised to iron and sulphuric acid. The low pH can stress shrimp directly, and if low enough can starve pond water of nutrients, release toxic ions and precipitate iron on shrimp gills and exoskeleton[22]. This can increase the need for high rates of water exchange (leading to increased pollution, compounded by the loss of the natural filtering services provided by mangrove habitats, groundwater exploitation and salinisation), and may increase incidence of disease and use of prophylactic and therapeutic drugs[1,22].

Ironically, removal of mangroves to create shrimp ponds actually undermines the basis of shrimp production. With loss of mangrove refuges and nursery grounds, it becomes progressively harder to obtain shrimp fry and broodstock to stock ponds[1,22,32,64,69] and the natural food supply brought in by the tides is reduced[1]. Shrimp farms require large volumes of clean, nutrient-rich water, which mangroves act to filter[22,32], and intensive and semi-intensive systems require fish products as feed components[31,32,64]. Mangroves also help to control erosion and protect against floods and storms, and thus help protect aquaculture operations against these natural disturbances[32].

There is clearly a conflict between the need for a healthy ecological support system and the effects of shrimp farming on the surrounding environment[64]. Although a shrimp farm's 'ecological footprint' (spatial ecosystem support) will depend on the intensity of farming[68], for semi-intensive shrimp farms in Colombia it has been estimated to be 35–190 times larger than the farm area, depending on the extent to which wild larvae and broodstock are required[64]. The mangrove nursery area required to produce shrimp larvae for the pond may be the largest support system, up to 160 times the pond area[64,68], while 2–22 ha of mangrove are needed to counter effluent from one hectare of semi-intensive shrimp pond[70].

In a recent study in India, each shrimp hatchery in East Godavari and Vishakapatnam Districts in Andhra Pradesh was found to have an average ecological footprint of 534 ha of mangrove for the input of *Penaeus monodon* spawners alone; the ecological footprint of intensive shrimp farms in the area was estimated to be up to 18 times the pond area just for postlarval input[23].

'In areas where shrimp farming occurs in Lampung [Indonesia] the condition and trend over time in terms of shoreline erosion, water quality, and mangroves is poor and decreasing. The threat to resource condition and quality of life from unsustainable shrimp farm practice is high'.

Dr James Tobey, Hermawati Poespitasari & Dr Budy Wiryawan, 2001[21].

LEFT: *Abandoned shrimp ponds, Vietnam. The productivity of shrimp aquaculture systems is heavily dependent on surrounding mangrove goods and services. Failure to acknowledge this life-support function of mangroves is one explanation for the uncontrolled expansion and intensification of shrimp culture, which has led to self-pollution and disease problems[9,32].*

According to an October 2001 ecological footprint analysis, five shrimp farms in northwestern Guatemala (506 ha) would need approximately 17,930 ha of healthy mangrove to provide clean water and shrimp larvae, and to process wastes, over the long term, yet there are only about 11,940 ha of mangrove forest in all of Guatemala[71].

Similarly, a recent footprint analysis in Thailand concluded that intensive shrimp farming is unlikely to be sustainable because of the extent of external mangrove ecosystem support needed[72]. With mangrove degradation, shrimp farming is becoming even less sustainable. In Sri Lanka, the mangrove area in Chilaw is now insufficient to support the current shrimp farm area and, by extrapolation based on shrimp farming methods and mangrove coverage, the country's total mangrove area is also estimated to be insufficient to support its shrimp farm industry[73].

In Thailand, it has been estimated that over 20% of shrimp farms located in former mangroves are abandoned after 2–4 years[75,76]. Studies in Sumatra indicated that average productivity in shrimp farms constructed in mangroves drops from around 10 tonnes/ha to around 2.5 tonnes/ha over four years[22]. In Ecuador, much of the 400 km^2 of mangroves converted for shrimp aquaculture by 1997 were reported to be unproductive due to salinisation and acidification[3]. Despite these concerns, in many countries destruction of primary and secondary mangroves for shrimp aquaculture development continues[10]. A major driving force behind the exploitation has been a widespread trend of under-valuation of mangrove and wetland products and services[2,9,32,37,39,77,78]. Indeed, in many countries, mangroves have been classified as 'wastelands', facilitating their exploitation by industry[14,37,54].

