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UNDP/GEF PROJECT ENTITLED "REDUCING ENVIRONMENTAL STRESS IN THE YELLOW SEA LARGE MARINE ECOSYSTEM"

UNDP/GEF/YS/RWG-F.3/10
Date: 26 September 2006
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Third Meeting of the Regional Working Group for the Fisheries Component
Weihai, China, 25-28 October 2006

Report on the Regional Review and Proposed Guidelines Towards a Joint Programme on Sustainable Mariculture

- Preliminary report -

The results from the review of the existing issues affecting the sustainability of mariculture in the YSLME region were compiled to suggest a Joint Programme on Sustainable Mariculture. This work was carried out from February to September 2006. The results from this activity aim to contribute to the Fisheries Chapter of the Transboundary Diagnostic Analysis (TDA).

A consultant from Pusan National University, Korea, was contracted to prepare a detailed proposal for a Joint Applied Research Programme for Sustainable Mariculture as well as a Set of Technical Guidelines with a Detailed Workplan for Training Courses on Sustainable Mariculture and Diseases, Diagnosis and Control Techniques. The preliminary version of the report is attached hereafter.

During the 3rd RWG-F Meeting, the consultant will present his results-to-date, highlight the regional status and trends of importance, and suggest a Joint Programme on Sustainable Mariculture.

After reviewing the report and presentation, participants will discuss the information presented, and suggest on how to improve the proposed guidelines for the next session of the RWG-F.

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UNDP/GEF Project entitled "Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem"

UNDP/GEF/YS/RWG-F.3/10
Date: 8 September 2006
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JOINT APPLIED RESEARCH PROGRAM FOR SUSTAINABLE MARICULTURE IN THE YSLME REGION

- progress report -

by

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Third Meeting of the Regional Working Group for the Fisheries Component

Weihai, China, 25 - 28 October 2006

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1 GENERAL ISSUES

1.1 Background of assignment

The Yellow Sea (YS) is that semi-enclosed body of water bounded by the Chinese mainland to the west, the ROK Peninsula to the east, and a line running from the north bank of the mouth of the Yangtze River (Chang Jiang) to the south side of Cheju Island. It covers an area of about 400,000 km2 and measures about 1,000 km (length) by 700 km (maximum width). The floor of the Yellow Sea is a geologically unique, post-glacially submerged, and shallow portion of the continental shelf. The seafloor has an average depth of 44 m, a maximum depth of about 100m, and slopes gently from the Chinese continent and more rapidly from the ROK Peninsula to a north-south trending seafloor valley with its axis close to the ROK Peninsula. This axis represents the path of the meandering Yellow River (Huang He) when it flowed across the exposed shelf during lowered sea level and emptied sediments into the Okinawa Trough. The Sea annually receives more than 1.6 billion tons of sediments, mostly from the Yellow River (Huang He) and Yangtze River, which have formed large deltas.

The Yellow Sea is connected to the East China Sea in the south, forming a linked circulation system. Major rivers discharging directly into the Yellow Sea include the Han, Yangtze, Datung, Yalu, Guang, and Sheyang. The Liao He, Hai He, and Yellow River around the Bo Hai have important effects on salinity in the western Yellow Sea, whereas the Yangtze River exerts strong influence on the hydrography of the southernmost part of the Sea. Recent reductions in Yellow River flow have led to changes in hydrography and water circulation, thereby leading to ecosystem changes. All rivers have peak runoff in summer and minimum discharge in winter

The area of YS occupies about 1.16% of total coastal area but mariculture production is more than about 10% of total mariculture production; 5,0% for finfish, 6.5 % for crustacean, 37.0% for shellfish and 8.3% for seaweed during last 5 years between 2000 and 2004 (FAO). The extensive tidal flat and continental shelf area has been sites for shellfish habitat as well as mariculture industry. More than one third of total shellfish production comes from in this YS LME coast.

The coast of the YS region has been highly populated and industrialized since last century and is a centre of fisheries and now mariculture industry in the RRC and ROK. This implies the importance of the YS as a center for the water resources exploitation. Therefore, the mariculture industry should be carried out under very restrict management regime of the integrated coastal zone management (ICZM) in both countries with close cooperation with YS Large Marine Ecosystem (YSLME) project.

1.2 Methods used to carry out assignment: Collection of mariculture data

Officially I visited two representative institutions in both countries and interviewed two responsible persons of each country. Dr. Fang J at Yellow Sea Fishery Research Institute, Chinese Academy of Fishery Sciences, China (YSFRI) and Dr. Jang IK at West Sea Fisheries Research Institute, National Fisheries Research Institute, Korea (NFRDI). They are are responsible to provide their country's data for this report.

Dr. Jang IK reported that data and information of aquaculture production are easy to access in websites or MOMAF, Korea. Reliable data or information on licenses (number of farms) and area of marine farms, however, are not easy to access from websites or related institutions. Although some information on licenses and area of aquaculture farms are shown in websites of MOMAF or Bureau of Statistics, these are mentioning total statistical figures of whole country only and don't classify into different provinces.

2 REVIEW OF MARICULTURE IN THE YSLME REGION

2.1 Review of mariculture statistics in the YS LME region

Overview of total farmed production and production per unit area in the YS region for last 10 years are shown in Figure 1. The aquaculture production is still increasing in the YS region; however, the production per unit area has been decreasing since 1997. Same trend of grouped species of shellfish and seaweeds are shown in Figure 2 for shellfish and Figure 3 for seaweed. Increasing trend of finfish production was stagnated and the production per unit area decreased since 2002 as shown in Figure 4. The production and production per unit area both increased in the crustacean aquaculture as shown in Figure 5

2.1.1 Finfish

The total production of marine and freshwater aquaculture together constituted 30% of the total fishery production in 1980. The ratio of marine fishery production in the west of the YS region in China was 47.6% of the total production had arrived 150,992 mt in 2004. The most common species of finfish under cultivation are flounder (*Paralichthys olivaceus*), sea bass (*Lateolabrax latus*) and puffers (Figure 6). The amount of production in the east of the YS in Korea is 8,049 mt in 2004. *Sebastes schlegeli*, *Paralichthys olivaceus* and *Muguil* spp. are common cultivar finfish species in this region (Figure 7).

2.1.2 Crustacean

Shrimp farming developed very slowly before the middle 1970's because of little support and low profits. Until in the late 1970's, to better promote shrimp culture in China, the State Fisheries Administration (formerly the Ministry of Fisheries) organized a joint research project on shrimp fry rearing. In the early 1980's, optimal conditions for temperature, water quality management and hatchery feed supply were intensively studied and techniques for industrial production of shrimp were developed.

Pond culture is the principal form of shrimp mariculture. The growout ponds are generally constructed by building embankments in the intertidal zone. In the case of raising shrimp larvae, quality management and adequate food supply are the important conditions for growth of cultured shrimps. Total annual production of cultured shrimp in China has jumped from 450 mt in 1978 to 535,230 mt in 2004.

The most common species of shrimp under cultivation are *Fenneropenaeus chinensis* and *Penaeus japonicus* in the four Yellow Sea coastal Provinces of China, Liaoning, Shandong, Hebei and Jiangsu, with amount of 92,079 mt in 2004 (Figure 8). *Fenneropenaeus chinensis* is also popular cultivar species in the east of the YS in Korea (Figure 9).

2.1.3 Shellfish

Shellfish have been successfully domesticated through aquaculture practice. Bivalve shellfish like mussels, clams and oysters are the predominant type of shellfish aquaculture in the world. There are six main species of bivalve shellfish that are cultured commercially in the west of the YS (Figure 10): *Crassostrea gigas*, *Rapana venosa*, *Cyclina sinensis*, *Scapharca subcrenata*, *Solen* spp. and *Mytilus coruscus*. Shellfish (mollusks) are the major marine species group farmed in the YS accounting for approximately 36.42 percent of total world shellfish mariculture production. The shellfish product has been very stable (totally accounts about 46% of the nation's yield) since1996. The first mollusk to be submitted to mariculture in China was the mussel, *Mytilus galloprovincialis*. Note that in 1986, when the production yielded 210,057 tons of mussels, mussels overtook *Laminaria* as the no. 1 mariculture organism.

Recently two scallops have been subjected to mariculture, namely, the local scallop, *Chlamys farreri*, and the introduced bay scallop, *Argopecten irradians*. The total production of scallop in 2004 was 910,352 mt and 548,295 mt were from Shandong Province.

Mollusc is important seafood for the coastal people but mariculture have depended on collecting natural spats for a long time, and progress in mariculture has been very slow. During the past 20 years, some spat has been successfully artificially bred by hatchery feeding and collected in a large scale. In the east of YS, *Ruditapes philippinarum* and *Crassostrea gigas* are major species cultivated in Korea (Figure 11).

2.1.4 Marine plants (seaweeds)

The production of the principal mariculture organism started with the seaweeds in China rather than shrimp and fish. This is because the seaweeds are autotrophic and have relatively simple life histories whereas the shrimp and fish are heterotrophic and have complicated life histories.

Scientific aquaculture in China started with the kelp *Laminaria japonica* in 1952. At the earlier stage, like all other mariculture organisms, natural sporelings of kelp were used, and growth of the young sporelings took place on sublittoral rocks. After several years of research, palm ropes in the form of rafts were used for collecting spores in twisted on larger ropes and hung in the sea for cultivation. For a long time, China has been the greatest producer of Japanese kelp in the world, production amounting to as much as 801,128 tons dry kelp per annum. Shandong and Liaoning Provinces is the main producing area of kelp, especially in the former, whose production count for more than 30% of the total. During the past years from 1993 to 2004, the wet kelp produced from the both Provinces is stable at 400,000 tons every year.

Following kelp cultivation, purple laver cultivation has been successful in China. China produced some *Porphyra* sp. by traditional methods of rock cleaning for a few hundred years. In China, large-scale cultivation of the species were conducted with a improvement of the traditional Japanese pillar method of cultivation in 1952.The main producing area of purple laver is one of the Yellow Sea coastal Province, Jiangsu, which counts for more than 80% of the total production in China and the production is about 10,000 tons per year.

Besides *Laminaria* sp. and *Porphyra* sp., several other seaweeds also have been subjected to cultivation, such as *Undaria pinnatifida* and *Hizikia fusiformis* among the brown algae, and *Gloiopeltis furcata*, *Gracilaria* spp., *Eucheuma gelatinae* and *Gelidium amansii* among the red algae (Figure 12). Now there are more than twenty species and groups of seaweeds under culture. Experiments prove that culturing by thalli farming can be successful in the coastal of Qingdao, Shandong Province, one of the Yellow Sea coastal Provinces. Although most of *Graciliara* sp. productions are produced from the South of China, it has been transplanted to the north under the policy of polyculture in recent years.

