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AN ECOLOGICAL APPROACH: A Viable Option for Aquaculture Industry in Malaysia

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ABSTRACT

Aquaculture sector in Malaysia is poised to play a major role to compensate for the declining capture fisheries, and is expected to emerge as one of the major agricultural contributors to the national economy. The industry is anticipated to increase the production to 600,000 mt, generating returns up to US$2.63 billion by 2010. This is a significant increase of approximately 360% in production compared to the current production of 167,894 mt valued at US$255.34 million.

Aquaculture involves utilization of natural resources such as clean water, vast tracks of land, feed materials and fertilizers to produce desirable products with simultaneous production of organic and chemical wastes. Thus, the successful development of this sector is dependent on the nation's ability to utilize its resources efficiently and sustain its growth without adversely affecting the aquatic environment. At present, most aquaculture practices in Malaysia generate adverse impacts on aquatic environment, the very resource that determine the success and the sustainability of the aquaculture industry. Wetland habitats such as mangroves, estuaries, sea-grass beds, coral reefs and mudflats are particularly vulnerable, especially when the impacts exceeded the ecosystem's resilience and carrying capacity. However, carrying capacity in various ecosystems is poorly known and thus the tendency to exceed the upper limit seems to be common in most environments. Adverse impacts associated with aquaculture, especially the intensive systems, include habitat destruction, discharge of effluents with high organic contents, contamination of the aquatic environment with chemicals, eutrophication, disease outbreak, effects of escaped- exotic species and decrease in biodiversity.

Ecological approach based on the efficient use of energy sources along the food chain with suitable microbial loop to process the wastes is one viable option to ensure that the aquaculture venture is commercially viable and sustainable. In the face of scarce raw resources such as land and water, appropriate measures are necessary to ensure that aquaculture industry does not cause irreparable damage to the aquatic ecosystems. Areas with the most promising improvements for aquaculture practice include integration of aquaculture facilities with the natural ecosystems and other related activities, reduction of allochthonous loadings through better management of external energy sources (feeds, fertilizers, chemicals), efficient utilization of food sources along the food chain through biomanipulation and biocontrol, maintaining efficient microbial loop through

bioremediation, waste treatment using biological processes and the possibility of using recycling system for efficient use of water supply.

Ecological approach in aquaculture industry need not be limited to producing products at low levels. With the modern biotechnology and engineering know-how, methods can be designed to harness the natural resources to maximize aquaculture production, and at the same time protect the valuable environment from the adverse impacts associated with aquaculture activities.

INTRODUCTION

Aquaculture, the farming of animals and plants in aquatic environment, is becoming an important industry worldwide to compensate the declining capture fisheries and to relief pressure on the marine resources. World aquaculture production is growing more than 10% per year, compared with 1.5% capture fisheries and 3% livestock (FAO, 2001). The rapid growth of aquaculture in the recent years involved small-scale ventures as well as large-scale enterprises; from low value crops for local consumption to high value products for international markets, which contributes significantly to foreign currency earning. The growth is expected to continue with Asian region contributing approximately 90% of the world's aquaculture production (FAO, 2001). Aquaculture industry, which involves different techniques for hundreds of fish species and aquatic invertebrates, has great potential for the increase in production of food, health and cosmetic products, as well as alleviation of poverty, and generation of wealth for nations with vast water-bodies.

Although the production systems may differ from region to region, depending the type of species cultured and related environmental factors, all forms of aquaculture involves utilization of natural resources and manipulation of biological systems. It involves the use of resources such as clean water and vast tracks of land, feed materials and fertilizers to produce desirable products with simultaneous production of organic wastes and chemicals. This organic waste, which is an inevitable consequence of aquaculture activity, would not be harmful as long as its loading into the environment can be processed and recycled efficiently into the ecological food chain. Problems arise when aquaculture practices do not address concerns to minimize organic wastes to suit the environmental carrying capacity, and refrain from using harmful chemicals and introduction of untested exotic species. Due to high cost associated with minimizing environmental impacts from aquaculture practices, most aquaculture activities cause serious undesirable impacts such as pollution, transfer of new pathogens and escape of exotic animals into the natural environment.

Ironically, the success of aquaculture activity very much depends on the quality of the natural environment. By discharging effluents into the water-bodies that supply water for the culture, the industry is undermining its own sustainability. This is probably because the adverse impacts are usually masked in the early stage of the farming due to the dilution effect in vast water-bodies. Thus, most aquaculture ventures are profitable only for the first few years, and subsequently yields begin to decline with the manifestation of eutrophication (Yusoff *et al*. 2001a). This paper presents the status of aquaculture in Malaysia, its impacts to the aquatic environment and some of the options to overcome the challenges of sustaining optimum production in aquaculture industry.

MALAYSIAN FISHERIES INDUSTRY

Malaysian fisheries industry contributes significantly to the national economy. The annual fish production, per capita fish consumption and the fisheries sector employment have been in the increase over the past decade. Total fish production in 2000 contributed 1.454 million mt valued at US$1.413 billion to the national fish supply, which was equivalent to 1.6% to the country's gross domestic production (DoFM, 2000). The industry supports about 103,768 people or 1.28% of the total labour force in Malaysia (DoFM, 2000). The development of fisheries sector in Malaysia is expected to emerge as one of the major agricultural contributors to the national economy, both as a source of foreign exchange and more importantly as a source of animal protein.

Being a land rich in aquatic resources, inevitably fish becomes an integral part of the Malaysian life. The national per capita fish consumption of 57.7 kg is much higher than the Asian average of 28.0 kg and the world's average of 15.8 kg (Williams, 2003). In fact, fish and fisheries products form 60-70% of the total protein intake, indicating the vital role of these aquatic resources in the nutritional status of the Malaysian population (Wan Rahimah and Adinan, 1992; Mohd. Mazlan, 1997; 2000). With the dwindling catch from the seas, the development of aquaculture sector in Malaysia is expected to emerge as one of the major agricultural contributors to the protein production and national economy. However, the successful development of this sector is dependent on the nation's ability to exploit resources efficiently and sustain its growth without adversely affecting the aquatic environment.

AQUACULTURE PRACTICES

The aquaculture industry in Malaysia began in the early 1900's when Chinese migrants cultured Chinese carps in old mining pools, initially as a supplementary food source, and eventually on a commercial scale (Ong, 1981). In the early days, the culture systems were mainly extensive, relying mainly on natural energy of the systems. Major events in aquaculture occurred in the 1970's with the introduction of cage aquaculture, green mussel culture and oyster farming in Sabah (Shariff et al., 1998). The involvement of corporate sectors in the industry in 1980s marked its transformation from the subsistence level to a market driven venture. However, commercialization of fisheries products has resulted in intensification of the culture system with concomitant increase in stocking rates, feeding rates and waste products.

Aquaculture production in 2000 was 167,894 mt valued at US$255.34 million (DoFM, 2000), which forms about 11-12% of the total fish production. Aquaculture growth in Malaysia is relatively slow with an average annual increase of 0.5% compared to the world's average of 10%. Strong support from the Government in an attempt to increase the production to 600,000 mt, generating returns up to US2.63 billion by 2010, has given an impetus to the expansion of aquaculture industry in Malaysia (Figure 1). Freshwater aquaculture sector produced 50,688 mt in 2000, an increase of about 36% compared to the production in 1996 (DoFM, 1996; 2000). In the same year, marine aquaculture produced 117,206 mt of fish/shellfish/seaweed valued at US$117 million, that is 35% higher compared to 1996 production of only 87,075 mt.