Rapid conversion of mangroves to shrimp farms has also been exacerbated as mangroves and other wetlands, being in the tidal zone, are often areas of public or open-access land, and often lack formalised or well-defined land rights[8,14,20]. It should also be noted that, while it is now widely recognised that mangroves are unsuitable for commercial shrimp culture, conversion may be driven by availability rather than suitability – in many countries mangroves may be the only land available to poorer farmers[10], thus making their protection all the more difficult.

OPPOSITE PAGE: *Mangroves, at the interface of land and sea, are highly productive ecosystems, home to a high diversity of species.*
© Monica Gutierrez-Quarto

BELOW: *Mangrove heron (*Butorides striatus*), Tobago.*
© Jeremy Stafford-Deitsch

Economic values of mangroves

There has been a great trend of under-valuation of natural wetlands, including mangroves. Failure to recognise and value all natural products and services provided by these ecosystems has been a major driving force behind the widespread, extensive loss of mangroves during recent decades[2,9,32,37,39,77,78].

This trend may be partly due to the difficulty involved in placing monetary value on mangrove goods and services that are (i) not traded on markets and so do not have a directly observable value or conventional market prices; and (ii) harvested or enjoyed outside of the mangrove system and therefore not readily acknowledged as generated by this system[37,77]. An important determinant to this trend may be lack of ecological knowledge and a holistic approach among valuators[32,37], and may be complicated by the high degree of interconnectedness within and between ecosystems[2]. Such under-valuation of mangroves has led to many decisions over land use being biased towards development, such as conversion of mangroves for shrimp aquaculture, which generates directly marketable products[78]. However, decisions based on narrow and short-term financial analyses alone risk supporting economically non-optimal developments, as well as promoting ecological damage[38]. In addition, economic valuations of shrimp farming often assume (i) that shrimp yields are constant over time, and (ii) that natural resources are limitless[54]. As neither of these assumptions can be said to hold, the value of shrimp farming may be overestimated, further biasing decisions to develop wetlands for shrimp aquaculture made solely on economic grounds[54] (though in Cambodia's Koh Kong Province, shrimp farms were found to be unprofitable on narrow financial analyses alone, with an average loss of US$1,103/ha[38]).

Capture fisheries production is thought to constitute the major value of marketed products from an un-exploited mangrove forest[9,32,84]; the market value of these fisheries can be substantial and, in addition to commercial fisheries, coastal subsistence economies in many developing countries are heavily dependent upon sustainable harvest of fish and shellfish from mangroves[32]. Environmental production in mangrove ecosystems shows large spatio-temporal variation throughout the tropics and subtropics[5,32] but it has been estimated that the annual fisheries catch may be as high as 1,100–11,800 kg/ha mangrove (equal to 3,600 kg/ha mean), with an annual market value of fisheries supported by mangroves in developing countries ranging from US$900–12,400 per ha mangrove (US$3,400/ha mean)[37,85]. In Andhra Pradesh, India, it has been estimated that the Godavari mangrove delta has a partial gross economic value of US$3–6 million per year for the provision of shrimp spawners alone[23].

However, fish and shellfish production is only one of the many services produced by mangroves, and additional efforts to estimate the economic value of forest resources and ecological services generated by mangroves will further highlight the significant value of these ecosystems and their support to subsistence, local and national economies[86]. In areas with developed commercial and subsistence fisheries, Dr Patrik Rönnbäck estimates that the annual value of natural products and ecological services generated by mangroves may be approximately US$20,000 ha/yr[85], while the estimated economic value of mangrove forests to a local community in Thailand has been estimated to be in the range of US$27,264–35,921 ha/yr[15].

A recent analysis of a mangrove system in Thailand revealed that conversion for aquaculture made sense in terms of short-term private benefits, but when benefits of mangrove cover including timber, charcoal, non-timber forestry products, offshore fisheries and storm protection were considered, the total economic value of the intact mangrove exceeded that of shrimp farming by 70% (approximately US$60,400 compared to approximately US$16,700)[19,80].

Acid sulphate soils

Many mangroves have soil that when disturbed to create shrimp ponds become oxidised 'acid sulphate' soils, which release acid and toxic levels of iron and aluminium upon wetting. This can promote productivity declines and pond abandonment[79]. Remediation of acid sulphate soils is expensive and the conditions can persist for years after ponds have been abandoned, leaving few other opportunities for use of the land.