Seaweeds have long history of aquaculture and have been important aquatic products in Korea. The seaweed production in YS coast reached 145.9 x 10^3 mt in 2004 and occupied 70.1% of the total mariculture production in the west coast of Korea. The two species, laver *Porphyra* sp. and sea mustard *Undaria* sp. occupied 92.5% of the total seaweed production (Figure 13). Other minor cultured species are kelp *Laminaria* sp., *Hijikia fusiforme*, and green algae *Enteromopha* sp.

2.2 Mariculture trend in the west coast of YS (China)

World aquaculture production now accounts for 38% of total fisheries production in 2004 (Food and Agriculture Organization (FAO) of the United Nations. Most of the expansion has been attributable to China, which is now responsible for more than two-thirds of total aquaculture production in terms of volume (32 million tonnes in 2004). Yellow Sea fishery area is the most important fishery production area in China, where provides about 46% of the total mariculture production.

China is the leading aquaculture nation of the world in terms of the number of species reared and volume produced. Traditionally fresh water culture has dominated, but in resent years the marine aquaculture has increased dramatically. This is partly due to the overexploitation of the natural fish stock in Chinese waters, which has forced many fishermen to change their profession to fish or shellfish farmers, especially in the YS region.

Farming of fish is increasing like other countries, which have developed an intensive mariculture. China has experienced health and environmental problems. Generally finfish aquaculture industry is faced with environmental issues such as accumulation of bio-deposition or fish feed and faeces and outbreaks of diseases, which may result in pollution, high mortality and low growth rates. In general the deterioration of the environment has negative effect both on the health and growth of mariculture organisms and on the natural habitat in the coastal zone.

The production of bivalves is the biggest mariculture industry in China mainly in the YS region mainly in the Shandong and Liaoning Provinces (Figure 14). Similar to other intensive mariculture regions worldwide, rapidly developed scallop culture and other mariculture industries in the last decade have overcrowded almost every potential culture site in shallow sea of China. As a consequence, low growth rate, high mortality and increased cost are challenging the sustainable development of mariculture industry in China. To find an effective or optimal culture model, which will not only yield high quality aquatic products, but gain ecological and social-economic benefits as well. Ranking all main culture species, polyculture models of seaweed+bivalves+fishes are deemed to be the best practices for mariculture in shallow sea areas in future.

2.3 Mariculture trend in the east coast of YS (Korea)

As west coast of the YS region in China, east coast in Korea has been major aquaculture production area for shellfish and seaweeds (Figure 15). Extensive tidal flat area of the YS east is a valuable site for several clams. Manila clams (Japanese carpet shell, Littleneck clam, shortneck clam), *Ruditapes philippinarum*, are mainly distributed in this region. Production of this clam showed steadily reducing trends from in the range of 12,700 mt (2004) and 30,000 mt (2000). Almost all the seedlings for aquaculture have been caught from wild habitat in the YS region. Recently, because of reduction in wild seedling resources at natural habitat in Korea, demands for import of foreign juveniles from China and North Korea are being increased. In addition to natural seedling catches, artificial hatchery-based spat producing techniques are already developed by shellfish research center of NFRDI, and development of mass producing techniques in the field still remain as a problem to be solved.

However, the suitable culture ground has been dramatically decrease by the land reclamation activity in Korea. Recently, Saemangum-project is the biggest one ever made and there are a lot of small land reclamation project proposed by local municipal government. This was the major cause of decrease in shellfish production in 1990's.

The finfish and crustacean aquaculture are rather new to shellfish and seaweed aquaculture industry in this region since 1980's. Shrimp farming was initially begun in the 1960s in Korea and the farming industry was developed in the 1980s. Farmed shrimp production has been rapidly increasing since 1990s. Farmed shrimp production reached 3,256 MT in 2001. The number of shrimp farms is about 450 and total farmed area is about 2,600 ha. More than 90% of shrimp farms are located in the YS region and the rest are along the southern coast. Two species, *Fenneropenaeus chinensis* (Chinese fleshy prawn) and *Marsupenaeus japonicus* (Japanese Kuruma shrimp) had been cultured before the middle of 1990s, but *M. japonicus* had not been cultured after the outbreak of WSSV (white spot syndrome virus) in 1993.

Finfish aquaculture is continuously increasing with same rates as other regions in Korea. Although some salt pens have changed to finfish culture ponds, there have been several problems like overwintering of low temperature. The east of YS area may not suitable for the marine finfish culture for the low temperature in winter season; however, specific local species like a gizzard shad is newly domesticated and could be promising cultivar. Seaweed production has been steadily increasing after recovery of late 1990's economic recess and its contribution maintained about at the level of 27% of total production.

2.4 Current aquaculture methods of marine farmed organisms

Mariculture is cultivation, management and harvesting of marine organisms in their natural habitat or in specially constructed rearing units, e.g. ponds, cages, pens, enclosures or tanks. For the purpose of FAO statistics, mariculture refers to cultivation of the end product in seawater even though earlier stages in the life cycle of the concerned aquatic organisms may be cultured in brackish water or freshwater. The followings are definitions of each culture system.

Table 1. Culture systems and definitions

CULTURE SYSTEM	DESCRIPTION
Bag	Off-bottom shellfish culture (e.g. oysters) in which on growing takes place in mesh bags held on intertidal trestles.
Bed	Bottom culture of mollusks on intertidal or deep-water beds.
Bottom	Type of extensive culture of mussels, oysters, scallops and clams in which on growing occurs on the seabed. After an appropriate period of growth period, the shellfish are harvested by dredging. Method also used for the culture of seaweeds.
Cage	Culture of stocks in cages.
Enclosure	Rearing of fish in enclosures.
Floating net	Seaweed culture method in which synthetic ropes are supported on the surface of the sea by buoys and held by anchors; a series of nets with small buoys are stretched between the ropes. It makes it possible to utilize even offshore waters of about 20 m depth with strong wave action.
Floating	Conchyliculture system in which growing mollusks are held in various types of containers suspended from floating devices such as rafts or longlines.
Long line	Form of open-water suspended culture in which cultured species are on grown on ropes or diverse containers (e.g. baskets, stacked trays, lantern nets) suspended from anchored and buoyed surface or subsurface ropes (longlines). Used for the culture of bivalve mollusks, e.g. mussels, oysters, scallops, and marine macroalgae.
Net	Seaweed culture method in which rectangular synthetic nets are suspended from bamboo poles driven into the bottom of the shallow sea so that the flat surface is parallel to the water surface.
Pen	The rearing of fish in pens.
Pond	Common term used to describe the cultivation of organisms in land-based ponds. Various pond designs are used in different stages of an organism’s development, such as spawning ponds, wintering ponds, fry ponds and on growing ponds.

Raft	Form of suspended culture in which the on growing structures (ropes, etc.) are suspended from a raft. Utilizes moored, floating rafts mostly for coastal shellfish culture; holes are punched in old shells and the shells are placed on strings, which are attached to the raft structure; after settling of spat on the shells, the rafts may be anchored in good growing areas.
Raft-rack	An Asian suspended culture technique in which a simple raft made of bamboo only is allowed to float within the confines of bamboo posts during the first two to three months of mussel or oyster culture; when the weight of the cultured mollusks become too heavy, the raft is tied to posts at a fixed position in the water; additional posts may then be added to further support the heavy raft transformed into a rack.
Stake	An off-bottom culture method of mussels or oysters where bamboo, wooden or cement stakes or sticks are driven into the bottom to catch spat. Grow-out may be in the spat-catching area itself or more often, in separate grow-out areas. Particularly useful in intertidal areas with soft bottom mud.
Stake-and-line	Aquaculture technique widely used in Asia for seaweed culture in which simple wood or bamboo stakes are knocked into muddy/sandy tidal areas to support a crossed network of nylon line set at intervals, 30-50 cm above the seabed; stems of seaweed are tied directly on to the line.
String	Type of mollusk suspended culture in which the cultured species are grown on hanging ropes (in nylon or as tubular netting), such as for example the French "corde marseillaise" (Marseilles rope).
Suspended	Culture method whereby cultured species (mollusks or seaweeds) are on grown on hanging ropes, or other structures, suspended from fixed or floating installations (buoys, frames, floating platforms, longlines).
Tray	An off-bottom cultural practice used for shellfish in coastal waters. Shellfish are placed in baskets or trays made of a mesh material such as fishing net, chicken wire, or plastic. These baskets/ trays are suspended from fixed racks or beneath rafts.

Culture species using suspending culture in shallow waters are macroalgae (kelp, *Undaria* spp,) and shellfish (Bay scallop *Argopecten irradians*, Japanese scallop *Patinopecten yessoensis*, Native scallop *Chlamys farreri,* Pacific oyster *Crassostrea gigas*, mussel and abalone.

Shellfish such as native scallop, Japanese scallop, clam, oyster, snail, and abalones, sea urchin and sea cucumber are grown in the long line culture methods in Shandong Province. Manila clam, razor clam, oyster, bloody clams, Cockles are cultivated in the mud flat culture or intertidal zone. Shrimps, crabs, fishes, shellfish and sea cucumber, etc. are mainly cultivated in the pond system. Finfish such as flounder and turbot and shrimps and abalone are commonly cultivated in the land based tank culture methods.

In Korea, tank, pond, and cage culture systems are popular for finfish aquaculture. Likewise, pond culture is common for crustaceans while hanging and bottom culture methods are for shellfish and floating net and long line culture methods are for seaweeds. Floating net seaweed culture for *Porphyra* occupies more than 80% of licensed culture area followed by the pond culture for fish and shrimp.

2.4.1 Ecological problems

- Large scale constructions on the coast changed formation of coastline, loss of ecological structure components, and the recession of environmental functions.
- Changes of ecological structure components may impose long-term negative impacts on the bay.
- Lack of adjustment of ecological functions resulted in low efficiency of resource utilization, may also incur disastrous environmental problems.
- Overexploitation of the tidal zone for mariculture destroyed the habitat of indigenous organisms, reduced biodiversity, and may result in the extinction of some species in the long run.
- Management coupled with the limitation of technology, could likely result in unbalanced development of these areas.

Feed conversion rate (FCR) for fish and shrimp is relatively low. Results show that about 33~66% of feed are dissolved in the waters without utilization. This will impose significant impact on the coastal environment. Improved formulation for artificial feed is a way to improve the feed conversion rate.

Intensive aquaculture is one of mainly source of pollutant, and recirculation system is a way of coping with this problem.

Intensive mariculture may damage the ecosystem. Large-scale and intensively cultivation of seaweeds and bivalves in some bays could also pose environmental problems if not properly controlled beneath the carrying capacity. e.g. long-line culture of seaweeds and bivalves may add to the water confinement, reduced current velocity, increased organic sedimentation, and accelerated the deterioration of environment of mariculture regions.

