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INTEGRATED FARMING OF SEAWEEDS WITH FINFISH AND SHELLFISH

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Capture fisheries landings have reached to around 85-95 million tonnes (FAO, 1999a), and most ocean fisheries stocks are now recognized as over exploited (NRC, 1999). This together with ever increasing population growth has encouraged for rapid growth in fish and shellfish farming through coastal aquaculture. Global aquaculture production more than doubled between 1986 and 1996 (FAO, 1999b). The potential of aquaculture has improved the export markets in Europe, U.S.A. and Japan (Stonich and Bailey, 2000) particularly from industrial shrimp farming. Even today, aquaculture provides over a quarter of the world's seafood supply and FAO expects it will increase to 50% by the year 2030 (Tidwell and Allen, 2001). With the diminishing availability of freshwater, most of this growth will take place in seawater.

Traditional shrimp farming

During 1950, production of shrimp was solely from wild catches (FAO, 1995). In Asia, shrimps had been grown in low-density monocultures, in polyculture with fish, or in rotation with rice in the *bheries* of West Bengal and *pokkalis* of Kerala in India (Shiva and Karir, 1997). The shrimp production in these systems was low-yielding and aimed for domestic markets. During 1970, when fishermen and hatchery operators began supplying large quantities of penaeid shrimp post larvae to farmers. With improved technologies and the introduction of commercial formulated feeds, the industry boomed during the 1980s.

Intensive shrimp farming

Small-scale intensive farms in Taiwan produced dozens of shrimp millionaires, and large-scale extensive farms in Ecuador recaptured their entire investment in the first year (Rosenberry, 1999). In 1975, the shrimp aquaculture industry contributed to 2.5% of total shrimp production, which gradually increased to around 30% of total shrimp supply in the 1990s. Almost 80 percent of cultured shrimp come from Asia with Thailand, China, Indonesia and India as the top producers. In the Western hemisphere, Ecuador is the major shrimp-producing country.

Although the pioneering R&D for penaeid shrimp farming was conducted in the 1930s on *Penaeus japonicus* by Motosaku Fujinaga of Japan, the explosive growth of shrimp farming with the tropical giant tiger shrimp *P. monodon*. This species comprised 56% of the total production during 1999 (Rosenberry, 1999).

Even at high stocking densities, *P. monodon* can reach marketable sizes of 20 cm and 35 g in three to six months and can reach a length of over 33 cm and a weight of over 150 g (Dore, 1994), if allowed to grow to full size. Thus it encourages the commercial aquaculturist to go ahead for the intensive framing (Muir and Roberts, 1982). The most important shortfall in the shrimp farming is susceptibility towards two of the most lethal shrimp viruses - yellowhead and whitespot Rosenberry (1999).

Intensive aquaculture operations can also lead to water pollution, which is also a major concern. When flushed into nearby coastal or river waters, heavy concentrations of fish feces, uneaten food, and other organic debris can lead to oxygen depletion and contribute to harmful algal blooms. In Thailand alone, shrimp ponds discharge some 1.3 billion cubic meters of effluent into coastal waters each year (Bob Holme, 1996).

In semi-intensive and intensive farms, artificial feeds provide most of the nitrogen (N), phosphorous (P) and organic matter inputs to the pond system. Only 17% (by dry weight) of the total amount of feeds applied to the pond is converted into shrimp biomass (Primavera, 1993). The rest is leached or otherwise not consumed, egested as faeces, eliminated as metabolites, etc. Effluent water during regular flushing and at harvest can account for 45% of nitrogen and 22% of organic matter output in intensive ponds (Briggs and Funge-Smith, 1994). Consequently, pond sediment is the major sink of N, P and organic matter, and accumulates in intensive shrimp ponds at the rate of almost 200 t (dry weight) per ha (Briggs and

Funge-Smith, 1994). This creates a stressful environment to the animal leading to many bacterial and viral diseases. During pond preparation between cropping the top sediment is removed and usually placed on pond dikes, from where it continuously leaks nutrients to the environment.