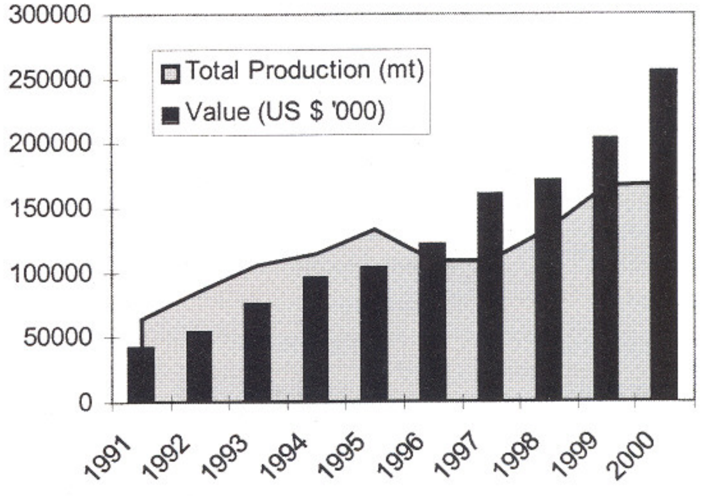

Figure 1: Trend of aquaculture production and value from 1991 to 2000

There are several systems that are employed in aquaculture production. The most common are ponds, which are usually excavated. However, in some areas, old tin mining pools are also used for fish culture. The culture of fish in floating net cages also represents an important aquaculture system and is normally carried out in deeper mining pools, reservoirs and lakes. Aquarium fish farming uses a combination of aquaria, tanks and small ponds. It is one of the most rapidly developing sectors in the aquaculture industry with annual production exceeding 306 million pieces valued at about US$18.9 million (DoFM, 2000)

The biggest proportion of local aquaculture production is contributed by the cockles (38.4%; Table 1). This is followed by freshwater pond (23,1%), and brackishwater pond aquaculture (10.4%). Seaweed farming, which is currently produced only in Sabah, has become increasingly important, contributing 9.6% to the total aquaculture production. Cage aquaculture production has stagnated around 6,000-8,000 mt/year.

Table 1. Aquaculture production in Malaysia for 2000 (DoFM, 2000).

System	**Production**		**Value**	
Mariculture	**(mt)**	%	**(US$ '000)**	%
On-bottom farming of cockles	64,396.25	38.4	13,329.90	5.2
Rack and raft culture of mussels	11,068.9	16.6	1,444.45	0.6
Raft culture of oysters	231.83	0.1	449.49	0.2
Seaweed	16,124.80	9.6	1,824.65	0.7
Brackishwater Aquaculture				
Pond culture of crustaceans and finfish	17,418.19	10.4	130,312.45	51.0
Cage culture of marine finfish	7,965.58	4.7	27,729.11	10.9
Subtotal (Coastal Aquaculture)	**117,205.56**	**69.8**	**175,090.05**	**68.6**
Freshwater Aquaculture				
Pond culture of finfish and crustaceans	38,852.78	23.1	66,223.34	25.9
Mining pool culture of finfish	6,437.61	3.8	5,952.63	2.3
Cage culture of finfish	3,929.45	2.4	6,376.98	2.5
Tank culture of finfish	960.62	0.6	1,069.31	0.4
Pen Culture	507.97	0.3	635.83	0.3
Subtotal (Freshwater Aquaculture)	**50,688.43**	**30.2**	**80,258.09**	**31.4**
Grand Total	**167,893.99**		**255,348.14**	

Pond Aquaculture

Pond culture represents the most dominant culture system employed in the country. Ponds are used for cultivation of freshwater fish and prawns as well as marine shrimps, especially the penaeids. In 1995, there were 31,350 ponds with a gross surface area of 9,150 ha in the country, but in 2000, the number of ponds increased to 43,578 with an area of 12,217 ha (DoFM, 1996; 2000). In addition, there are 379 used-mining pools with a total surface area of 1,635 ha used for aquaculture. These mining pools were part of a larger resource of over 4,300 disused mining pools, covering an area of 16,440 ha, especially in Perak, Selangor, Johore and Pahang, where mining was once an important economic activity (Yusoff and Gopinath, 1995). Besides aquaculture, these mining pools are also used for water supply, recreation and waste disposal.

Freshwater pond aquaculture is the major contributor in aquaculture production, producing more than 61% of total pond output for the last five years (DoFM, 1996; 2000). However, brackishwater pond commodities contributed significantly higher earnings of US$130.3 million compared to US$66.2 million from freshwater ponds (DoFM, 2000). The main commodities produced in the brackishwater aquaculture sub-sector are penaeid shrimps and finfish, particularly the sea bass (*Lates calcarifer*), mangrove snapper (*Lutjanus argentimaculatus*), and grouper (*Epinephelus* sp.)

Shrimp is the most important commodity from brackishwater ponds, accounting for approximately 91% of the brackishwater production and 95% of its value in 2000. The main shrimps reared are the penaeid, especially the tiger shrimp, *Penaeus monodon*, which accounted for 98% of crustacean production. Other crustacean species are banana shrimp (*P. merguiensis*), and mud crab (*Scylla serrata*).

Tiger shrimp production has been increasing steadily over the years. Production of 1997 has expanded by 224% from the 1991 production of 2,895 mt (Fig. 2). This increase in production is partly due to the 61% increase in the pond area. In addition, production increase was also brought about from intensification of production. Despite intractable disease problems faced by many farms (Wang et al., 1999), unit production increased from 1.8 mt/ha in 1991 to 2.6 mt/ha in 1995, an increase of 44%. In 2000, unit production decreased to approximately 2.4 mt/ha due to the occurrence of white spot syndrome virus in mid and late 1990's.

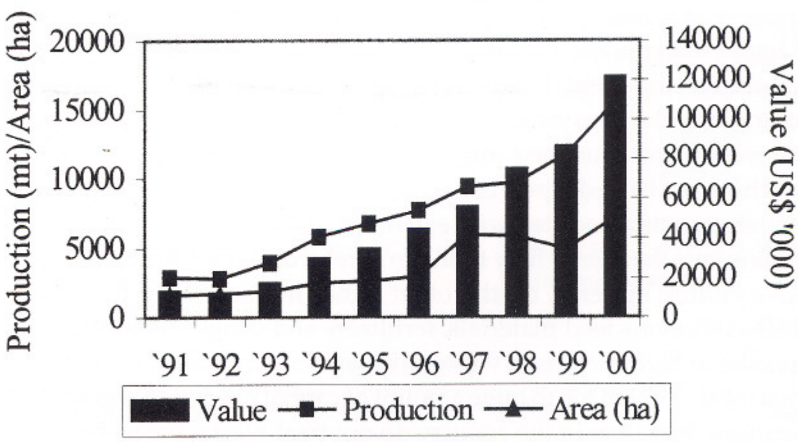

Figure 2: Trends of value, production and area for shrimp from 1991 to 2000

Cage Aquaculture

The culture of fish in floating cages was introduced into the country only in early 1970's (Chua and Teng, 1977). It has since become a major industry in its own right particularly in the production of marine fish. There has been a significant increase cage culture area from 326,390 m^2 in 1991 to 794,785 m^2 in 1995, and to 1.04 million m^2 in 2000. Production in 2000 amounted to 11,895 mt, giving an average production of about 11.5 kg m^{-2}, compared to 9.2 kg m^{-2} in 1995 (DoFM, 1996; 2000).

In 2000, freshwater cage aquaculture contributed about 7.8% of the total freshwater fish production. Red tilapia (66%) is the main species reared in cages followed by patin (*Pangasius*, 21%) and river catfish (*Mystus nemurus*, 6%). The main marine finfish reared in cages are the sea bass, and the red snapper, which in 2000, accounted for 80% of the total cage aquaculture production. Other organisms reared in cages include the groupers, red tilapia and crabs.

Yield increase in cage aquaculture came from an intensification of production. Despite intractable disease problems faced by many farms (Shariff and Arulampalam, 1996), unit production from marine cage farms increased from 7.1 kg/m^2 in 1991 to 9.4 kg/m^2, in 2000. As with shrimp farmers, increasing production efficiencies had also led to additional tonnage. The fluctuating production however implies that some kind of upper limit may have been reached where these efficiencies are concerned.

IMPACTS OF AQUACULTURE PRACTICES ON THE ENVIRONMENT

The Department of Fisheries statistics show that the increase in aquaculture production is due to the boost of a few species, mainly from pond and cage aquaculture. Thus, the severity of impacts on the environment would roughly mirror the production tonnage. In addition, all the environmental impacts of aquaculture are dependent on the sensitivity and type of a particular ecosystem as well as the type of farm practice. The amount of aquaculture wastes and thus their impacts on the environment are closely related to the culture method, cultured species, feed-type and farm management practices. Environmental impacts associated with extensive culture systems are considered minimal as the systems mimic the energy flow found in natural ecological systems. In semi-intensive and intensive culture systems, on the other hand, high stocking rates necessitate high loading of allochthonous feed materials, fertilizers and drugs. In addition, high stocking rates also results in high metabolic waste, such as ammonia from the cultured organisms (Shishehchian et al., 1999). Due to huge amount of capital needed to ensure clean discharge, most aquaculture operators in the country do not treat waste-waters before discharge.