2.4.2 Emerging trends and experiences

With continued pro-active government policies, adequate advanced planning, scientifically designed production technologies, sound management and the increasingly important world demand for aquaculture products, aquaculture in China can be and is likely to be productively stable, sustainable and competitive both domestically and internationally.

There are valuable lessons which can be learnt from the Chinese experience:

(1) aquaculture can be developed in a sustainable manner to generate food and jobs, and improve income and livelihoods of rural and urban populations, thus alleviating hunger and poverty;

(2) the engine for an economically resilient and sustainable aquaculture is the Government’s will and determination to establish sound policies in support of the development of the sector, especially issue specific policies; it is also the

market determined demand for the product;

(3) full employment of productive factors, including human resources, continuous improvements in legal and regulatory framework for the development of the sector, and scientific breakthroughs in production technologies will strengthen aquaculture and ensure its sustainability, thereby making aquaculture a good contributor to the country's overall economic growth.

2.4.3 Pollution

The quality of inshore water is continuing to deteriorate in shellfish aquaculture bays on the coastline of the YS. Accumulation of organic waste beneath finfish and shellfish farm cages is a common consequence of the fed farming operations. The scale of these accumulations, as well as the scale of effects on sediment structure and benthic communities, depends on farm size and local hydrographic conditions (e.g. water exchange and current exposure). Stratified, semi-enclosed water bodies with poor water exchange are most at risk from the adverse effects of mariculture inputs. Measures have since been introduced to minimise the impacts of farming in the area.

In some areas with poor flushing characteristics, the deposition of organic detritus beneath suspended mussels has resulted in benthic enrichment. Mussel longlines have caused significant benthic enrichment in sections of the bay subject to poor water exchange. The impacts include increased organic content of sediments, decreased faunal diversity and the prominence of opportunistic polychaetes. Deposits of pseudo-faeces beneath longlines are also prevalent and it is likely that continued expansion of mussel farming.

High intensity shellfish cultivation in the YS region has potential to alter the nutrient flow within embayments. Clearly, the potential impacts of bivalve culture in poorly flushed embayments subject to high stocking densities need to be carefully assessed prior to developing new installations.

Pollution of the marine environment from inputs of organic fish faeces and nutrients from surplus fish feed, as well as from chemicals such as antibiotics, other chemotherapeutants and pesticides used in fish farming, result in localized impacts on the seabed and water quality deterioration. Fish farming operations may be adversely affected by pollution from other sources such as sewage from urban areas, animal slurry and other agricultural run-off, oil and chemical spills, radioactive discharges from nuclear reprocessing plants, and so forth. Even the seaweed raft culture, one of the extractive aquaculture, causes organic pollution due to discarding of leftover holdfast and blade fragments.

2.4.4 Disease

The occurrence and spread of infectious diseases in farmed fish is due to the high densities at which the fish are held. The agents (bacteria, viruses and parasites) causing these diseases are ubiquitous in the environment and are capable of creating serious diseases in both farmed and wild fish. Disease transmission between farmed fish and wild fish is most likely to occur at farm sites or by the escape of farmed fish. No information on the trends or current incidences of diseases in mariculture within Region III was available for this assessment.

Intensive fish farming involves raising finfish in densely packed unnatural conditions that provide favourable circumstances for the growth and spread of diseases and parasites. This makes fighting disease and parasitic infections a constant battle. The sea cages are open circulation systems that allow pathogens and parasites to transfer to wild populations, and *vice versa*, by the various vectors (direct contact, intermediary host or waterborne contamination). Hence finfish farmers are heavily reliant on the use of antibiotics — including many of those used to treat human infections — and other drugs and pesticides (chemotherapeutants) to control disease. Many such chemicals are toxic, persistent and bioaccumulate. Traces of these substances may be passed on to consumers and contribute to the dangerous increase of antibiotic resistant disease worldwide.

Regarding disease control in aquaculture, the authorities state that efforts should focus first on prevention (good management practices, vaccines, etc.) rather than cure, but the use of veterinary medicines is necessary in certain circumstances. It is important to encourage partnership between farmers and to develop good management practices, including preventive measures aiming to avoid introduction of new pathogens and the spread of diseases to farmed and wild stock.

2.4.5 Checklist of major issues affecting the sustainability of the Yellow Sea mariculture Industry

a. Large scale constructions on the coast changed formation of coastline - loss of ecological structure components, and the recession of environmental functions.

b. Changes of ecological structure components may impose long-term negative impacts on the bay.

c. Lack of adjustment of ecological functions resulted in low efficiency of resource utilization, may also incur disastrous environmental problems.

d. Overexploitation of the tidal zone for mariculture destroyed the habitat of indigenous organisms, reduced biodiversity, and may result in the extinction of some species in the long run.

e. Management coupled with the limitation of technology, could likely result in unbalanced development of these areas.

f. High Feed conversion rate (FCR) may result in self-pollution

g. Intensive mariculture may damage the surrounding environment

h. The quality of inshore water is continuing to deteriorate in shellfish aquaculture bays on the coastline of the YS.

i. The occurrence and spread of infectious diseases in farmed fish is due to the high densities

2.4.6 Problem-solving ideas

Aquaculture industry in the YS and all other regions is facing with more problems today than ever before. Issues like diseases, low productivity and environmental pollution are acknowledged impediments for sustainable development of aquaculture. Environmental protection and remediation is the most effective way to resolve this problem.

Long-term monitoring and emergency monitoring are equally helpful in finding the impact of aquaculture on the environment, and forms the basis for decision-making. Policymaking and enforcement are also important in keeping the industry on the right track. The blind development of aquaculture is sometimes the result of shortage of guidelines. China has been putting more effort on aquaculture legislation, such as the drafting of Standards for Harvesting Area Classification, and has highlighted the introduction of EU or US management regimes. Through persistent hard work of researchers and lawmakers, it is predictable that aquaculture management in China will achieve a higher standard in the future. Technology improvement is vital in pollution control for aquaculture. Study on carrying capacity, environment remediation and polyculture techniques have all contributed to enhance productivity, as well as protect the environment. Other factors that support a sustainable aquaculture include: the establishment of easily accessible information system, and public awareness of the importance of harmonized development of economy, social culture and the environment.

3 SUSTAINABLE MARICULTURE

3.1 Aquaculture systems and definition of sustainability

Sustainable development and sustainability are complex issues that are difficult to define and apply to aquaculture. The *systems approach*, however, can assist understanding of these issues, as they relate to aquaculture development.

The term sustainability has been defined in various ways but perhaps the most widely used is based on the definition of sustainable development in the Brundtland report; **sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.** An even more succinct definition is that of the International Union for the Conservation of Nature (IUCN): sustainable development improves people's quality of life within the context of the Earth's carrying capacity.

These definitions contain two key concepts; meeting the present and future needs of the world's people, and accepting the limitations of the environment to provide resources and to receive wastes for the present and for the future. The Food and Agriculture Organization of the United Nations (FAO), in particular, recognized that increased capacity at the national level is required to achieve sustainable development by including the need for 'institutional change' in definitions of sustainable agricultural development (FAO, 1995). The recognition that institutions are important highlights the need for education and training, effective institutional arrangements and a legal and policy framework to underpin sustainable development of agriculture, and indeed aquaculture. The WCED has advocated aquaculture as one of the measures that world help attain sustainable development (WCED, 1987)

The FAO (1991) has defined sustainable development is a similar manner, meaning, it to be the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable.

These attributes of sustainability suggest well-planed changes in the management of natural resources; in animal production on land and in the water, it means using less energy, recycling, reduction and substitution of raw material inputs, and the like.

The quest for environmental sustainability implies a move away from monocultures in a viable transition to acceptable, complex, multigoal-oriented bioproduction system

3.2 Environmental aspects of aquaculture

Environmental issues have become of increasing concern for several reasons. The first is recognition of the increasing pressure on resources in some coastal and inland areas. More attention has been given to the impact of aquaculture on the environment in recent years, partly induced by some well publicized "crashes" within the shrimp industry. This has been accompanied by the publicity given to environmental and social issues surrounding aquaculture. This type of exposure has had a profound impact on the public's perception of aquaculture, changing it from the "blue revolution" which would improve the availability of cheap, affordable protein to poorer people, to that of being an environmentally unsound means to produce luxury food items for consumers in developed nations.

3.3 The link between existing aquaculture practices and coastal management

Coastal zone of the YS is the most populated area in both countries. There are many big cities sitting along the coastline, and the highest density is found near colossal cosmopolitans. Coastal zone of the YS in China and Korea is also the center for industry and business activities. Aquaculture management is an important integral part of Integrated Coastal Zone Management (ICZM). The aquaculture is a key function of local town and village administration, and once conflicts occur, either between or within the industries, it is the responsibility of local administrations for mediation or reconciliation. Environmental protection authority, fisheries authority, and different authorities of local government usually participate in its settlement. ICZM is all the more difficult to be enforced in a country like China and Korea, where most part of the coastal zone is already exploited, or overexploited. All the interest groups are likely to hold on to their gained benefit, and hinder the implementation of new management regime, even though it will bring them future recompenses. The followings are several options for the **management strategy**.

3.3.1 Responsible Aquaculture Program

Guiding Principles for Responsible Aquaculture: Over the past several years, the Global Aquaculture Alliance developed the **R**esponsible **A**quaculture **P**rogram to promote best management practices for aquaculture. The RAP program encourages the culture of safe, wholesome seafood in an environmentally and socially responsible manner. More importantly, it is also intended to improve the efficiency and long-term sustainability of the aquaculture industry.

The Responsible Aquaculture Program began as a straightforward set of **"Guiding Principles for Responsible Aquaculture"** that promote a cooperative approach to establishing aquaculture operations that reflect environmental, economic, and social sustainability. The principles call for minimal ecological impacts, water conservation, improved feed and drug use, and reductions in effluents.

The Global Aquaculture Alliance exists both to promote the aquaculture industry and to advance environmental and social responsibility throughout the process of raising, processing and distributing aquaculture products.

3.3.2 Minimizing negative impacts

Guidance is emerging for the application of practices for improved environmental management, and strategies have been identified for the following:

Technology and farming systems: In recognizing the importance of appropriate farming technology/system and management of inputs and outputs, special attention is given to the major resources used (i.e. feed, water, sediments and seed). At this level, management actions mainly involve farmers and input suppliers.

Adoption of integrated coastal area management approaches: The importance of integrating aquaculture projects within existing ecological systems in coastal areas is increasingly recognized. This approach requires the consideration of proper site selection and the application of planning and management strategies that allow the allocation of resources among different users.

Policy and institutional support: It is necessary to have a clear and supportive policy framework for aquaculture. Particular issues include aquaculture legislation, economic incentives and disincentives, actions for the public image of the activity, private-sector and community participation in policy formulation, and increasing the effectiveness of research, extension and information exchange. Policy decisions and their implementation play a strong role in influencing the management possibilities at both the farm and local area levels.