To counteract the disease antibiotics are frequently used in many of the shrimp ponds and their persistence in sediments tends to lead to the proliferation of antibiotic resistant pathogens, which may complicate disease treatment. The presence of antibiotics in bottom sediments may also affect bacterial decomposition of wastes and hence influence the ecological structure of the benthic microbial communities. Antibiotic use reduces natural microbial activity, which leads to waste accumulation and affect nutrient recycling. Finally accumulation of hydrogen sulphide was found in the pond bottom.

There appears to be a clear linkage between environmental conditions and disease outbreak. The development of acid sulphate soils or fluctuations in normal environmental conditions (e.g. oxygen, temperature. and salinity) may indirectly cause production failure by increasing physiological stresses and lowering the immune response. For example, low oxygen levels, which is a common problem in ponds with high shrimp stocking density, increases sensitivity to vibriosis in penaeid shrimp (LeMoullac et al., 1998).

Chemicals used in shrimp culture may be classified as therapeutants, disinfectants, water and soil treatment compounds. algicides and pesticides, plankton growth inducers (fertilisers and minerals) and feed additives. Excessive and unwanted use of such chemicals results in problems related to toxicity to non-target species (cultured species, human consumers and wild biota), development of antibiotic resistance and accumulation of residues (Primavera, 1998). There are many potential side effects from excessive use of antibiotics, which are now being widely acknowledged in Europe, the U.S.A. and elsewhere. The antibiotic oxytetracyclin and oxolinic acid were detected above permissible levels in almost 10% of *Penaeus monodon* sampled from Thai domestic markets in 1990-91 (Saitanu et al., 1994).

Biological filteration is the most suitable and alternative approach for sustainable aquaculture. A primary role of biofiltration in finfish/shrimp aquaculture is the treatment by uptake and conversion of toxic metabolites and pollutants. Bacterial biofilters oxidize ammonia to the much less toxic but equally polluting nitrate (Touchette and Burkholder, 2001) while microalgae photosynthetically convert the dissolved inorganic nutrients into particulate "nutrient packs that are still suspended in the water (Kaiser et al., 1998 and Troell and Norberg, 1998). Macroalgae in contrast, sequester the nutrients out of the water. The clean and oxygen-rich effluent of a seaweed biofilter can therefore be readily recirculated back to the fishponds or discharged (Pei-Yaan Quan *et al.*, 1996; Troell *et al.*, 1999; Jones *et al.*, 2001; Nelson *et al.*, 2001). This aquaculture management can be made by either polyculture of marine organisms such as fish and shrimp with seaweeds or by recirculating the effluents from the culture tank to the treatment tanks supplemented with seaweeds. In some cases these methods have been around for centuries, but they have rarely been adopted in the modern aquaculture industry. There are alternate methods for sustainable aquaculture. They are

- ecological aquaculture,
- organic aquaculture,
- polyculture and integrated aquaculture,
- closed and low discharge systems.

There are six main principles of ecological aquaculture: to preserve the form and function of natural resources; to ensure trophic level efficiency (using animal wastes and plants, rather than fishmeal as sustenance); to ensure that chemicals and nutrients from the system are not discharged as pollutants; to use native species so as not to contribute to "biological pollution"; to ensure that the system is integrated into the local economy and community in terms of food production and employment; and to share the practices and information on a global scale (Costa-Pierce, 2002).

In organic food production, all parts of the operations are connected and integrated with each other, such as the nutrient inputs, the animals, the environment, and the wastes being produced. Organic aquaculture standards have been developed in many nations around the world and they are in the final stages of development in the United States. Some of the basic principles of organic aquaculture according to the International Federation of Organic Agriculture Movements are as follows: to encourage natural biological cycles in the production of aquatic organisms; using feed that is not intended or appropriate for human consumption; using various methods of disease control; not using synthetic fertilizer or other chemicals in production; and using polyculture techniques whenever possible ((IFOAM, 2000).

Polyculture and integrated aquaculture are methods of raising diverse organisms within the same farming system, where each species utilizes a distinct niche and distinct resources within the farming complex (Stickney,. 2000).In either case, the wastes from one organism are used as inputs to another, resulting in the optimal use of resources and less pollution overall (FAO,2001).