Wetland habitats such as mangroves, estuaries, sea-grass beds, coral reefs and mudflats are particularly vulnerable, especially when the impacts exceeded the ecosystem's carrying capacity. However, carrying capacity in various ecosystems is poorly known and thus the tendency to exceed the upper limit seems to be common in most environments. Adverse impacts associated with aquaculture, especially the intensive systems, include habitat destruction, discharge of effluents with high organic contents, contamination of the aquatic environment with chemicals, eutrophication, disease outbreaks, effects of exotic species and decrease in biodiversity.

Habitat Destruction

Many aquaculture practices involve clearing of wetlands and utilizing land areas devoted to other crops such as rice fields. One of the largest users of these wetlands is shrimp farming. Globally, shrimp industry grew at an annual percentage of about 16.8% between 1988 to 1995. The world's penaeid shrimp production totaled 942,000 tonnes with the tiger shrimp, *P.monodon* contributing about 52% of the total. Cultured shrimps are predominantly produced in Asia with Thailand as the largest world's producer (FAO, 1997). Rapid expansion of shrimp culture, driven by high demand and prices, led to the destruction of vast areas of mangroves (Table 2), disrupting the balance of this highly important ecosystem.

Mangroves are known to be one of the most productive ecosystems in the world supporting the billion dollar fishing industry in the adjacent seas. The highly complex and stable mangrove ecosystems serve as the spawning, breeding and nursery grounds for many species of fish and aquatic invertebrates. Thus, these ecosystems play a very significant role in sustaining fisheries resources through the tidal flushing of nutrients and detritus that form the food base for the fisheries production, not only in the coastal areas, but also the off-shore waters. Studies have illustrated that seas, which have mangroves in their coastal areas, have higher fish catch compared to those without mangrove belts (Martosubroto and Naamin, 1997; Sasekumar and Chong, 1987). Other natural functions of mangroves include shoreline protection from erosion (Salleh and Chan, 1988) as well as sanctuaries for wildlife, such as the aquatic birds.

Table 2. Mangrove areas in shrimp producing countries

Country	Tot. Mangrove Area (ha)	Area Cleared	Area for shrimp farming	References
Malaysia	641,172	30%	1%	Choo, 2001
Thailand	372,488 (1961)	168,000 (1993)	64% (1993)	Yashiro, 1997
Philippines	450,000 (1920)	31% 310,275 (1988)	68% 210,457 (1988)	Zamora, 1989
Indonesia	4 mill.	Na	(5%) 200,000	Phillips, 1997

Aquaculture ponds excavated in mangroves areas have acidic bottom soil with low pH of less than 4. Productivity in ponds from these areas is low and the operation cost is high. In addition, the effluents released to the public waters may also be acidic and cause adverse impacts to the biological communities.

Other habitat changes due to brackish-water aquaculture include saline soil in rice fields and saline water in freshwater-wells. In addition, the use of large amount groundwater has led to ground subsidence. In early 1990s, massive use of groundwater in a 2000-ha aquaculture facility in Nenasi, Pahang caused wells to dry, salt water intrusion and beach erosion (Raman, 1997).

Eutrophication

Eutrophication is organic pollution associated with massive blooms of noxious algae, low dissolved oxygen, and high concentrations of toxic compounds, resulting in undesirable changes in biotic communities, such as shift in dominant species and decrease in biodiversity. Generally, high levels of phosphorus and nitrogen are the two important factors leading to eutrophication, especially in tropical waters where other factors such as light and temperature do not usually become limiting for algal growth (Yusoff and McNabb, 1989). In fact, the availability of these nutrients determine the trophic status of different water bodies (Yusoff et al., 1997). Shallow lentic systems are vulnerable to eutrophication due to nutrient contributions from the enriched bottom sediment (Yusoff and Sharr, 1987; Yusoff and Patimah, 1994; Yusoff and Anton, 1997). Deep reservoirs where vegetations were not removed prior to flooding are also rich in nutrients in the bottom layers, but the strong thermal stratification found in tropical areas usually prevents the onset of eutrophication (Yusoff and Lock, 1995; Yusoff et al., 1998b). However, these reservoirs are very vulnerable to additional nutrient loadings from outside sources, such as domestic effluents or cage aquaculture (Yusoff, 1996). This is because the receiving systems have limited capacity to assimilate concentrated and regular pulses of nutrient enriched water, especially those systems with highly enriched sediment and hypolimnion. At some point, the carrying capacity of the water-body is exceeded which results in negative impacts on the environment as well as the local fauna and flora (Law and Yusoff, 1997).

Many anthropogenic activities with massive use of nutrient-rich products, especially agro-industries, have dramatically enhanced eutrophication by increasing the nutrient input into water-bodies. In fact, intensive development such aquaculture has been accompanied by strong controversies on the environmental, economic and social impacts.

In most cases in Malaysia, shrimp faming would be lucrative for the first few years before it is plagued by different disease problems resulting in crop failures and low production. Part of the problem was the lack of treatment facilities for effluent treatment. Water is discharged from the ponds, usually drained into the sea or estuary in raw form, not far from the intake point. The existence of many shrimp farms in estuarine areas/coastal areas accelerated the eutrophication of the surrounding seas. In such areas, water has to be treated before use for the culture. Yusoff et al (2001a) showed that in the untreated ponds, the noxious blue-green algae formed 89% of the total phytoplankton populations, whilst green algae, diatoms and euglenoids each contributed 9%, 2% and <1% respectively. In the treated ponds however, the beneficial diatoms dominated (61%) the phytoplankton populations, followed by green algae (17%), blue green algae (8%), brown algae (7%), dinoflagellates (5%) and euglenoids (3%). Mean total ammonia-nitrogen in the untreated ponds was 335.0 ± 77.0 μg/L while in treated ponds, it was below 100.0 μg/L.

Phytoplankton communities are an essential component of most aquaculture systems as they form the base of the food chain, produce dissolved oxygen and assimilate ammonia, which would be otherwise toxic to cultured animals. Their temporal and vertical distributions are closely related to the changes in water quality as well as biotic interactions (Yusoff et al. 1998b; Yusoff et al. 2002a). In pristine marine tropical waters, diatoms normally form more than 80% of the total phytoplankton. With the onset of eutrophication, diatom populations decrease and other groups of algae, such as dinoflagellates and cyanobacteria persist (Yusoff et al., 2002b).

Phytoplankton dominance does not only affect water quality but also the other organisms along the food chain. Centric diatoms have been classed as the most desirable phytoplankton in coastal waters (Ryther and Officer, 1981) because they are important as food items for higher consumers, do not form noxious algal blooms and are not toxic. On the other hand, cyanobacteria are considered nuisance as they are relatively poor base for aquatic food chains, impart unpleasant flavours to water and fish, produce compounds which are toxic to aquatic animals and deteriorate water quality (Paerl and Tucker, 1995). Yusoff et al., (2001a) showed that cyanobacteria formed approximately 90% of the total phytoplankton populations in ponds with eutrophic waters containing high mean total ammonia-nitrogen ($335.0 \pm 77.0\ \mu g/L$). In these ponds, beneficial algae; green algae, diatoms and euglenoids together contributed less than 10% of the total phytoplankton. In less enriched ponds, diatoms were dominant contributing approximately 60%, whilst cyanobacteria contributed less than 10% of the total phytoplankton. Culture ponds with eutrophic waters from the seas or estuaries showed that cyanobacteria was dominant throughout the culture cycle. Under this condition, the occurrence of frequent algal crash resulted in poor water quality and low shrimp production.