4 EDUCATION AND TRAINING

With the aid of a comprehensive policy framework, aquaculture can be safely managed to ensure a sustainable and productive future. The federal government can catalyze sustainable development in the sector by providing a cohesive, integrated and coordinated federal response. The first is the education and training in this response.

4.1 Investing in people through education and training

Further investments in education and training are essential to build the knowledge, skills and attitude of all people involved in the sector. Human capacity development can be made more cost-effective and responsive to needs through: using participatory approaches to curriculum development; improving co-operation and networking between agencies and institutions; multidisciplinary and problem-based approaches to learning; and use of modern training, education and communication tools, such as the Internet and distance learning, to promote regional and inter-regional co-operation and networking in the development of curricula, exchange of experiences and development of supporting knowledge bases and resource materials; and providing a balance of practical and theoretical approaches to train farmers and provide more skilful and innovative staff to industry.

Table 2. Topics that should be dealt in the education and training component **of an ideal Responsible Aquaculture Programme (RAP):**

Topic	Sub-Topic
Sustainable management options	▪ Integrated coastal zone management (ICM or ICZM) ▪ Ecosystem-Based, Environmentally-sustainable management
Conventional methods applied in YS region of China and Korea	
Sustainable method options	▪ Polyculture ▪ Offshore culture ▪ Closed circulation ▪ Sustainable mariculture disease control

4.2 ICZM as the logical tool to accommodate various uses: Sustainable management options

There are many different users of the coastal areas. Integrated coastal zone management (ICZM), often simply referred to as coastal zone management (CZM), seeks to provide an integrating framework to resolve conflicts among sectors or user groups and ensure smooth integration of areas plans into a national coastal policy framework. Socio-economic aspects of planning should be fitted around the environmental constraints. There is a key role in defining these for the aquatic environmental sciences

Integration of coastal stakeholders must have a local base and works best from the bottom up - all stretches of coast are, after all, different from one another in their characteristics – but that it helps if the governmental unit involved facilitates the creation of an administrative structure to make management not only ecologically sound but also fair and equitable.

Accommodating new installations in about-to-be-developed coastal areas is easier than dealing with existing ones. These latter have had the tendency, in Asia and elsewhere, to exceed the carrying capacities for aquaculture. The interplay of the biological and technical bases for the rearing of aquatic organisms with the many social and economic forces that impinge on the domestication of these organisms – for that is that is at stake.

4.3 Ecosystem-Based, Environmentally-sustainable management: Sustainable management options

Implementation of these laws and regulations are equally important. Education and training of the law-enforcement team and the work force of the industry is truly necessary for the ICZM. It should be acknowledged that a polluted and damaged environment will eventually fail to support a rewarding production, and to protect the environment is to protect the industry. China and Korea have issued and drafted a series of fishery laws and/or regulations in recent years, which cover all the aspects of aquaculture activity, from cultivation and harvesting area classification, through the processing to the end products.

Functional division of the marine areas is vital for ecosystem-based management.

Functional division is the foundation of ICZM. It is expected that China will increase her input in the near future in terms of both funding and manpower, in the fundamental research and practice of marine area functional division. International cooperation in this area is also necessary to enhance the practice.

Ecosystem Based Aquaculture in integrated Coast Management requires followings stepwise approach

1. Analyze status of fishery and aquaculture
2. Find out positive and negative ecological factors and changes from aquaculture
3. Analyzing the link between existing aquaculture practices and coastal management
4. Suggest problem-solving ideas of aquaculture and Ecosystem-based Management
5. Apply Ecosystem-based Management

4.4 Sustainable Mariculture techniques

4.4.1 Conventional methods applied in YS region of China and Korea: Brief review of current general aquaculture methods of marine farmed organisms

Pump Ashore/Land-based Culture

Land-based marine aquaculture systems have several advantages. Technology is rapidly advancing in this field and the cost of equipment, such as chillers and pumps, is decreasing. A land-based system allows the water quality to be controlled more easily via filtration.

Submerged Line Culture

Submerged line culture is often the preferred method for culturing bivalve species such as mussels and oysters.

Net Pen Culture

Net pens are often used for many finfish culture. There is increasing interest to convert net pens from salmon culture to other finfish culture.

Challenges for Developing Aquaculture Systems

It is often expensive to find solutions to technical problems associated with marine aquaculture. There are often high costs associated with initial investment of equipment and labor followed by high costs for feed and continuous maintenance.

The high costs associated with aquaculture systems has forced the industry to explore cost-cutting technology. For example, researchers are interested in collaborating with organizations that create waste heat (e.g. power plants and natural gas companies) to reduce the cost of heating water via electricity.

A building capacity programme to deal with these issues should include both lecture and hands-on laboratory sessions, participants will learn about:

- Fish production systems (ponds, flow-through, net pens, and recirculating aquaculture technology) commercially used throughout the world
- Various components and functions of fresh and salt water recirculating aquaculture systems
- Integration of hydroponics and recirculating aquaculture systems
- Interdependence of food science, horticulture and fishery biology in aquaculture
- Nutrition of various fish (herbivores, omnivores, and carnivores)
- Characteristics and management of solid and liquid wastes
- Issues associated with the discharge of wastewaters into public receiving waters
- Treatment of sick fish
- Recognizing the early stages of disease
- Sampling skin and gill tissue
- Performing a necropsy

4.4.2 Polyculture (multi-trophic integrated aquaculture)

The underlying goal of polyculture involves increasing productivity by more efficiently utilizing ecological resources within an aquatic environment. This type of aquaculture is accomplished (or attempted) by stocking species with different feeding habits and different habitat preferences (say, benthic vs pelagic). Stocking two or more complementary species can increase the maximum standing crop of a pond by allowing a wider range of available foods and pond volume to be utilized.

Currently a great deal of emphasis is placed on responsible marine aquaculture practices worldwide. One concept that is currently being examined is polyculture or integrated aquaculture. This is the idea of growing finfish, shellfish and marine plants together for the benefit of all crops and the environment.

Polyculture is not just about more production. It's also often about more profits. Polyculture is often of greatest benefit in extensive or moderately-intensive fish production. For the same reasons, it may be difficult to adapt to modern industrial-scale fish and shellfish farming. But, just as economics, regulatory policies, and social consciousness will eventually force the adoption of more fuel-efficient vehicles, aquaculture will be faced with similar pressures to improve efficiency and reduce environmental impacts in the coming decades. Polyculture, with its natural emphasis on increased utilization of water and nutrients, will almost certainly play an important role in this process.

4.4.3 Recirculating tank production system

To facilitate sustainable aquaculture in the region through: (a) reinforcing within the aquaculture industry the need for a commitment to environmental sustainable practices and a duty of care for the environment in which the industry is located; (b) ensuring environmental factors are considered in site selection for the optimum siting of new aquaculture enterprises; (c) ensuring environmental factors are considered in the planning, design and operation of all aquaculture enterprises.

The purpose of the recirculating aquaculture tank production system is to promote economically and environmentally sustainable land-based aquaculture by providing guidance for responsible aquaculture practices. Land based aquaculture facilities for ponds, tanks, hatcheries, raceways, farm dams and fish outs may include facilities for:

- holding, breeding, harvesting and purging of stock
- associated facilities for the preparation or storage of feed
- processing, manufacturing, packaging or distribution of products
- administration, laboratory, storage and maintenance facilties
- waste management
- water extraction, storage, reticulation and recirculation systems
- transport facilities including access
- any related tourist or fishout activities.

Several potential **advantages** include:

- reduced water use and production effluent
- improved water quality
- easier accessibility to fish from raceways
- increase in species diversity
- increased sustainability

Several possible **disadvantages** of these systems include:

- need to pump or mechanically move water
- higher fish production costs compared to open pond culture due to increased pumping costs

- unproven economic feasibility in some cases

4.4.4 Offshore aquaculture

The future of aquaculture will likely be the development of large complexes of submerged net cages, anchored to the seafloor in deeper, offshore waters. Whether these ventures succeed in becoming sustainable depends, as with near-shore aquaculture, on the type of fish being farmed and how they are farmed.

The overall goal of the project is to stimulate the further development of commercial aquaculture in New England, thereby increasing seafood production, creating new employment opportunities, and contributing to economic and community development. For the reasons given above, several faculty members at the University of New Hampshire, all of whom had extensive experience in aquaculture research, sought to further develop aquaculture in New England. To accomplish this goal, significant biological, technical and socio-economic issues needed to be resolved before aquaculture could become part of the solution to our fisheries crisis. Among the most significant of these issues was siting an aquaculture industry in New England. Because our inshore coastal waters are already heavily used for recreation, commercial fishing, and shipping, it was assumed that at least some aquaculture activities would need to take place in offshore areas where there would be fewer conflicts with existing user groups. The high energy (winds and waves) of such exposed locations present significant technical challenges in the design, testing and construction of aquaculture systems that are capable of surviving in these areas. In addition to these technical challenges, there are many biological, regulatory, social and economic problems to be solved.

The ocean beyond nearshore waters has long beckoned as a next area to be used for cultivation. One of the most frequently mentioned options for expansion of the mariculture industry is to move offshore into more open waters. Offshore mariculture presents a unique opportunity for sustainability

If such facilities are placed in offshore waters where circulation is excellent, and if the facilities are properly sized, no significant negative impact on local environmental conditions should occur. Thus offshore mariculture represents a next logical step in the development of the industry.

Careful attention to the density of offshore mariculture facilities within a given locale will ensure that the sustainability of the activity is maintained.

4.5 Sustainable mariculture disease control

For aquaculture species with mature technologies, the major constraints in production are usually related to health maintenance, disease occurrence, and product quality. These issues are inter-related, especially if disease prevention or control implements have long-term effects on the environment or produce residues that make products unacceptable for consumption. Although fish health is a relatively young discipline, numerous publications are already available for reference. One of the best references that discuss about disease, health, monitoring and surveillance is the **survey toolbox for aquatic animal diseases**. Most of the information in this section is derived from various sections of that book.

4.5.1 Health and Disease (fish)

Disease is usually defined as any abnormality of structure or function. This means that whenever there is something abnormal about the animal, we can consider it to be a disease. Health is simply the normal state of an animal, or the absence of disease. Determining if an animal is healthy or not does not just mean that we have to identify some physical abnormality or a disease agent. The level of production can be an indicator of whether an animal is healthy or diseased. Measures of production to indicate health status can be very useful. Ensuring good farm production and animal health starts at the planning stage of every aquaculture venture. At each step of planning and production, questions and answers should be anticipated on how to decrease the possibility of pathogen entry and environmental contamination. These considerations include the following:

- Selection of a production site
- Selection of water source
- Water quality management and control
- Maintenance of various life stages
- Feed quality and feeding practices
- Fish health management
- Proper use of chemicals and veterinary drugs
- Proper sanitation
- Harvesting, holding and transport
- Detailed record keeping

4.5.2 Sources of Infection

Different measures are required to maintain cleanliness and hygiene within culture premises. Prevention and control measures for specific diseases are discussed in the sections on diseases in eggs and larvae, and in diseases in juveniles and adults.