The polyculture systems developed in Eastern Asia, with Laminaria - abalone, Laminaria - scallop and Laminaria - Undaria can be used to improve the productivity and profitability per unit area. There is also good evidence that polyculture of seaweeds with mollusc may also enhance the production of both Laminaria and mollusc in comparison with monoculture systems (UNDP/FAO, 1989). There is potential with some culture systems to integrate seaweed culture with other forms of aquaculture to make better use of marine resources and reduce the impacts of more intensive forms of aquaculture. Experiments in Japan have shown that cage culture of yellowtail (*Seriola quinqueradiata*) and red sea bream (*Pagrus major*) can be successfully integrated with *Laminaria* culture. Environmental studies have shown that alternate rows of seaweed and finfish cages help to improve dissolved oxygen concentrations during daytime hours and reduce levels of potentially harmful ammonia. Recent studies by Levin (1990) have also demonstrated that *Porphyra palmata* reduced ammonia concentration by 60% and phosphorous by 32% in effluent from land-based salmon mariculture systems. Neori (1990) has also shown that *Ulva lactuca* and *Gracilaria conferta* can be used to remove ammonia from effluent from intensive *Sparus aurata* ponds.

In Thailand, polyculture of *Gracilaria* on grouper cages can yield 16-20 kg (fresh weight) of seaweed per month in a 5 x 6 x 2 m cage, providing an extra source of income for the farmer, as well as possibly improving conditions for the caged fish. Integrated mariculture can take place in coastal waters or in ponds and can be highly intensified. Today's technologies are well studied and documented. They are generic, modular and adaptable for several culture combinations of fish, shrimp, shellfish, abalone, sea urchin and several species of commercially important seaweeds and vegetables. A 1-ha land-based integrated seabream-shellfish-seaweed farm can produce 25 tons of fish, 50 tons of bivalves and 30 tons fresh weight of seaweeds annually. Therefore, modern integrated systems in general, and seaweed-based systems in particular, are bound to play a major role in the sustainable expansion of world aquaculture (Neori *et al.*, 2003).

Concerns for water conservation and reduced waste discharges have prompted the increased use of closed recirculating aquaculture systems (Chen *et al.*, 2002). Recirculating systems generally consist of landbased tanks with constantly flowing water. The systems are made up of three basic components: culture chamber, settling chamber, and biological filter. Water enters the culture chamber, flows through the settling chamber and then moves through the biological filter to remove additional particulate matter. The water is then circulated back through the systems' culture chambers (Stickney, 2004).

Land-based marine aquaculture appears to have immediate potential for economic growth. Seawater is pumped or diverted into the holding structures and subsequently discharged to sea, recirculated or utilised elsewhere. This form of aquaculture is relatively free of many of the technical problems, which beset marine-based operations. Compared with the criteria for marine-based aquaculture, the criteria for land-based proposals are simpler. Key criteria include salinity of water source, contaminants, water temperature, water quality, water intake site, and waste discharge. Land-based aquaculture systems offer much promise for sustainability in tropical, subtropical and temperate mariculture. Issues such as solid waste management, nutrient recycling and feed conversion enhancement are more easily and profitably addressed on an industrial scale on land than in open-water fish farms.

Hirata et al. 1994 calculated that in addition to all other benefits, in a recirculation system, each kilogram of *Ulva* stock produces enough oxygen daily to supply the entire demand of 2 kg of fish stock. . Fish effluent treated with *Ulva lactuca* showed reduction of ammonia by 88.8% and 76.03 % with respect to control within 20 days of treatment, whereas nitrite concentration was reduced by 98.6% within 30 days and 98.9% with respect to control. Shrimp effluent treated with *Ulva* *reticulata* showed reduction of ammonia by 92.05% and nitrite by 91.47% with respect to control within 30 days of treatment (Seema and Reeta, 2005).

In Thailand, experiments are being carried out using *Gracilaria* to remove nutrients from effluent water in attempts to reduce the impact of effluent on receiving waters. In Thailand and Taiwan, experiments are underway to assess the potential for using *Gracilaria* to improve the quality of water entering shrimp ponds. Unpublished studies in Taiwan and India indicate that *Gracilaria* can be used to remove ammonia, heavy metals and trace organics before water enters the shrimp ponds. These forms of integrated aquaculture offer good scope for the development of techniques which make efficient use of the coastal environment and maximising the production per unit area and in some cases for reducing some of the environmental impacts associated with intensive aquaculture (Reeta, unpublished).