Our study on nutritional analyses of five tropical marine phytoplankton representing green algae, yellow-brown algae, diatoms and cyanobacteria, indicated that cyanobacteria was found to be poorer in nutritional contents such as protein, essential amino acids, lipids and polyunsaturated fatty acids compared to diatoms or green algae. The important polyunsaturated fatty acids such as arachidonic acid (20:4n-6), EPA (20:5n-3), DPA (22:5n-3) and DHA (22:6n-3) were significantly lower in the cyanobacteria compared to others. Thus, nutrients such as phosphorus, nitrogen and silica in ponds should be properly managed to promote the dominance of diatoms which, not only form an important item in the aquatic food chain, but also contributes to the maintenance of good water quality of the pond.

Pond Effluents

The most significant impact of aquaculture wastes is the increased nutrient concentrations in natural waters that can increase the microbial and harmful algal populations. The main sources of this waste are the uneaten artificial feed and the metabolites, resulting in built-up of organic matter and deterioration of water quality in aquaculture ponds. Various nutrients leach out of the feed pellets and contribute to the load of dissolved nutrients in the water. In these ponds, ammonia concentrations usually increase to undesirable levels as the culture progresses due to unconsumed feed, shrimp excretion (Shishehchian et al., 1999) and microbial degradation processes. Unionised ammonia-nitrogen at >100 µg/l are reported to be toxic to shrimp (Chin and Chen, 1987). Prolonged exposure to unionised ammonia increases the susceptibility of cultured organisms to infections (Soderberg, 1985; Yusoff and Subasinghe, 1995). The sediment in culture ponds is usually black in colour after the first two months due ferrous sulphide. The bottom soil-water interphase normally has high concentrations of hydrogen sulphide and ammonia, rendering the place unhabitable for bottom dwelling organisms such as the cultured tiger shrimp, *P. monodon*. In addition, the anoxic bottoms are not suitable for most benthic communities which are important feed items for the shrimp (Shishehchian and Yusoff, 1999). Under this condition, shrimps are deprived of their live food sources.

Water exchange between culture ponds and their surrounding environment is a standard practice in aquaculture to avoid excessive build up of waste products and increased eutrophication in ponds, and to maintain healthy plankton bloom. Extensive culture system require a daily exchange rate of up to 5%, whereas the intensive systems require an exchange rate of up to 30%. Studies of nutrients budget indicated that more than 76% of nitrogen and 87% of phosphorus inputs is retained within the pond water and sediments (Robertson and Philips, 1995). These nutrients, in water and sediments, are discharged to the surrounding environment whenever the pond water is exchanged, during harvests or when the ponds are dredged out.

Commonly used chemicals such as antibiotics, pesticides, anti-foulants and hormones may also pose dangers in areas that receive aquaculture discharges. Hormones are used to induce reproductive maturation, for sex reversal and to promote growth. Bath and feed incorporated hormones are obviously more of a concern than controlled injection into individual animals because they become readily released into surrounding waters where they can persist in the environment or aquaculture products. Many pesticides used to control parasites and fungi are biologically potent even in quantities below chemical detection limit (Choo, 2001).

Discharges from Cage Aquaculture

In Malaysia, fish cages are normally located in protected and usually shallow areas with generally less water circulation, such as in estuaries, bays or lagoons. In this environment, flushing time is longer and ecosystems may reach eutrophication level quicker than those exposed off-shore areas. Construction of cage culture units is relatively cheap compared to equivalent land-based structures and by being immersed in natural waters, the system avoids the need for expensive delivery of clean water and removal of effluents.

In cage aquaculture system, excess organic matter, including excretory products, are directly discharged into the aquatic environment in a highly biological active form. The effects of dissolved wastes on the environment depend on the speed at which these nutrients are diluted before being assimilated by the pelagic ecosystem. Chemicals used in cage farming such as antibiotics and other compounds ranging from very simple materials to complex ones like malachite green, which is carcinogenic, caused much concern with regard to the potential environmental impact.

Many reports have shown linkages between cage culture and the increasing levels of eutrophication. Sorokin et al. (1996) reported that a dense bloom of toxic dinoflagellate in Italian lagoon was linked to intensive aquaculture activities in the area. Hall et al., (1992) found that 67-80% of the nitrogen added to the cage is lost to the environment. In several areas of the enclosed seas of Japan where cage culture has been practiced for many years, sediments around fish farm may become anoxic during summer months (Pearson and Black, 2001). In Malaysia, increasing number of cages in narrow sheltered channel caused water quality degradation (Arulampalam et al. 1998), resulting in annual mass mortality. In Saguling hydroelectric dam in Indonesia, rapid expansion of cage culture from 756 units in 1988 to 4425 in 1995 resulted in high mortality of fish due to low oxygen levels and deterioration of water quality of the reservoir (Djuangsih et al., 1999).

Harmful Phytoplankton Bloom

Phytoplankton bloom due to the rapid growth of one or more microalgal species, may lead to the production of toxin in sufficient concentrations to elicit effects obvious to the public at large. Harmful phytoplankton may contain potent neurotoxins (e.g. brevetoxins, ciguatoxins, domoic acids, saxitoxins, neosaxotoxins and gonyautoxins), which can become concentrated through biomagnification, and pose a serious public health threat (Richardson, 1997). On a global scale, approximately 300 people die annually as a result of eating shellfish contaminated with toxic phytoplankton (Hallegraef, 1993). Other phytoplankton species contain toxins that can induce sublethal responses in humans such as diarrhoe, eye/skin irritation, and breathing difficulties. Some phytotoxin appear to be carcinogenic (Falconer 1991; Carmichael 1992).

Red tide is a common phytoplankton bloom due to rapid growth of dinoflagellates, as a result of increase in nutrients from waste-water and sediment discharges. In Sabah, the occurrence of red-tides has become an annual event resulting in problems related to paralytic shellfish poison (PSP). In the Straits of Malacca, occurrences of harmful algal blooms occurred in areas associated with increased activities of aquaculture such as in mollusk culture areas off the Malacca coasts (Anton et al., 2000) and in coastal areas in the vicinity of shrimp farms (Khoo, 1985). In countries with high aquaculture production, the number of red-tide incidence has increased with outbreaks coincided with activities related to eutrophication (Choo, 2001).

Disease Outbreak

Another major impact associated with aquaculture is the outbreak of disease in aquaculture systems and its spread to natural populations. Advances in live aquatic animal trade, facilitated by improved transportation efficiency are now recognized as having played a pivotal role in the introduction and spread of pathogens and diseases in many aquaculture systems (Subasinghe et al., 2001).

In most aquaculture systems, crowded and stressful conditions frequently lead to outbreaks of infection. Shariff et al. (2001a; 2001b) reported that cultured organisms tend to be under stress and vulnerable to infections if the water and sediments are bad. In poorly managed farms, shrimp yields were low due to water and sediment quality deterioration (Yusoff et al., 2001a; Matias et al., 2002).

In mid 1980's, Taiwan was one of the largest producers of cultured shrimp. However, a combination of industrial pollution, bacterial and viral diseases led to 66% decrease in production in 1988 (Chamberlain, 1997). Similarly in China, Chamberlain (1977) reported that the decline in shrimp production was attributed to deterioration in water quality linked to industrial, agricultural and domestic pollution, and organic pollution from adjacent farms. White spot syndrome virus (WSSV) was first reported in Taiwan and China between 1991-1992, and is currently the major disease affecting almost all shrimp producing countries in Asia and South America (Subasinghe et al. 2001)). Shrimp farming in Thailand was also affected by disease outbreaks, and production dropped by 25-40% in 1996 (Chamberlain, 1997). Losses were in the range of US$400 million in China in 1993, US$17.6 million in India in 1994 and US$600 million in Thailand in 1997 (Subasinghe et al. 2001).

In Malaysia, WSSV caused millions of losses and many farms were forced to close (Shariff, 1998). Since there is no cure for this viral infection, prevention through thorough screening of the virus and good management practices are important to avoid heavy losses. In general, environmental parameters are very important in determining the health and growth of cultured organisms (Yusoff and Subasinghe, 1995; Hoque et al., 1998; Yusoff et al., 1998a; 1998d). In many cases, disease outbreaks are due to poor farm management practices resulting in stress, which in turn make the cultured organisms more susceptible to diseases.