4.5.3 Hatchery Facilities

Maintenance of hygiene in the hatchery can be done simply by disinfecting with chlorine all facilities (reservoir, larval rearing tanks, algal tanks, rotifer tanks, *Artemia* tanks, etc.) and materials (nets, hoses, pails and other paraphernalia). A well-designed hatchery should have a disposal system for contaminated effluents to prevent contact with natural bodies of water. If a broodstock facility is incorporated in the design, this should be separated from larval rearing facilities since it is well known that broodstock harbor and transmit various infectious diseases. Precautionary measures such as provision of footbaths at entrance and exits of production buildings are effective measures to prevent diseases.

4.5.4 Animals

Any stage of live animals for culture that is brought into new sites or aquaculture facilities may carry with it associated microorganisms, including those that cause diseases. Therefore, disinfection and quarantine are carried out to avoid introduction of new and exotic pathogens. Guidelines and protocols regarding introductions are discussed in various manuals and agreed-upon Codes of Practices for prevention and spread of diseases.

Natural food: Hatchery technicians should ensure that their phytoplankton and zooplankton cultures are free of contaminants such as saprophytic protozoans that may become nuisance during culture.

4.5.5 Regular Record Keeping

Individual experiences in hatchery and farm operation build up information on acceptable survival and growth rates. However, careful monitoring and record keeping provide data on most profitable operational protocols that result in highest production possible. Records of water quality, stocking rate and date, daily feeding quantities, water management schemes, harvesting dates and quantities, etc. provide a picture of how each culture unit performs under a certain management regime. The accumulated information can be the linked with production rates and become the basis for optimized and profitable operations in the hatchery and farm.

The survival and growth rate of each population depends on factors like stocking density, predation, feed, temperature and other site-specific and farmer-specific aspects. One way to increase the predictability of production outcomes is by monitoring the health status of animals. Carefully analyzed records of the presence of morphological deformities or of indicator microorganisms can generally prevent sudden mass kills. The records also enable farmers to investigate the causes of low level mortality over a period of time.

4.5.6 Disease Monitoring and Sampling

Data obtained from frequent and regular monitoring of farmed animals has predictive value if the examinations are based on a good number of samples. Diseases or characteristics to evaluate during a microscopic examination of larvae may include the following:

- Larval stage
- Presence and severity of microbial fouling and infection
- Presence of shell necrosis
- Presence of missing appendages or body parts, and abdominal or appendage deformities
- Gut fullness
- Discoloration of larvae

In aquatic culture systems, it is difficult to determined the exact number of animals in the population because of their small size at the larval stages and because they are swimming in the water column. Obtaining the representative number and kind of samples for monitoring purposes is difficult. Sampling is the process of selecting this group from the population. Each member of the sample will be examined and the results are used to generate a picture of the status of the entire population from which the sample was drawn. However, when disease is suspected in the population, a different sampling guideline and sample number should be used.

4.5.7 Levels of Diagnosis

The Asia Diagnostic Guide provides guide for the pathogens and diseases listed in the NACA/FAO/OIE Quarterly Aquatic Animal Disease Reporting System. It has been developed from a large amount of technical contribution from aquatic animal health scientists in the Asia-Pacific region who supported the regional programme. The Asia Diagnostic Guide could be effectively used for both farm and laboratory level diagnosis in the region. It complements the Manual of Procedures for the Implementation of the Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals. It also assists countries in expanding national and regional aquatic animal health diagnostic capabilities to meet the requirements in the International Aquatic Animal Code and the Diagnostic Manual for Aquatic Animal Diseases of the Office International des Epizooties (OIE).

Definition of levels of diagnosis

- Level I : Diagnostic activity includes observation of animal and the environment and clinical examination (Diagnosis site: Field);
- Level II: Diagnostic activity includes parasitology, bacteriology, mycology, and histopathology (Diagnosis site: Laboratory);
- Level III: Diagnostic activity includes virology, electron microscopy, molecular biology and immunology (Diagnosis site: Laboratory).

4.5.8 Sending Samples for Diagnosis

Farm site diagnosis is very important in order to gather information about diseases, especially for emerging problems caused by infectious microorganisms. Strong disease recognition capability at Level I, coupled with more understanding about the course of disease after Level II and III diagnoses, will fast-track our understanding of disease problems affecting aquatic animals. Recognizing the limited facilities for laboratory diagnosis, it is very important for farmers and technicians to know where samples can be sent. Based on the recommended number of representative samples, good quality specimens can be submitted. Farmers and technicians should know where to contact fishery officers and laboratories near their culture sites so that disease outbreaks can readily be reported and investigated.

4.5.9 Reporting on the Disease

Reporting on the diseases on the *National List* of reportable diseases of aquatic animals shall:

- international disease reporting obligations
- provide a tool for negotiations in trade flora to support export certification and quarantine import policy;
- enable international acceptance of disease free zones;
- enhance the effectiveness of the control programs administered by individual country by ensuring national awareness of the diseases of concern of each country;
- guide the further development of diagnostic tests and surveillance protocols to meet the needs of the aquatic industries; and
- guide the development of an aquatic animal disease surveillance and monitoring system.

4.5.10 Responsible Use of Antibiotics in Aquaculture

Antibiotics are drugs of natural or synthetic origin that have the capacity to kill or to inhibit the growth of micro-organisms. Antibiotics that are sufficiently non-toxic to the host are used as chemotherapeutic agents in the treatment of infectious diseases of humans, animals and plants. They have long been present in the environment and have played a crucial role in the battle between man and microbe. Drug choices for the treatment of common infectious diseases are becoming increasingly limited. In aquaculture, antibiotics have been used mainly for therapeutic purposes and as prophylactic agents. Some recommendations on responsible conduct in this context are proposed, aimed at diminishing the threat of build up of antimicrobial resistance.

5 CONCLUSIONS

The YS region provides more than about 10% of total mariculture production; 5.0% for finfish, 6.5 % for crustacean, 37.0% for shellfish and 8.3% for seaweed during last 5 years between 2000 and 2004 (FAO & Tables) from 417,000km2, about 1.16% of total coastal area in the world. The extensive tidal flat and continental shelf area has been site for shellfish habitat as well as mariculture industry. More than one third of total shellfish production comes from in this YS LME coast. Therefore, the mariculture industry should be carried out under very restrict management regime of the ICZM in both countries.

Table 3. Suggested actions and major target

MAJOR ISSUES (*)	SUGGESTED ACTIONS	TARGET
▪ Analysis of aquaculture systems in terms of their carrying capacity of stocking density with respect to the whole surrounding waters column and sediment below ▪ Habitat loss and deterioration (water quality and sediment health) ▪ Pollution ▪ Disease ▪ Socio-economic aspects of domestic and international trades	<u>Ecosystem based aquaculture management</u> ▪ Analyze status of fishery and aquaculture ▪ Find out positive and negative ecological factors and changes from aquaculture ▪ Analyzing the link between existing aquaculture practices and coastal management ▪ Suggest problem-solving ideas of aquaculture and Ecosystem-based Management ▪ Apply Ecosystem-based Management <u>Best Management Practices</u> ▪ Selection of a production site ▪ Selection of water source ▪ Water quality management and control ▪ Maintenance of various life stages ▪ Feed quality and feeding practices ▪ Fish health management ▪ Proper use of chemicals and veterinary drugs ▪ Proper sanitation ▪ Harvesting, holding and transport ▪ Detailed record keeping	Joint-regional applied research programme for sustainable mariculture ▪ Define Carrying Capacity of the Aquaculture System ▪ Application of the Ecosystem Based Aquaculture Management ▪ Application of the Integrated Coastal Zone Management with specific aquaculture practice

(*)affecting the sustainability of YS mariculture -

6 REFERENCES

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- http://nsgd.gso.uri.edu/lsu/lsug97007.pdf (Urban Aquaculture for the 21st Century - Using Recirculating Systems)
- http://www.are.admin.ch/are/en/nachhaltig/international_uno/unterseite02330/ (WCED; The Brundtland Report, 1987)
- http://www.fao.org (FAO)
- (http://www.fao.org/fi/glossary/aquaculture/ ().
- http://www.gaalliance.org/resp.html (Responsible Aquaculture Programme)
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UNDP/GEF Project entitled "Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem"

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TECHNICAL GUIDELINES FOR THE DEVELOPMENT OF TRAINING COURSES IN DISEASES, DIAGNOSIS AND CONTROL TECHNIQUES & MARICULTURE TECHNIQUES (TOWARDS SUSTAINABILITY) &

by

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Third Meeting of the Regional Working Group for the Fisheries Component

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1 TECHNICAL GUIDELINES FOR THE DEVELOPMENT OF A TRAINING COURSES IN DISEASES, DIAGNOSIS AND CONTROL TECHNIQUES

1.1 INTRODUCTION

1.1.1 Current status and impact of infectious diseases on aquaculture

The Yellow Sea Large Marine Ecosystem (YS LME) region has been one of the major aquaculture production areas in the world. This region occupies about 1.2% of total coastal area but mariculture production is more than about 10% of total world mariculture production. With large-scale aquaculture production in this region, the levels of mariculture techniques and other related industries are also highest in the world. However, the outbreaks of disease have severely impeded on the sustainability of the aquaculture industry in this region during last two decades. After experiencing several outbreaks of disease, especially in case of the shrimp aquaculture, both countries have been developing practical measures to maintain aquatic animal and plant health and to deal disease and establishing disease protection system and procedures to cope with diseases. The regional cooperation in aquatic animal health in the YS LME region as a part of the Asia-Pacific region is also required. Country's specific needs have been identified and several national strategies have already been established. There have been many international workshops' outputs such as agreed regional frameworks of the "Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals" (FAO/NACA, 2001). Additional guidelines for disease control are found in the homepage of the Korean National Fisheries Research and Development Institute (http://fdcc.nfrda.re.kr) and several Chinese sites provide limited information (http://china-fisheries.net; http://www.chinafish.net.; http://www.china-fisheries.org/breed/). Unfortunately, those information are available to those only for Korean or Chinese speaking people.

As a part the YS LME project, it is right time to review the established procedures and systems with basic criteria and very fundamental guidelines; because the trans-boundary movement of live aquatic animals is one of the principal reasons for increased occurrence and spread of several serious diseases in other regions (Subasinghe *et al*, 2001). The discussions and recommendations from the Asia Regional Advisory Group (NACA 2004; OIE 2006) on aquatic animal health issue in the Asia-Pacific region should be reviewed as well.