The major species of Korean aquaculture are seaweed, shellfish and finfish. Seaweed and shellfish account for more than 90% of total aquaculture production, and marine finfish represents only 7%. However, marine finfish farming is growing and gaining attention from government and industry, and it is becoming an important part of the Korean aquaculture industry today. Also, there is an increasing demand in the research sector for the diversification of artificial breeding for high value marine fish species. There are approx. 10 species currently employed for marine aquaculture, Flounder, Black Rockfish, Sea Bream, Sea Bass and Yellow tails are the most important species farmed.

Aquaculture industry in Korea is faced with many challenges nowadays. Reduction in the overall output due to the environmental problem in coastal area is caused mainly by the use of moisture pellet feeding and disease, and increased import of live fish from China is high on the agenda. These challenges demand changes and they are now taking place rapidly. There is a growing demand for restructuring in the aquaculture sector as it is fragmented with small units. Requirements for advanced technology and equipment are gaining momentum, in order to reduce the production cost and increase efficiency.

In modern coastal integrated mariculture, shellfish and seaweed are cultured in proximity to net pen fish culture. These studies have shown the potential of open-water integrated mariculture, once conditions are right (Troell et.al. 2003). It should be noted, however, that the biofiltration of effluents by shellfish converts "nutrient packs," in the form of microorganisms, into dissolved nutrients, which, may negatively impact the environment (Kaiser et.al., 1998 and Troell and Norberg, 1998). The water quality processes in open-water integrated mariculture are closest to the natural ones. To function well, seaweed culture and/or shellfish culture take place near the fish net pens and as much as possible in the same waters. Kelp (brown algae) and red algae efficiently take up dissolved inorganic nitrogen present in fish net pen effluents Troell, 1998, and seaweed production and quality are therefore often higher in areas surrounding fish net pens than Seaweed growth on mariculture effluents has been also shown to be superior to that on fertilizer-enriched clean seawater (Neori et al 1991). Agar yield and gel strength in the agarophytic red alga *Gracilaria* have been shown to improve when it is cultivated in salmon culture effluents Martinez and Buschmann, 1996).

Integration with seaweeds and/or filter feeders is often the only economically feasible alternative for waste treatment in open-water systems (Troell et al., 2003). Indeed, a hybrid open-water/onshore integrated mariculture of seaweed, fish and shellfish has formed an integral part of the mariculture operations planned for the nutrient-rich upwelled water for generation of electricity by OTEC (Ocean Thermal Energy Conversion) in Hawaii (Mencher et al., 1983). Another interesting complementary integrated approach for the reduction of the environmental impact on the sea bottom by the net pen sludge has been the culture underneath them of scavengers (gray mullets— Katz et al 1996); sea cucumbers (Ahlgren, 1998), or worms in the pond sludge (Honda and Kikuchi, 2002) as secondary crops.

The environmental impact of sea-cage fish farming could be significantly reduced by the cultivation of seaweeds on site and provide a potentially lucrative second income for fish farmers, says Dr Maeve Kelly from the Scottish Association for Marine Science (SAMS) in Oban, Scotland. Dr Kelly said: "Fish excreta and waste fish food, primary components of the matter lost from fish-farms to the environment, provide well balanced nutrients for marine plant growth. At SAMS a project to assess the ability of commercially important seaweeds, cultivated in the immediate vicinity of caged fish, to reduce the impact of nutrient. By using seaweeds of commercial value, for potential consumption by humans and for cultivated shellfish, the fish farmer could also generate a second income.

Marketable biofilter organisms are essential to the commercial viability of integrated mariculture farms (Neori et al, 2001a&b). Polyculture systems can provide mutual benefits to the organisms reared by creating symbiotic relationships while allowing for a balanced use of the available aquatic resources. In addition, integrated systems can increase the economic efficiency of fish farms through improved conversion rates of input materials. For example, the integration of fish culture with the culture of algal and/or shellfish species shows potential for reducing the risks of eutrophication and also for exploitation of the large amounts of wastes produced by fish farms. Further research is needed however, to determine the effectiveness of such systems, especially in open marine environments.