Chemical Residues and Development of Antibiotic Resistant Bacteria

In aquaculture practices, many types of chemicals are used at different stages, mainly to kill foreign organisms or to improve soil and water quality. The use of pesticide and piscicides in aquaculture is to remove pest species from the culture system. Residues are often highly toxic and may persist for weeks in the water and sediment often killing non-target organisms. In Malaysia, tea-seed cake (saponin-active ingredient), formalin, chlorine, malachite green and copper sulphate are used to kill wild organisms that may interfere with the cultured animals. In Asian region, the organopı osphate, dipterex, is widely used to kill copepods and other crustaceans that are carriers of WSSV. Reports on the impacts of these residues in Asian countries are scarce although some studies in Europe (Egidius and Moster, 1987) indicated that uses of pesticides could be highly toxic to non-target organisms.

The use of antibiotics poses a great concern due to the possible emergence and selection of antibiotic resistant bacteria. It is generally accepted that antibiotic resistance is associated with its frequent use in the environment. Antimicrobials used in shrimp farms include sulfonamides, tetracyclines, oxolinic acid, nitrofurans, chloramphenicol and virginiamycin (Shariff et al, 2000). The residues may threaten human health by being acutely or cumulatively allergenic, toxic, teratogenic, mutagenic, or carcinogenic (Anon, 1999; Choo, 2001). Long term exposure to low concentrations of antibiotics is known to enhance the development of resistant strains of bacteria, which can influence treatment therapy for fish and humans, and later the environment for aquatic farming. In Vietnam, for example, it is easy to find antibiotic resistant bacteria such as those resistant to chloramphenicol. Transmission of antibiotic pathogenic bacteria of animal origin to man may be possible, urging the importing countries to be concern on the import of shrimp.

In the early 1990's, shrimp consignments from Thailand and Indonesia were rejected by Japan, because of detection of antibiotic residues (Yashiro, 1997). Rejection of consignments from Asia into European market indicated that some producer countries are still using the banned drugs in aquaculture industry. Recent exports of shrimps from Thailand, Myanmar and Vietnam were barred by the European Union member countries, as the consignments were tainted with banned antibiotic (nitrofuran and chloramphenical) residues (Anon., 2002). After the rejection of consignments, shrimp producing countries are scrambling to overcome the use of antibiotics. Perhaps, the requirement of residue-free-products by international trade is one of the effective means to discourage the use of antibiotics in aquaculture activities. There has been a general trend in some countries to move away from heavy use of chemicals and to use more environmental friendly approach such as lowering stocking density and using probiotics to improve water quality and improve production.

Impacts of Exotic Species

In Malaysia, most of the cultured species are exotics. In fact, aquaculture which began in 1930's started with the culture of Chinese carps. Today, tilapia, which was introduced in Malaysia during 1940's, is one of the most important commodities in the aquaculture industry. Bartley (1999) recorded that 654 aquatic species belonging to 140 families have been introduced throughout the world.

Concerns related to the introductions of exotics include potential adverse ecological impacts causing extinction of the local flora and fauna, transmission of unknown diseases and alteration of habitats. Exotic fish can easily escaped from the cages. Carnivorous-introduced species can cause displacement of indigenous species by predation and competition.

Baluyut (1983) reported that introduction of *Oreochromis mossambicus* in Lake Butu Philippines has almost resulted in the extinction of local species *Mistichthys luzonensis*. In fact, *O. mossambicus* introduced in many countries is considered a pest and threat to native species (Pullin et al. 1997). Yusoff (1990) illustrated that wild tilapia suppressed the growth of cultured carp species.

Escapes of exotic species may directly interfere with the indigenous species resulting in competition of resources or genetic pollution. In addition, the transfer of broodstock and fry between different regions of the globe could have an effect on biodiversity through the introduction of exotic species and diseases. Taura syndrome caused by TSV virus may have spread through shrimp cultures by the transfer of diseased postlarvae and broodstocks of Pacific white shrimp (*Litopenaeus vannamei*) which originated from the Central America. The impact of this introduced virus is unknown. In Malaysia, the culture of white shrimp is banned although some farmers are culturing this species.

Decrease in Biodiversity

Ecologically biological diversity is defined as the richness in variability and evenness in distribution among living organisms at genetics, species and ecosystem levels (Odum, 1993; Tan and Yusoff, 2001). It is related to the sustainable use in the sense that the utilization of the biological diversity should not lead to its long-term decline in order to maintain its potential to meet the needs of the present and future generations.

Aquaculture practices have many effects on biodiversity, ranging from the obvious (such as the genetic effects of large scale deliberate release of farmed fish into the wild) to the subtle effects such as the competition for resources between escaped exotics with the local species. Impacts of aquaculture on biodiversity are mostly negative (Beveridge et al., 1994). Aquaculture can modify, degrade or destroy habitat, disrupt trophic systems, deplete natural stocks, transmit diseases and reduce genetic variability. Estuaries and bays have been enriched with nutrient loadings and benthic habitats affected by sedimentation from aquaculture activities. This overlay of sediment can also shift the composition of benthic communities towards pollution tolerant species, a clear biodiversity effect. During storms, the sediments can be drawn up into water columns and cause heavy mortality by blocking gills of bivalves.

Until today, the global shrimp and prawn farming industry relied on wild-caught larvae or larvae produced in wild-caught females carrying fertilized eggs. Collection of fry and removal of gravid females from the natural environment affects recruitment into wild populations by reducing the parental stock. In the 1980s and early 1990s, huge quantities of Malaysian shrimp broodstocks, each with a price of US$150-300 were exported to Taiwan. In recent years, due to shortage of spawners for own consumption, the export of wild caught tiger shrimp was banned to prevent the collapse of natural reproductive stocks.

REMEDIAL MEASURES THROUGH ECOLOGICAL APPROACH

An ecosystem is a natural ecological system in which biotic and abiotic factors interact harmoniously to maintain a complex web of life. Any aquaculture system can be thought of as an ecosystem through which the energy flows along the food chain to drive the ecological processes and mechanisms on which all the organisms depend. The stability of this ecosystem depends on its complexity to ensure the adequacy of the trophic levels, which in turns determines the completeness of the nutrient cycles. In a structurally and functionally efficient ecosystem, production at one trophic level is utilized at the next trophic level along the food chain, and all the wastes are processes through a microbial loop, generating continuous nutrient cycles with minimal adverse impacts.

Most aquaculture systems nowadays tend to move away from the basic tenets of ecology by altering natural habitats, destroying their ecological functions and produce high loads of wastes. In most cases, aquaculture wastes are not treated, but discharged into rivers and coastal waters, which eventually become polluted once their carrying capacities are exceeded. The further away the culture practice deviates from the ecological principles, the higher are the environmental risks and the adverse effects. In extensive aquaculture system where fish depends on natural food, the adverse impacts are minimal as the system is structurally and functionally similar to the natural one. Similarly, mussel raft-culture that depends on *in-situ* food sources (autochthonous-based organic source) is a good example of efficient utilization of natural resource to produce new biomass. Extensive system, however, becomes less popular amongst aquaculture entrepreneurs as its production is low and not commercially viable.

Commercial aquaculture systems nowadays are mainly semi-intensive or intensive monoculture with high loadings of formulated diets (allochthonous-based source) to increase yields. Excess feed may burden the microbial processes, driving the environment from aerobic to anaerobic. Briggs and Funge-Smith (1994) indicated that in commercial shrimp farms, approximately 80% of the carbon, 75% of the nitrogen and 78% of the phosphorus from the feed materials were not utilized and entered the microbial loop. In addition, the anoxic condition at the pond bottom precludes any kind of life except anaerobic microorganisms. Under this condition, again the food chain will be interrupted, as the organic matter will not be demineralized aerobically in the absence of aerobic microorganisms. Instead, the anaerobes will dominate and produce toxic compounds harmful to all organisms in the culture system. However, if the ecological efficiencies can be improved and nutrient cycles can be completed in aquaculture systems, much of the wastes can be turned into new biomass. Yusoff and McNabb (1989) demonstrated that enhancement of primary producers (phytoplankton and macrophytes) in ponds resulted in higher fish yields, and wastes produced were naturally recycled as to decrease the requirement of additional feeds. Thus, areas with the most promising improvements for aquaculture practice include reduction of wastes through better management of external energy sources (feeds, fertilizers, chemicals), maintaining healthy aerobic microbial loop (bioremediation), efficient utilization of food sources along the food chain (biomanipulation) and overall management of the water and sediment quality. All these remedial measures would not only reduce stress and accelerate growth of the cultured organisms, but also improve the quality of aquaculture effluents.