Disease in general can devastate a population, so it is important for producers to know. While there are many pathogens that affect aquaculture, viral diseases in particular can be disastrous; outbreaks often result in high mortality with little or no treatment possible. Often the only recourse is to quarantine and destroy infected stock, followed by rigorous disinfection of all facilities when possible.

This can be traumatic for producer, so effective preventative measures are important. These include: proper management and quarantine of new stock, getting brood stock from areas outside the known range of the virus, careful inspection and evaluation of imported stocks, screening via sampling of individuals, and avoiding the introduction of exotic species into new regions, which can exterminate native populations.

Although aquaculture is one of the fastest growing food production sectors in the world, aquatic animal diseases remain one of the major bottlenecks for the development of the sector. As aquaculture has intensified and expanded, both nationally and regionally, more and more new diseases have emerged, and more will emerge and spread in the future.

1.1.2 Trans-boundary movement and associated pathogen transfer

Trans-boundary movement of live aquatic animals and plants is one of the principal reasons for increased occurrence and spread of several serious diseases (Subasinghe *et al*., 2001). The spread of aquatic animal and plant pathogens has directly led to serious disease outbreaks in Asia, affecting aquaculture productivity, livelihoods, trade and national economies. Such problems have also indirectly affected trade of aquatic animal products, within Asia, and between Asia and major trading partners, such as through indiscriminate use of chemicals in disease control (FAO/NACA, 2001).

Aquaculture has suffered significant losses due to trans-boundary diseases, and increasing risks are foreseen in future as aquaculture expands in the region. Enabling government policies coupled with strong resolve and commitment among stakeholders, will not only help in disease con4trol but also facilitate responsible movement of aquatic animals and contribute to development of sustainable aquaculture in the region, and responsible trade with major trading partners. Recent advances in trade and transport have further enhanced the feasibility of large-scale movements of many species over great distances, both within Asia, and between Asia and other parts of the world.

Quarantine measures are outlined in most codes on introduced fishes. The International Council has also developed policies dealing with introduction of aquatic species, including methods to minimize disease transfers, for the Exploration of the Sea (ICES) for marine introductions. The Office International des Épizooties (OIE) has also developed recommendations and protocols for prevention of international spread of specific diseases of aquatic organisms, as described in the *International Aquatic Animal Health Code*. This includes protocols for health surveillance of animals for domestic and international trade (OIE, 2006). All these information are available in the web.

1.1.3 Better management practices (BMP)

Exploration and validation of the effective extension approaches to promote widespread adoption of better management practices (BMPs). For example, in India it is possible to reduce risks of crop losses from shrimp disease and improve productivity and profitability of small-scale shrimp farms through disease control programs by providing access to science-based disease control principles, by providing technical support that enables farmers to adapt BMPs principles to their own circumstances and by promoting local self-help groups to make cooperation and communicate BMPs to a wider group of farmers, and to collectively address health management problems.

Various global instruments, codes of practice and guidelines exist that provide certain levels of protection, all aimed at minimizing the risks due to pathogens/diseases associated with aquatic animal movement. Within Asia, The Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals and their associated implementation plan, the Beijing Consensus and Implementation Strategy (BCIS), (FAO/NACA, 2000) provide the basic framework and guidance for national and regional efforts in reducing the risks of disease due to trans-boundary movement of live aquatic animals. There has been strong endorsement by many regional, inter-governmental and global organizations and a shared commitment from national governments to support its implementation.

It is the responsibility of the governments to act now, and make provisions within their development plans to implement the technical guidelines. Stakeholders and farmers are also responsible and act as the main body. Most countries face significant challenges in the practical implementation of health management strategies, specifically in areas of diagnosis, surveillance, risk analysis, emergency preparedness and quarantine and certification programs. This is mainly due to inadequate national capacity. There is therefore a need to continue the strong regional cooperation in aquatic animal health in the YS LME region as in the Asia-Pacific region. Both countries' specific needs have been identified and several national strategies have been developed.

1.2 SCOPE AND PURPOSE

This manual provides practical concept and basic guidelines to deal aquatic animal and plant health and diseases in the YS LME region. This manual *does not* provide detailed technical procedures of disease nor the full list of disease in depth, but is designed to assist participants to review of the aquatic animal and plant health and disease in the YS LME region. Several technical guidelines provide an outline of procedures and considerations required for achieving effective aquatic animal disease control. They also outline procedures required to implement relevant provisions as in the FAO *Code of Conduct for Responsible Fisheries* (CCRF) (FAO, 1995) and to meet standards of related international treaties and agreements applicable to the Asian Region. Other manuals provide details and approaches, which need to be developed to meet the special manual and guidelines.

1.2.1 The principles of health management in aquaculture

The aim of this course is to introduce to the participants the principles of health management in aquaculture. You should be able to:

1. RECOGNIZE diseased shrimps and fish;
2. IDENTIFY the cause(s) of the disease;
3. EXPLAIN how a disease develops;
4. APPLY preventive and control measures to lessen the risks posed by the disease;
5. USE appropriate techniques for the preparation of samples for disease diagnosis.

1.2.2 Review the existing measures to disease control

The course may provide brief information and recommend reviewing the several topics concerning to the specific fields required in the workshop among the following twelve modules:

UNIT	MODULE	DESCRIPTION
Unit I Introduction to Fish Health Management	Module 1	Impact of Disease Development in Aquaculture
Unit II Infectious Diseases of Fish and Crustaceans	Module 2	Viral Diseases
	Module 3	Bacterial Diseases
	Module 4	Fungal Diseases
	Module 5	Parasitic Diseases and Pests
Unit III Non-infectious Diseases of Fish and Crustaceans	Module 6	Nutritional Diseases
	Module 7	Environmental & Non-infectious Diseases
	Module 8	Harmful and Toxic Algae
Unit IV Disease Diagnosis, Prevention, and Control of Fish and Crustaceans	Module 9	Histology as a Tool in Disease Diagnosis
	Module 10	Serology and Molecular Techniques in Disease Diagnosis
	Module 11	Immunity and Biological Methods of Disease Prevention and Control
	Module 12	Physical, Environmental, and Chemical Methods of Disease Prevention and Control

1.2.3 International Conventions and Codes of Practice

Policies, legislation, practices and guidelines concerning aquatic animal health and the movement of live aquatic animals are in a state of constant change. Frequent revisions and modifications are needed:

1. Rapid world-wide developments in aquaculture and culture-based fisheries;
2. Increasing knowledge on diseases of aquatic animals;
3. Improved or new diagnostic tools; and
4. Improved pathogen detection procedures.

In addition, changing trade patterns that reflect changes in the political, social, industrial and economic environments of individual countries and regions also contribute to the dynamics of risk assessment sensitivity. As an adjunct to national legislation, policies, guidelines and codes of practice have been developed by international agencies or working groups with responsibility for aquatic animal disease control.

1.2.4 Implementation of workshops

It is advised to develop the practical guidelines concerning aquatic animal and plant health and their disease control measures in the YS LME region through workshops. These workshops could be organized by either Korea or China who may have better understanding in the interested field in order to transfer of technology and extension service. Frequent revisions and modifications are necessary to maintain aquatic animal and plant health.

The recommendations include:

- Workshop of disease free shrimp culture method by Korea
- Workshop of developing a web-based manual of disease control in English, Chinese and Korean

1.3 HEALTH MAINTENANCE AND MONITORING

For aquaculture species with mature technologies, the major constraints in production are usually related to health maintenance, disease occurrence, and product quality. These issues are inter-related, especially if disease prevention or control implements have long-term effects on the environment or produce residues that make products unacceptable for consumption. Although fish health is a relatively young discipline, numerous publications are already available for reference. One of the best references that discuss about disease, health, monitoring and surveillance is the survey toolbox for aquatic animal diseases. Most of the information in this section is derived from various sections of that book.

1.3.1 Health and Disease (fish)

Disease is usually defined as any abnormality of structure or function. This means that whenever there is something abnormal about the animal, we can consider it to be a disease. Health is simply the normal state of an animal, or the absence of disease. Determining if an animal is healthy or not does not just mean that we have to identify some physical abnormality or a disease agent. The level of production can be an indicator of whether an animal is healthy or diseased. Measures of production to indicate health status can be very useful. Ensuring good farm production and animal health starts at the planning stage of every aquaculture venture. At each step of planning and production, questions and answers should be anticipated on how to decrease the possibility of pathogen entry and environmental contamination. These considerations include the following:

- Selection of a production site
- Selection of water source
- Water quality management and control
- Maintenance of various life stages

- Feed quality and feeding practices
- Fish health management
- Proper use of chemicals and veterinary drugs
- Proper sanitation
- Harvesting, holding and transport
- Detailed record keeping

1.3.2 Sources of Infection

Different measures are required to maintain cleanliness and hygiene within culture premises. Prevention and control measures for specific diseases are discussed in the sections on diseases in eggs and larvae, and in diseases in juveniles and adults.

1.3.3 Hatchery Facilities

Maintenance of hygiene in the hatchery can be done simply by disinfecting with chlorine all facilities (reservoir, larval rearing tanks, algal tanks, rotifer tanks, Artemia tanks, etc.) and materials (nets, hoses, pails and other paraphernalia). A well-designed hatchery should have a disposal system for contaminated effluents to prevent contact with natural bodies of water. If a broodstock facility is incorporated in the design, this should be separated from larval rearing facilities since it is well known that broodstock harbor and transmit various infectious diseases. Precautionary measures such as provision of footbaths at entrance and exits of production buildings are effective measures to prevent diseases.

1.3.4 Animals

Any stage of live animals for culture that is brought into new sites or aquaculture facilities may carry with it associated microorganisms, including those that cause diseases. Therefore, disinfection and quarantine are carried out to avoid introduction of new and exotic pathogens. Guidelines and protocols regarding introductions are discussed in various manuals and agreed-upon Codes of Practices for prevention and spread of diseases.

Natural food: Hatchery technicians should ensure that their phytoplankton and zooplankton cultures are free of contaminants such as saprophytic protozoans that may become nuisance during culture.

1.3.5 Regular Record Keeping

Individual experiences in hatchery and farm operation build up information on acceptable survival and growth rates. However, careful monitoring and record keeping provide data on most profitable operational protocols that result in highest production possible. Records of water quality, stocking rate and date, daily feeding quantities, water management schemes, harvesting dates and quantities, etc. provide a picture of how each culture unit performs under a certain management regime. The accumulated information can be the linked with production rates and become the basis for optimized and profitable operations in the hatchery and farm.

The survival and growth rate of each population depends on factors like stocking density, predation, feed, temperature and other site-specific and farmer-specific aspects. One way to increase the predictability of production outcomes is by monitoring the health status of animals. Carefully analyzed records of the presence of morphological deformities or of indicator microorganisms can generally prevent sudden mass kills. The records also enable farmers to investigate the causes of low level mortality over a period of time.