Economically valuable, ecologically essential

A recent analysis of a Thai mangrove system revealed that the total economic value of intact mangroves exceeded that of shrimp farming by 70%[80] (see box, left). Further studies into the economic value of mangrove forest resources and ecological services are needed (particularly as mangrove areas can differ widely with respect to their provision of different ecological services[5,32,81]). However, it is becoming increasingly evident that when the full range of mangrove products and services are considered, and factors such as increased costs of construction in mangroves, vulnerability of former mangrove sites to storms, and decline in shrimp yields over time are included, development of shrimp farms in mangroves not only has serious environmental and social impacts, but is also not economically sound (see box, left)[6,22,31,38,39,54,78,82,83].

Due to the high potential profits from shrimp aquaculture it has been estimated that, in many intensive and semi-intensive systems, farm owners may only need a few successful harvests in order to make a profit[54]. Together with a lack of awareness of the values of mangroves and wetlands, this can mean that (without adequate legislation), there may be little incentive for owners to adopt a long-term approach and protect mangrove resources, or to invest in the land or in improved production systems.

Mangroves and medicine

Mangroves are biochemically unique, producing a large array of novel natural products. Substances in mangroves have long been used in folk medicine to treat disease[24], from the use of *Excoecaria agallcha* for the treatment of ulcers, leprosy and epilepsy in Vietnam[88] to the use of *Xylocarpus granatum* for stomach problems and hernias in Southern Africa[89]. Modern techniques have now proven that extracts of certain mangrove products show activity against human, animal and plant pathogenic viruses, including human-immuno deficiency virus (HIV), Encephalomyocarditis virus, and Hepatitis-B virus[24]. A few mangrove species, especially those in the family Rhizophoraceae, show particularly strong anti-viral activity, and purified active fractions like acid polysaccharides show potent anti-HIV activity[24]. Mangrove extracts have also been found to kill mosquito larvae, while smoke from burned extracts of stilt roots repels and kills both *Aedes aegypti* and *Culex quinquefasciatus* mosquitoes, and extracts applied directly to human skin repel adult *A. aegypti*[24]. Bacteria isolated from mangrove sediments include *Bacillus thuringiensis*, which has been found to show insecticidal activity against mosquito larvae; and actinomycetes that occur in many mangrove habitats may show antifungal activity. Compounds extracted from Mangrove Tunicates (*Ecteinascidia turbinata,* a colonial ascidian that grows primarily on the submerged prop roots of *Rhizophora mangle*), have been found to show strong activity against a variety of cancers (carcinomas, melanomas and lymphomas), and these tunicates are currently the only source of the potent anti-tumour drugs, ecteinascidins[24,90].

Legal protection

Legislation to protect mangroves has improved in recent years, and there have been considerable efforts to promote better practice within the industry. A number of countries have implemented policies that ban or restrict the cutting of mangroves for aquaculture, and industry-led codes of conduct (such as those of the Global Aquaculture Alliance and Aquaculture Certification Council) emphasise mangrove protection.

However, even where legislation is in place, it is often poorly enforced (such as in Honduras, see page 19). Farmers may also lack funds necessary to comply with regulations, or be reluctant to take measures demanded by regulations without reassurance others will follow[54]. In many countries, appropriate regulations for the protection of mangroves (preferably within the context of comprehensive, integrated coastal zone management plans focusing on community-based natural resource management) still need to be established, and enforcement of legislation needs to be more tightly controlled.

A number of countries have initiated mangrove reforestation programmes in degraded mangrove systems and abandoned shrimp ponds[20,37]. This should be encouraged wherever possible, but it should be recognised that rehabilitation of shrimp ponds can be a lengthy and expensive process[22], and there remains considerable debate about the feasibility of restoring mangrove forests to their former diversity and ecological significance in such areas[12,54]. Estimates of the costs of restoring abandoned shrimp ponds vary from US$225/ha to US$216,000/ha, depending on the methodology used[91]. Simply planting mangrove seeds is the cheapest option (US$100–200/ha) but is prone to failure[91]. Hydrological restoration improves the likelihood of success for similar costs and ecological functions can be restored relatively quickly, with fish populations normalising within five years[91]. However, one of the major challenges is restoring water circulation, a process that can require the use of heavy machinery when there is little economic incentive[91,92]. Community participation and education are key to successful mangrove rehabilitation.

The potential for use of economic instruments and financial incentives to assist with enforcement of regulations and protection and rehabilitation of mangroves and other natural resources should be explored and promoted.