In recent years, aquaculture activities have been under great pressure from the government and the public to conform to the regulations and guidelines to ensure their sustainability. Food and Agricultural Organization (FAO) has formulated a programme on the Code of Conduct for Responsible Fisheries, with Article 9 of the code devoted to aquaculture (FAO, 1995), and the development of Technical Guidelines for Responsible Aquaculture (FAO, 1997).

Utilization of Natural Ecosystem Structure and Processes

Overcoming habitat destruction

One of the most serious environmental concerns related to aquaculture practice is the loss of natural habitats, such as the mangroves. To overcome the serious problems associated with clearing of mangrove habitats, many ASEAN countries such as Malaysia, Indonesia, Thailand, and the Philippines advocate a mangrove buffer zone between the sea and the farm. The mangrove belt acts as a sink and can improve the water quality to the shrimp farms as well as protecting the farm from erosion. In Malaysia, the National Mangrove Committee (NATMANCOM, 1986) recommended a 100 m wide buffer zone along the coast between the pond site and the mean high level of the sea.

Proper site selection is usually the best tool to avoid adverse environmental impacts of aquaculture practices. Nearshore areas are easily vulnerable to pollution caused by uncontrolled effluent discharges from large-scale aquaculture operations since deposition of waste could build up over a large area. Thus, offshore areas are more suitable as the carrying capacity of the area is much larger. Good site selection should include optimal flushing and dispersal of nutrients which could actually promote productivity, especially in oligotrophic and mesotrophic systems with additional substrate heterogeneity such as the building of artificial reefs. The key issue is not to allow nutrients to cause eutrophication, but to be utilized efficiently through the food webs of the culture systems.

Mangrove can be also an effective sink for nutrient discharges from aquaculture facilities. Robertson and Philips (1995) showed that approximately 3 ha of mangrove is required to assimilate nutrients load generated by 1 ha semi-intensive shrimp farm. Thus, the capacity of the proposed farm site to assimilate nutrients should be examined prior to consent of using the site in order to minimize potential impacts.

Replacement of Natural Supply of Brood-stocks and Post-larvae

The heavy pressure from the harvest of gravid females and larvae to support the shrimp industry in some countries such as Thailand, Ecuador and Malaysia has adversely affected the recruitment of fry in the natural waters. However, there is still a heavy reliance on wild-caught spawners in shrimp farming since the quality of natural spawners is far more superior than the cultured ones. Thus efforts should be taken to boost the wild stock populations by public stocking and conservation of habitats critical for fish/shrimp populations. In many areas, the trend is towards maintenance of broodstocks in hatcheries and the complete closing of life cycle in captivity using induced spawning techniques. The other long term investment would be to domesticate spawners through selective breeding over several generations.

Efficient Flow of Energy Through Food Chain

Polyculture, the growing of two or more species belonging to different trophic levels in the same system, is thought to have begun during Tang Dynasty in China during 618-904 AD (Choo, 2001). As far back as then, basic principles of ecology were utilized to ensure that natural energy flowing through the food chain was efficiently harnessed. In general, polyculture makes better use of the available resources and minimize waste production from the culture system. However, polyculture works well only if there is no overlap in the feeding niches of the different cultured species. Application of polyculture in intensive farming may result in competition for food and causes poorer growth of the main cultured species, if the subordinate species is more efficient in feeding. For example, polyculture of tilapias and shrimp did not increase the shrimp yields as expected as the former was a better competitor for feed than the later (Shishehchian, pers. comm.).

Efficient flow of energy through the food chain can still be achieved in intensive monoculture as long as there are different key players in each trophic level. In this case, it is important that the nutrient concentrations and ratios in the water are suitable to promote the growth of beneficial microalgae (Yusoff and McNabb, 1997), which in turn enhances the growth of different size range of zooplankton, such as rotifers and copepods. Rotifers and copepods serve as food for the next trophic level such as the benthos. In fact, both zooplankton and benthos form highly nutritious life feed for the shrimp at different life stages. Management of life food sources for cultured organism should be enhanced to increase its growth rate and production. Both fish and shrimp fed with live-food seems to have higher resistance to diseases. Enhancement of resistance to white spot syndrome virus (WSSV) in *Penaeus monodon* was observed when they are fed with *Chironomid* larvae (Shishehchian et al., 2001). In addition, the growth rate of shrimp fed with combined artificial diet and chironomid larvae was significantly higher than those fed with artificial diet alone (unpublished report).

Other alternatives for maximizing ecological efficiency are to practice crop rotation for pond culture or site rotation for cage aquaculture, allowing the sea-bed to return to normal conditions for several months before farming again. In fact, there is a need of coupling mariculture with artisinal and sport fisheries as a way of helping nutrients to cycle and produce additional positive effects or neutralize potential negative impacts.

Integrated culture is another concept of increasing ecological efficiency by synergistically utilizing the outputs of interrelated farm activities, including the wastes. Fertilization of ponds with organic manure from animal husbandry has been widely practiced in Asia. Wastes from one activity, such as chicken farming can be used to increase the aquatic primary productivity, which in turn increases fish production (Yusoff and McNabb, 1989). This ecological approach also enhances the nutrient cycling by efficiently converting the wastes into fish flesh. However, waste-water fed aquaculture is not acceptable in some societies due to fears that such a system may be hazardous to health. In this case, perhaps it is more socially acceptable if waste-water fed culture be used to produce fish for mass production of high omega-3 fish meal, rather than producing fish for human consumption. In Malaysia, import of animal feed runs into billions, and one of the main operating costs in most animal husbandry in this country is feed. Production of cheap high quality fish-meal can help to reduce the country's trade imbalance.

In addition, utilization of waste-water from agro-industry, such as animal husbandry and food related industries helps to reduce the level of excess nutrients discharged into the aquatic environment and prevent pollution. Yusoff and Chan (1997) and Habib et al. (1998) illustrated that agro-industrial effluents of palm oil mills and rubber processing factories have adequate essential nutrients to produce high quality microalgae. In addition, Habib et al. (1997) also showed that *Chironomid* larvae grown in palm oil mill effluents had higher nutritional quality than those grown in inorganically fertilized water. In freshwater culture, organically rich water from culture systems (ponds, hatcheries, raceways) can be used to fertilize crops adjacent to fish farms in an integrated farming system.

Allochthonous Loading and Biomanipulation

Allochthonous Loading

Rates and frequency of organic loadings into an aquaculture system such as feed, fertilizer, and other necessary materials should be efficiently managed to minimize waste production and reduce production cost. In fact, feeding is the most expensive part in commercial aquaculture farming. In practice, overfeeding often occurs leading not only to high cost production and wastage, but also water and sediment quality degradation. In semi-intensive and intensive aquaculture systems, tons of highly proteinacious feed are loaded into culture ponds. In fact, the quantities of uneaten food and waste products vary with species and the type/quality of feed. In intensive shrimp culture pond, about 15% is lost through leaching and unconsumed feed (Primavera, 1994). Briggs and Funge-Smith (1994) found that 60-70% of the nitrogen added to shrimp pond is lost to the sediment. Hall et al

(1992) noted that 67-80% of the nitrogen added to cage culture is lost to the environment. In intensive culture ponds, feed input is high in proteins, resulting in high concentration of ammonia in pond water and the amount of unconsumed feed in intensive shrimp pond was reported to be around 7-10 tonnes/ha/crop (Rao *et al.*, 1997).

To reduce artificial feeding in intensive culture ponds, growth enhancement of natural feed items such as microalgae, zooplankton and benthic organisms should be done to ensure that they are available throughout the culture period. Shishehchian and Yusoff (1999) demonstrated that shrimps rely on benthic organisms as one of the preferred food items, but these organisms were only available in the first part of the culture cycle. Benthic organisms were not found during the later stage of cycle due to the highly toxic environment with high concentrations of ammonia and hydrogen sulphide (Shariff et al., 2001a; Shishehchian et al. 1999; Shishehchian et al., 2001). In fact, if there is adequate supply of natural feed items, artificial diet is not necessary in the first month of culture.