1.3.6 Disease Monitoring and Sampling

Data obtained from frequent and regular monitoring of farmed animals has predictive value if the examinations are based on a good number of samples. Diseases or characteristics to evaluate during a microscopic examination of larvae may include the following:

- Larval stage
- Presence and severity of microbial fouling and infection
- Presence of shell necrosis
- Presence of missing appendages or body parts, and abdominal or appendage deformities
- Gut fullness
- Discoloration of larvae

In aquatic culture systems, it is difficult to determined the exact number of animals in the population because of their small size at the larval stages and because they are swimming in the water column. Obtaining the representative number and kind of samples for monitoring purposes is difficult. Sampling is the process of selecting this group from the population. Each member of the sample will be examined and the results are used to generate a picture of the status of the entire population from which the sample was drawn. However, when disease is suspected in the population, a different sampling guideline and sample number should be used.

1.3.7 Levels of Diagnosis

The Asia Diagnostic Guide provides guide for the pathogens and diseases listed in the NACA/FAO/OIE Quarterly Aquatic Animal Disease Reporting System. It has been developed from a large amount of technical contribution from aquatic animal health scientists in the Asia-Pacific region who supported the regional programme. The Asia Diagnostic Guide could be effectively used for both farm and laboratory level diagnosis in the region. It complements the Manual of Procedures for the Implementation of the Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals. It also assists countries in expanding national and regional aquatic animal health diagnostic capabilities to meet the requirements in the International Aquatic Animal Code and the Diagnostic Manual for Aquatic Animal Diseases of the Office International des Epizooties (OIE).

Definition of levels of diagnosis

Level I	Diagnostic activity includes observation of animal and the environment and clinical examination (Diagnosis site: Field);
Level II	Diagnostic activity includes parasitology, bacteriology, mycology, and histopathology (Diagnosis site: Laboratory);
Level III	Diagnostic activity includes virology, electron microscopy, molecular biology and immunology (Diagnosis site: Laboratory).

1.3.8 Sending Samples for Diagnosis

Farm site diagnosis is very important in order to gather information about diseases, especially for emerging problems caused by infectious microorganisms. Strong disease recognition capability at Level I, coupled with more understanding about the course of disease after Level II and III diagnoses, will fast-track our understanding of disease problems affecting aquatic animals. Recognizing the limited facilities for laboratory diagnosis, it is very important for farmers and technicians to know where samples can be sent. Based on the recommended number of representative samples, good quality specimens can be submitted. Farmers and technicians should know where to contact fishery officers and laboratories near their culture sites so that disease outbreaks can readily be reported and investigated.

1.3.9 Reporting on the Disease

Reporting on the diseases on the *National List* of reportable diseases of aquatic animals shall:

- international disease reporting obligations
- provide a tool for negotiations in trade flora to support export certification and quarantine import policy;
- enable international acceptance of disease free zones;
- enhance the effectiveness of the control programs administered by individual country by ensuring national awareness of the diseases of concern of each country;
- guide the further development of diagnostic tests and surveillance protocols to meet the needs of the aquatic industries; and
- guide the development of an aquatic animal disease surveillance and monitoring system.

1.3.10 Responsible Use of Antibiotics in Aquaculture

Antibiotics are drugs of natural or synthetic origin that have the capacity to kill or to inhibit the growth of micro-organisms. Antibiotics that are sufficiently non-toxic to the host are used as chemotherapeutic agents in the treatment of infectious diseases of humans, animals and plants. They have long been present in the environment and have played a crucial role in the battle between man and microbe. Drug choices for the treatment of common infectious diseases are becoming increasingly limited. In aquaculture, antibiotics have been used mainly for therapeutic purposes and as prophylactic agents. Some recommendations on responsible conduct in this context are proposed, aimed at diminishing the threat of build up of antimicrobial resistance.

1.4 DISEASE DIAGNOSIS

The material presented in this section supports the web information related to the *Technical Guidelines*. Diagnosis requires several levels of data, starting with farm- or site-level observations and progressing in technical complexity to electron microscopy, immunology, nucleic-acid assays and other biomolecular methods. This means that all levels of expertise, including that of the farmer and extension officer, make contributions that are critical for rapid and accurate disease diagnosis. The *Technical Guidelines* deliberately emphasize capacity building (facilities and expertise) for basic diagnosis and surveillance at the farm level (Level I). This is the essential foundation for early disease detection and implementation of effective response protocols that can minimize social and economic losses.

Levels of Disease Diagnosis

The accurate diagnosis of aquatic animal diseases requires different levels of disease surveillance and data collection, ranging from farm-site observations through to the use of state-of-the-art diagnostic technology. Development of expertise at each level of diagnosis requires investment in training and infrastructure, with successive levels requiring more complex training and greater financial resources.

The investment required at the three different levels of disease surveillance (termed Levels I-III). Some countries will need to increase investment to meet diagnostic requirements for listed diseases which need Level II and III capability for their identification and/or confirmation. Where such diseases (or the potential for their introduction) have limited probability of occurrence, diagnostic/surveillance assurances can be achieved by enhanced links with the required diagnostic capabilities in other participating countries. For OIE-listed diseases, OIE Reference Laboratories can be used. For other diseases of regional concern, Regional Resource Centers (RRCs) can be consulted. It is important to note, however, that all three levels of diagnostics capability are necessary for the diagnosis of new or rare diseases.

Level I diagnostics is especially valuable for compiling complete case histories which can accompany and assist diagnosis of samples submitted for Level II or III diagnosis. Such information helps focus diagnostic effort, enhancing speed and accuracy of results. Level I diagnosis is generally appropriate for: macroscopic ectoparasites, which are easily identified; diseases with specific gross pathology; and farms/sites with an established history and/or susceptibility to specific diseases.

Level II diagnostics is required for diseases whose clinical signs could be caused by a variety of infectious (and non-infectious) agents. Level II (and occasionally, Level III capability) is also required for external and internal pathogens that are not readily recognized by gross examination using the naked eye (e.g., microbial agents, many types of parasites). In these cases, bacteriology (culture characteristics, chemical profiles or light microscope examination), mycology (as for bacteriology) or histology (preserved and stained sections.

1.5 AQUATIC DISEASE CONTROL

1.5.1 Finfish aquaculture disease control

(1) It is unlawful for any person to import into or transport finfish aquaculture products without first having obtained a permit to do so issued by the authorized department (department). A copy of the transport permit shall accompany the finfish aquaculture products at all times, and must be presented upon request.

(2) The director of the authorized department (director) may impose conditions on a transport permit as necessary to ensure the protection of aquaculture products and native finfish from disease when the

director concludes that there is a reasonable risk of disease transmission associated with the finfish aquaculture products.

(3) Upon the initial detection of a regulated pathogen, the department's fish health unit must be notified by the end of the following working day after diagnosis is made. The department will confirm or deny the presence of the regulated pathogen.

(4) The director will issue, upon request, copies of the rules and policies dealing with finfish disease control.

(5) The director will issue or deny a transport permit within thirty days after a completed application containing all requested information is received by the department's fish health unit.

(6) Violation of these rules or the conditions of the transport permit may result in the suspension or revocation of the permit.

(7) In the event of denial, suspension, or revocation of a transport permit, the affected person may appeal the decision to the director. The department will advise the person of the appeals process. Additional appeals may be made through the additional legislation.

(8) Any person desiring to conduct *in vivo* research using a regulated finfish pathogen is required to first obtain permission in writing from the department prior to beginning the research.

1.5.2 Crustacean aquaculture disease control

(1) It is unlawful for any person to import or possess live imported aquatic invertebrates, except market ready shellfish, without first obtaining an aquatic invertebrate import permit issued by the department. A copy of the permit shall accompany the aquatic invertebrates at all times, and must be presented upon request to department employees.

(2) The director shall appoint an advisory committee consisting of specialists from the scientific, governmental

1.5.3 Shellfish aquaculture disease control

(1) It is unlawful for any person to import or possess live imported aquatic invertebrates, except market ready shellfish, without first obtaining an aquatic invertebrate import permit issued by the department. A copy of the permit shall accompany the aquatic invertebrates at all times, and must be presented upon request to department employees.

(2) The director shall appoint an advisory committee consisting of specialists from the scientific, governmental and private fields. The committee will advise the department on importation of aquatic invertebrates, make recommendations on classification of shellfish diseases, and review department policy. Recommendations of the committee are not binding on the commission or director.

(3) Established species from existing import areas with current disease free tissue certification from areas of origin free of Class A shellfish diseases are eligible for continued importation.

- An additional disease free tissue certification must be submitted regularly like every three years. The department will waive the certification requirement if there is sufficient information that the source area is free of Class A shellfish diseases.

- Additional disease free certification may be required upon discovery or reports of disease at the geographic source.

(4) Established species from new areas of origin are eligible for import if health history documentation and disease free tissue certification are provided to the department. Import into quarantine is required for imports originating from outside the west coast commerce region.

- Conditional importation approval will be initiated by permit application.
- Presence of any Class A shellfish disease in the area of origin will result in denial of conditional approval.
- At least one additional disease free certification will be required during the first year of importation. In the absence of disease during the first year of importation, established species will be eligible for continued importation, and the provisions of subsection (3) of this section will apply.

(5) Nonestablished species for which a health history documentation and disease free tissue certification have been initiated by permit application are eligible for importation only into quarantine.

- A SEPA checklist is required for any importation of a new species.

(6) Health history documentation will be based on available documentation over five years prior to application for an import permit, unless a longer documentation is required for cause, and is required to be provided by the applicant. Disease free tissue certification is required from representative invertebrates proposed for import, and must be certified by a department-approved invertebrate health care professional. Disease-free tissue certification may be waived for aquatic invertebrate species placed into a terminal quarantine facility upon approval of an aquatic invertebrate import permit application.

(7) Department employees may inspect quarantine facilities used for permitted shellfish imports at reasonable times without prior notification.

(8) Importers are required to immediately report to the department any epizootic, significant mortality potentially attributable to an infectious disease or discovery of a Class A shellfish disease in an approved source area. The report is required to be made within 24 hours of the event or discovery. Annual reporting of the presence or absence of Class A or Class B shellfish diseases may be a condition of any permit.

(9) Violation of these rules or the conditions of the permit, confirmation of a Class A shellfish disease at the geographic source, or verification of substantial shellfish mortality at the geographic source may result in the suspension or revocation of the import permit.

In the event of denial, suspension, or revocation of an import permit, the affected party may appeal through the appropriate legislation procedure. A suspended or revoked permit will remain suspended or revoked during the appeal process.

1.5.4 Marine plant aquaculture disease control

(1) It is unlawful for any person to import marine plant aquaculture products without having first obtained a permit to do so issued by the department. A copy of the permit shall accompany the imported marine plant aquaculture products at all times until the initial point of entry into the marine environment, and must be presented upon request to department employees.