ANNEX II: SEAGRASSES & CORAL REEFS

Seagrasses are the only exclusively-marine flowering plants, and are more closely related to terrestrial plants than to seaweeds[1]. Seagrasses often grow in dense, extensive beds, which fringe sandy and muddy tropical and temperate coasts, and form the basis of extremely productive ecosystems. Although there are relatively few species of seagrass, the complex physical structure and high productivity of these ecosystems enables them to support a considerable biomass and diversity of associated species[2]. Seagrasses themselves are a critically important food source for vulnerable dugongs (*Dugong dugon*), manatees, and sea turtles (including the endangered green turtle, *Chelonia mydas*), as well as for many other species of fish and invertebrates including seahorses, shrimp and scallops[1,2,3]. Other marine species utilise seagrasses for part of their lifecycle, often for breeding or as juveniles[2]; and many of these species are commercially valuable[4].

Seagrasses are considered to be one of the most important shallow-marine ecosystems to humans[2]. They perform crucial ecological services, filtering and binding sediments, maintaining water quality[1,3,4,5] and providing some protection from coastal erosion, and they play significant roles in fisheries production[2] and in global carbon and nutrient cycling[4].

Healthy coral reefs constitute the most diverse of all known marine ecosystems, with a greater array of life forms than any other ecosystem on the planet[6]. About 4,000 species of reef fish and 800 species of scleractinian (reef-building) corals have been described[6,7], but it is estimated that only 10% of marine species associated with coral reefs have been identified to date. Southeast Asia has nearly 100,000 km^2 of coral reefs, almost 34% of the world total, and with over 600 reef-building coral species these reefs have the highest level of marine biodiversity on Earth[6].

This diversity generates very high productivity[6], and coral reefs provide an accessible area for small-scale fishing[8]. Nearly one third of all fish species live on coral reefs, and fisheries capture from reefs contributes about 10% of human fish consumption globally[9]. In tropical Asia, 70–90% of all fish caught by coastal fisheries are reef-dependent for one stage in their life-cycle[10]. If properly managed, it is estimated that reefs can yield on average 15 tons of fish and other seafood per km^2 each year[7], and the total annual net benefit of sustainable coral reef fisheries across Southeast Asia is estimated to be as high as US$2.4 billion per year[6]. The coral reefs of Indonesia and the Philippines provide annual economic benefits estimated at US$1.6 billion and US$1.1 billion per year, respectively[6]. In addition to their support of fisheries, coral reefs are also very important for employment, tourism, pharmaceutical research and coastal protection.

ABOVE: *'Loss of coastal habitat, suitable for [seahorses], is a concern in many countries... Mangrove cutting and associated shrimp and prawn farming are causing concern in countries as far apart as Bangladesh, Brazil, Ecuador and Kenya'*[11].

BELOW: *Staghorn coral in seagrass.*

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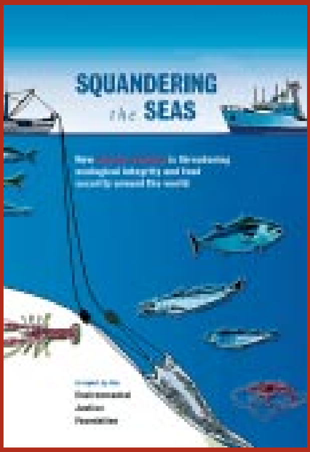

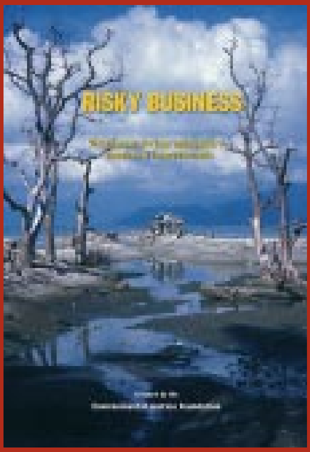

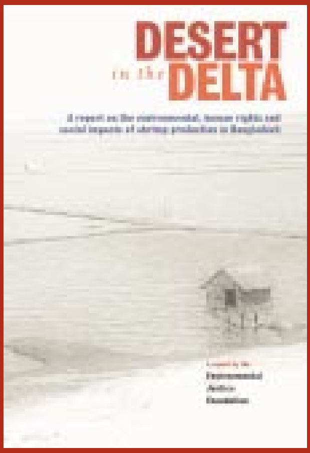

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