Formulated feed low in phosphorus and nitrogen should be used in shrimp farming to reduce the occurrence of eutrophication. However, no obvious efforts have been made in this direction, perhaps due to economic constraints and lack of environmental pressures. In aquaculture activities, minimizing the inputs of nutrients can be achieved by improving the efficiency of food conversion. Improving feed formulation to achieve better palatability and increased uptake would reduce wastage and decrease organic loading to the aquaculture system and related environment. In addition, using efficient strain of cultured organisms would also result in minimal wastage. In Norwegian salmon faming, feed conversions ratios (FCR) have been continuously improving as feeds have been tailored to dietary needs and reduction of wastage (Ennel, 1995). Ackefors (1999) reported that there was a drop in FCR in salmon cage aquaculture from 2.3 to 1.3 in Nordic countries, as a result of decrease in nitrogen content from 7.7% to 6.8% and phosphorus from 1.7% to 1%. Modern diets tend to contain more lipid and less protein resulting in reduction of FCR and nitrogenous wastes.

Biomanipulation

Environmental burdens of aquaculture systems are mainly linked to water and sediment pollution resulting from organic loadings and chemical compounds. While aquaculture operations produce polluted effluents, the operations themselves are threatened by the poor quality of water supply. In spite of the risk of self-pollution, effluent treatment in most aquaculture farms is almost non-existent due to economic reasons. However, this practice has to change in the near future as shortage of water supply and pollution will provoke strict regulations.

To ensure good quality of water supply, Briggs and Funge-Smith (1994) suggested the use of influent reservoir to reduce nutrient levels through settlement of particles in the water, for the culture ponds. In this reservoir, different aquatic species with various feeding behaviour, such as filter feeders (mollusks), detrital feeders (shrimps and crabs), herbivores (zooplankotn and fishes) and carnivores (aquatic invertebrates and fishes) should be stocked to utilize different types of organic matter and to improve water quality. According to Boyd (1996), chlorination is used widely in aquaculture for disinfecting fish and shrimp hatcheries and sometimes used to disinfect production ponds in preparation for stocking. Nowadays, chlorination in aquaculture has been used to destroy pathogens, control phytoplankton abundance and improve water quality in culture ponds. However, the use of chlorine could make the water sterile, and beneficial organisms have to be seeded to promote the life food supply.

Efforts should also be made to ensure that water sources for aquaculture use are of high quality and adequate. Artificial reefs seeded with micro and macroalgae would increase the rate of nutrient sequestering in the coastal areas, which receive high nutrient input, and thus improve the water quality for the aquaculture supply. Concomitantly, these artificial reef areas provide suitable refuge, feeding and breeding areas for myriads of fish species (Hota, pers. comm.)

Once in the culture systems, effective water management is crucial, especially for intensive grow-out culture, since it determines the final production of the system. As the water progressively becomes enriched with the culture period, biofilms or periphyton aggregation can be used to sequester the excess nutrients in ponds and prevents eutrophication. Khatoon et al. (2003) explored the possibility of using periphyton in shrimp ponds, not only to sequester the excess nutrients, but also to serve as food for the tiger shrimps. In addition, the use of macroalgae such as *Glacilaria* and *Euchauma* to utilize the excess nutrients in aquaculture facilities would not only improve the water quality, but also provide extra produce from the system. Macroalgae has many uses in food, drug and cosmetic industries.

Biocontrol

Biocontrol is a process of limiting or eliminating pests/pathogens by the introduction of adverse organisms, like parasites or specific pathogens and it has gained greater attention in aquaculture in recent times (Gatesoupe, 1999). Maeda et al. (1997) defined it as the antagonism among microorganisms through which pathogens can be killed or reduced in number in the aquaculture environment. Biocontrol can be observed either singly or in combination of inhibition and competitive exclusion. In the former, the microorganism can inhibit the targeted pathogen, but it replaces the pathogen by competing for nutrients and/or space in the latter. Use of microorganisms to control pathogens in aquaculture ponds might be a better alternative to antibiotics (Austin, 1985).

There is no report on isolation of *Bacillus* species with antagonistic property from the marine sediment, in particular, from the Malaysian coastal environment. Our studies, however, have shown three strains of *Bacillus* species, which were isolated from the marine sediment showed antagonistic property against pathogenic vibrios. The inhibition properties of these *Bacillus* species can be utilized to protect cultured organisms such as shrimps from pathogenic vibrios and white spot syndrome virus (Yusoff et al. 2001c).

Waste Management and Bioremediation

Aquaculture wastes should be managed and cleaned before being discharged into public waters to prevent eutrophication. Edwards (1993) reported that intensive culture systems are 22-44 times more polluting than semi-intensive systems. In fact, the waste problems associated with intensive culture of high-value marine fin-fish and shrimp have led to the beginnings of reform in industrial practices in certain counties. In Thailand, all shrimp farms of more than 8 ha in size are required to have sedimentation ponds covering not less than 10% of pond area for waste treatment (Choo, 2001).

Pond bottom sediment is a major source of nutrients as organic matter from uneaten feed and feces accumulate with the progress of the culture period. Yusoff et al. (2001b) reported that interstitial water from the bottom sediment is rich in nutrients containing total phosphorus with concentration of >25.0 mg/l and total nitrogen of > 65.0 mg/l. Different types of microalgae such as diatoms, green algae, and cyanobacteria showed better growth rate and superior nutritional quality when grown in interstitial water extracted from shrimp ponds. The growth rates of beneficial microalgae such as diatoms and green algae cultured in interstitial water were significantly higher than those grown in standard culture medium. This indicates that interstitial water extracted from aquaculture ponds, in sterilized diluted form, has the potential to be used as effective and cheap medium for the culture of microalgae on a commercial scale in areas where pond aquaculture activity is common.

Recovery of nutrients from the effluent water can also be accomplished by using plants such as in the plant filter (artificial gravel beds with plants such as *Typha*, *Juncus* or *Phragmites* in freshwater and macroalgae and sea-grasses in marine waters) hydroponics or even biofilms. Sansana-yuth et al. (1996) in their study of using artificial wetland to treat effluent waters from shrimp farms reported that BOD and nutrients can be reduced by 30-90%. Nutrients in the effluent water can be recovered in plant/algal tissue such as hydrophonics. In marine aquaculture system, seaweeds, plankton, bivalves, crustaceans and fish can be used to efficiently transfer energy at different levels of the food chain. In this system, the wastes at one level can be converted to the protein at other levels. Chareonpanich et al. (1993) showed that there was a rapid degradation of accumulated organic material by seeding seabed with a large numbers of *Capitella* sp.

Organic wastes without chemical contamination from aquaculture farm can also be used to fertilize nutrient poor waters in the offshore areas. Adding nutrients to this oligotrophic water would eventually enhance fisheries resources, especially in the offshore areas which have good flushing rate for dispersal of nutrients.

Bioremediation is defined as a biotechnological process of reducing hazardous compounds to less hazardous levels by using micro- or macroorganisms (Thomas et al., 1992). Application of bioremediation technology in oil spills, agricultural pollution and several other industrial pollutions has been extensively used (Head, 1998).

Microorganisms have a huge metabolic repertoire that enables them to degrade different organic pollutants and in many cases the complex biochemistry and molecular biology of the catabolic pathways involved have been unravelled (Head, 1998). Despite valuable basic knowledge on the mechanisms of pollutant biodegradation, bioremediation has yet to be accepted as a routine treatment technology and the environmental industry is wary of applying bioremediation for the treatment of contaminated sites.

Due to heavy loading of organic matter in aquaculture ponds, it is essential to rapidly decompose it to avoid its accumulation and harmful effects (Moriarty, 1997a; 1997b). Naturally occurring microflora might not be able to degrade the accumulated wastes efficiently in intensive culture system and supplementing them with selected bacteria in sufficient numbers might be useful (Moriarty, 1996). Introducing active aerobic bacterial populations (e.g., *Bacillus* species) that can adapt to rapid degradation of complex organic compounds might become an effective strategy (Verschuere *et al.*, 2000). Addition of selected beneficial bacteria helped in improving the health status of cultured organisms (Rengpipat *et al.*, 1998a; 1998b; 2000). Our studies showed that selected *Bacillus* isolates significantly reduced toxic ammonia levels in a relatively short period of time. These beneficial microorganisms might be of great use in formulating an indigenous microbial product for bioremediation in aquaculture ponds (Devaraja *et al.* 2002).

Aquaculture, although often associated with negative impacts to public waters, can also be used as a form of management and restoration. Some fish species, such as big head carps, silver carps and kissing gouramy are capable of grazing and thus reducing nuisance algae (Arumugam et al. 1993). In Brazil, Starling et al. (1998) used silver carps in net-pen enclosures to reduce algal levels in man-made lakes. These net-pen enclosures are extensive cage culture where captive fish feed on organisms available *in situ*.

In holding systems such as ponds or tanks the effluents should be treated to remove suspended solids, thus decreasing the organic load, which lowers the BOD (biochemical oxygen demand) and COD (chemical oxygen demand) in the waste water and is a prerequisite in reducing the impact of discharged water on adjacent ecosystems. The sludge from the pretreatment and post treatment can be supplied to an anaerobic digestor to produce biogas. Artificial gravel beds with plants like *Phragmites* or *Typha* in freshwater or seaweeds or seagrass in marine systems can efficiently remove nutrients. Post treatment of freshwater (Seawright et al., 1998) and marine (Neori et al., 1991) aquaculture effluents indicated positive results. The combination of fish, seaweed and invertebrate animals reduce nutrient discharge and increases yields (Neori et al., 2000).

Recirculating Systems

Water supply to aquaculture systems (ponds, tanks, raceways) can be opened (through-flow) or closed (recirculating) system. In an open system, the water is pumped from nearby river or sea, passed through aquaculture systems and discharged back into the same or different water-body. In this system the incoming water often needs to be treated before being used, such as settling of suspended solids, filtering or removing plankton and debris. At present, most farms in Malaysia discharge untreated effluents into the natural waters to avoid the additional cost of waste treatment.

The shortage of good quality fresh, brackish and marine water is already causing problems for aquaculture in many areas and it is expected that this problem will become more severe in the future. A major problem that aquaculture farms are faced with is the increasing levels of general environmental pollution. In some countries, semi-enclosed and closed systems are usually used in areas prone to disease problems. In the early days of aquaculture when good quality water was abundant, the traditional practice was to exchange pond water at the rate of 20% per day. In shrimp farming, due to increasing pollution, no water exchange is usually carried out in the first two months of culture. In the third month, as much as 10% of the water is exchanged daily, while in the fourth month may require changes of about 20% of the pond volume.

In Malaysia, more than 70% of the rivers are polluted and water quality of most of estuaries are in the third and fifth class (DoE, 2001). Recirculating water system will overcome the problem of using polluted water and will play an important role for the future development of sustainable aquaculture. Recent shrimp culture practice shows a shift towards closed-culture system where there is no water exchange with external sources during the culture period, especially in areas prone to diseases.

The recirculating system is a way to achieve complete control of water quality in rearing systems. The primary treatment is to maintain water quality in the culture tanks and the secondary treatment is to purify the water discharged from the primary treatment. The system is based on ecological principle, which involves the transformation of excreted organic nitrogen and phosphorus into inorganic forms by biofilters, followed by utilization of these nutrients by the primary producers. The recirculating systems uses different levels of water inputs, which are fully automized and include complete water treatment. Fish/ shrimp are stocked at high densities and they are fed with artificial diet. Water is treated to remove suspended solids and reduce nutrients before it is discharged into the environment to reduce the adverse impact on the natural ecosystems. In recirculating system, water exchange is less than 10% of the system volume per day. The make-up water is pumped from natural waters and the effluent water is released into the natural waters after post treatment.

Advantages of using closed system include prevention of mixing domesticated species with wild populations and reduction of effluents being discharged into the surrounding environment. Closed culture facilities are expensive and can only be afforded by well-capitalized firms, which perceive greater opportunities for long term planning to minimize risks and environmental impacts. Improvements in the design and engineering efficiencies of modern recycled aquaculture systems would allow for higher stocking rate, less disease outbreaks, low operating costs, reduction of eutrophication potential and affordable by the majority of aquaculture entrepreneurs.

CONCLUSIONS

The contribution of aquaculture to food production and security is becoming increasingly important. Technological advances improve product quality and the efficiency by which aquatic organisms are bred and grown. For example, in the past, the financial success of some industry such as shrimp farming has led to increased production with little environmental planning. Two of the world's largest oil producers, the Kingdom of Saudi Arabia and the Islamic Republic of Iran, are leading the frenzied rush towards making shrimp farming a major industry. Within the last three decades during which shrimp farming became a global phenomenon, there has been no substantial scientific breakthrough beyond the present capability of raising shrimp intensively. Most of the shrimps produced still come from wild-caught spawners. In addition, fishmeal is still a major component of shrimp feeds and diseases still pose major risks. Denunciations by environmentalists over commercial shrimp farming's perceived negative effect on the environment remain strident.

Aquaculture has a wide range of potential impacts that are both harmful to the industry itself as well as on the surrounding environment. The shortage of clean water sources (fresh, brackish, and marine) is already causing problems for aquaculture in many areas and it is expected to become even more severe in the near future. A major problem that aquaculture industries are faced with is the increasing levels of general environmental pollution caused by itelf or industrial, domestic or agriculture activities. Deteriorated water quality with low oxygen, high toxic compounds and toxic algal blooms are of particular concern as it could lead to a chain reaction leading to low production. An environmental policy to reduce domestic, industrial and agricultural nutrients input into aquatic ecosystems would probably restore the pristine quality of the environment.

In addition, the current management practices in aquaculture, such as the discharge of untreated water and mismanagement of feeding cause environmental degradation and poor water quality. Semi-enclosed ecosystems such as sheltered bays are particularly sensitive to pollution resulting from aquaculture practices. The effluents of aquaculture industries can carry numerous risks. Nutrients contribute to the eutrophication and various substances used in intensive aquaculture such as disinfectants, antibiotics, bactericides, fungicides, parasiticides, algicides, herbicides, piscicides and hormones. It is widely accepted that disease outbreaks in farms is due to environmental stress.

While aquaculture is necessary in cases where there is overexploitation of natural fish stocks, intensive system, which require large input of resources, may cause pressures on capture fisheries in general. More intensive systems are ecologically unbalanced and subsequently can contribute to environmental degradation. Thus, environmental management is required to minimize the severity of impacts on the environment arising from aquaculture. In fact, system ecology is advocated as a framework for the analysis of aquaculture systems and environmental interactions

In spite of the many adverse environmental impacts arising from aquaculture farming, with proper technology and farming management, the industry can be made sustainable. It is obvious that environmental concerns need to be addressed in parallel with technological obstacles that currently hinder the expansion of aquaculture industry. For a long-term sustainability, it is pertinent that aquaculture practices should minimize its hazardous impacts on the surrounding environment where its very own production depends. More ecologically-based approaches and efficient technology, such as closed systems, need to be introduced for a long-term viable and sustainable aquaculture industry. Policies to regulate and prevent the degradation of the environment should be given high priority by the government. Besides self pollution from aquaculture practices, pollution from industrial and agricultural based activities also require strict implementation of laws to avoid discharge of pollutants into the environment that have adverse consequences to aquatic based industries.

The present findings indicate that aquaculture pond management should include strategies to reduce nutrient inputs (from both internal and external sources), maintain aerobic condition in the pond including the microlayer between the sediment-water interphase, and maintain appropriate nitrogen, silica and phosphorus ratios in the water. All these would sustain suitable plankton growth, and good water and sediment quality, to enhance shrimp health and production. There is also a need for further research on bioremediation which should consider the use of indigenous bacterial species to improve the effectiveness and least alterations to the natural ecosystem for the sustainable development of the shrimp industry.

In conclusion, ecological approach in aquaculture industry need not be limited to producing products at low levels. With the modern biotechnology and engineering know-how, methods can be designed to harness the natural resources to maximize aquaculture production, but at the same time protect the valuable environment from the horrors of pollution associated with aquaculture activities.

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