(2) The director may impose permit conditions as necessary to ensure the protection of aquaculture products and native marine plants from disease or pests when the director concludes there is a reasonable risk of disease or pest transmission associated with marine plant aquaculture products.

(3) For Porphyra yezoensis and P. tenera, the director will issue import and transfer permits if the plants are in the form of:

- Unialgal conchocelis culture of free living material; or
- Conchocelis-phase culture in shells after the shells and conchocelis have been washed and soaked in fresh water for at least twenty-four hours; or
- Blade phase on netting after two weeks at a temperature of minus twenty degrees centigrade or lower.

(4) For import of other species, the department will consider at least the following criteria, which may require the importer to provide a detailed life history and comply with the requirements of SEPA:

- The ability of the marine plant aquaculture product to naturally reproduce or interbreed with existing species in state waters.
- The ability of the marine plant aquaculture product to compete with existing species.

(5) Importation of marine plant aquaculture products for scientific study in a laboratory or under other controlled conditions is allowed without having obtained a permit when measures are taken to prevent release of the products or release of their gametes, spores, or tissue fragments into state waters. The director may inspect facilities to ensure appropriate control measures.

(6) For purposes of verification of the disease-free status of the marine plant aquaculture product in subsections (3), (4), and (5) of this section, the department may require sufficient samples for evaluation. In event of failure to obtain permit approval, consideration will be given to introduction after laboratory production of a second generation.

(7) It is unlawful to transfer marine plant aquaculture products between any of the following geographic areas without having first obtained a transfer permit. When required, a copy of the transfer permit shall accompany the marine plant aquaculture products at all times until the products are reintroduced, and the transfer permit must be presented upon request to department employees.

(8) Violation of these rules, or the condition of any permit may result in suspension or revocation of the permit.

(9) In the event of denial, suspension, or revocation of an importation or transfer permit, the affected person may appeal the decision to the director. Additional appeals may be made through the appropriate legislation procedure. A suspended or revoked permit will remain suspended or revoked during the appellate process.

1.5.5 Aquaculture disease control — Emergency provisions

(1) The director may take the following emergency enforcement actions when evidence indicates these actions are necessary to protect aquaculture products and native stocks from disease causing severe mortality:

- Deny issuance of a transport permit.
- Quarantine the aquaculture products.
- Confiscate or order the destruction of the aquaculture products.
- Require removal of the aquaculture product from state waters.

(2) For finfish, shellfish, amphibian, and marine plant aquaculture products:

- Quarantine may be ordered without a hearing when aquaculture products are transferred without appropriate inspections or permits or transferred in violation of the conditions of a permit.
- Quarantine may be ordered without a hearing when evidence demonstrates that aquaculture products, previously imported, may introduce a disease not known to occur in Washington.

(3) For finfish aquaculture products, if an epizootic caused by a regulated finfish pathogen is detected, quarantine may be ordered without a hearing.

(4) For shellfish aquaculture products, an outbreak of serious mortality in which contagious disease is suspected may result in quarantine or require removal of the suspected diseased shellfish aquaculture products from state waters, subject to the aquatic farmer's right to an emergency departmental hearing, if removal from state waters is ordered.

(5) When there is evidence that continued presence of aquaculture products in state waters may cause disease that would harm other aquaculture products or native fauna or flora, the director may order quarantine, confiscation, destruction, or removal from state waters. Except as provided for in subsection (3) of this section, the aquatic farmer has a right to a departmental hearing. In the event the director has ordered emergency action of confiscation, destruction, or removal from state waters, the director shall give notice to the affected aquatic farmer. At the time of notice of emergency action, the affected aquatic farmer may request an emergency departmental hearing. If requested, the hearing will take place no later than the third working day after notice is received by the aquatic farmer. The hearing will be presided over by a hearing officer appointed by the

director, who will consider the severity of the disease outbreak, remedies, and alternate courses of action. The hearing officer shall present a recommendation to the director. The director will then review the emergency action and, if appropriate, order confiscation, destruction, or removal from state waters. If so ordered, the emergency action will take place no sooner than forty-eight hours after service of the order. If no request for an emergency departmental hearing is received, the emergency action of confiscation, destruction, or removal from state waters, may take place immediately after the third working day after the notice is served on the aquatic farmer.

(6) If the department refuses to issue a transport permit, or orders quarantine or isolation of aquaculture products, the aquatic farmer has a right to a hearing under the appropriate legislation procedure.

1.5.6 Aquaculture facility inspection authority.

Authorized department employees shall, at reasonable times and in a reasonable manner, have access to all finfish aquaculture facilities to conduct inspections for the prevention and suppression of aquaculture diseases, including, but not limited to, taking samples for detection of regulated finfish pathogens and other diseases. If the department is denied access, a court of competent jurisdiction may issue a search warrant authorizing access to the facility upon a showing that the facility is engaged in aquaculture production and that access has been denied.

1.6 DEFINITIONS

TERM	DEFINITION
Accredited Fish Health Inspector	A person recognized by the government, as competent and ethical in the conduct of fish health surveillance and monitoring.
Accredited Fish Pathologist	A person recognized by the government as competent and ethical in the conduct of fish health management, surveillance, and monitoring.
Accredited inspector	The individual responsible for conducting monitoring and surveillance of farmed and wild aquatic animals for diseases and pathogens of concern. This person must be an Accredited Veterinarian, an Accredited Fish Health Inspector, or an Accredited Fish Pathologist.
Accredited Veterinarian	A person recognized by government as competent and ethical in the conduct of aquatic animal health management, surveillance, and monitoring for diseases and pathogens of aquatic animals; is licensed to practice veterinary medicine in the government.
Appropriate level of protection (ALOP)	The level of sanitary measures necessary for the protection of human, animal, or plant life determined by a country as appropriate to its needs, as described in the SPS Agreement.
Approved laboratory	A laboratory in a member Office International des Epizooties (OIE) country

	that is approved by the Competent Authorities of that country.
Aquaculture	The rearing of aquatic animals under controlled and managed conditions for one or more of the following purposes: providing food for human consumption; enhancing and supplementing free ranging/wild populations; restoring depleted or endangered aquatic animal species; and providing economic opportunities and development.
Authorized finfish inspector	The individual who conducts or supervises testing in an authorized laboratory and attests to the results obtained. This individual signs/cosigns inspection and diagnostic reports and health certificates. The director shall maintain and provide upon request a roster of authorized finfish inspectors.
Certifying official	The person authorized by the Competent Authorities of a member OIE country to sign health certificates for aquatic animals.
Class A shellfish disease	An infectious disease which can cause significant mortality or loss of condition or quality in affected shellfish.
Class B shellfish disease	An infectious disease which is not known to cause significant mortality or loss of condition or quality in affected shellfish.
Disease	Infection, contagious disease, parasite, or pest, occurring on or within the aquaculture product, or other shellfish or finfish, or on or within the water or substrate associated with the aquaculture product, shellfish, or finfish, or an occurrence of significant mortality suspected of being of an infectious or contagious nature; clinical or non-clinical infection with one or more of the etiological agents of the diseases listed in this plan or in the OIE Code
Diseases notifiable to OIE	The lists of transmissible diseases considered to be of socio-economic and/or public health importance within countries and are significant in the international trade of aquatic animals and aquatic animal products. Reports are made annually to the OIE by member countries concerning the presence or absence of notifiable diseases in those countries, with the exception that OIE is to be notified within 24 hours of the finding of a disease notifiable to OIE if this is the first occurrence in a free country or zone or a re-occurrence in a country or zone in which the disease was thought to have been eradicated.
Diseases of significance	Diseases that are of national or regional significance, including the list of diseases notifiable to the OIE. In addition to the diseases notifiable to the OIE, the United States or a region within the United States may establish its own list of diseases of significance, provided they can demonstrate that the diseases in question are of socio-economic and biological importance to their country/zone, and that a mandatory control program for said diseases does not exist in the respective country/zone.
Emergency exotic pathogen (EEP)	A pathogen not previously known to occur in a zone/region and is known to cause significant economic and biological impacts. An emergency exotic pathogen may be present in a host without clinical disease. Finding of a pathogen in this classification will result in immediate management actions.

Epizootic	The occurrence of a specific disease which can be detected in fifty percent of the mortality or moribund individual fish in an affected container or shellfish on an affected bed or within an affected population, and which results in an average daily mortality of at least one-half of one percent of the affected individual fish for five or more days in any thirty-day period.
Fallowing	The process by which aquatic animal premises are kept vacant for a period of time for the control and management of aquatic animal pathogens.
Finfish	Live fish, fish eggs, or fish gametes, but not to include aquaria species commonly sold in the pet store trade when raised in containers that do not discharge to the water[s] of the state, indigenous marine baitfish, or mosquito fish.
Free aquaculture establishment	An aquaculture facility that fulfills the requirements for recognition as free of the specified pathogens of significance as specified by this technical working document and recognized as such by the Competent Authorities.
Free country	A country that fulfills the requirements for recognition as free of the specified diseases/pathogens of significance as specified by regulation.
Free zone	A zone that fulfills the requirements for recognition as free from the specified diseases/pathogens of significance as determined by regulation.
Health certificate	The official document signed by a certifying official attesting to the health and pathogen status of aquatic animals.
Incidence	The number of new outbreaks of disease within a specified period in a defined aquatic animal population.
Infected zone	A clearly defined zone in which a disease/pathogen of significance has been diagnosed. This area must be clearly defined (as per this consultation) according to the area's physical dimensions and boundaries, the different ecological and environmental factors involved, and the epidemiological factors.
Inspection	The procedure conducted by or under the direct supervision of an accredited inspector in order to determine the status of aquatic animals with regard to diseases or pathogens considered in this plan. The inspection may include a clinical examination, laboratory tests, and the application of procedures that could reveal the presence of infection in the population.
Kelp	Any species of brown algae of the order Laminariales.
Laboratory inspection report	The written results of testing conducted by an authorized finfish inspector.
Lot	A group of aquatic animals of the same species in one aquaculture establishment. The group must have originated from the same spawning population, and must have always shared the same water supply.
Lot of fish	a group of fish of the same species and age that originated from the same

	spawning stock and share a common water supply.
Marine plant	Nonvascular plants belonging to the phlya Chlorophyta, Phaeophyta, or Rhodophyta and vascular plants belonging to the family Zosteraceae when growing in marine or estuarine waters, and includes the seeds, spores, or any life-history phase of the plants.
Market ready shellfish	Aquatic invertebrate species, which are intended for immediate human consumption and will not be placed into or come in contact with state waters.
Notifiable pathogens (NP)	The pathogens that cause diseases of aquatic animals that are considered to be of economic and/or biological importance within regions, and that are significant in the international trade of aquatic animals and aquatic animal products. A notifiable pathogen may be present in a host without clinical disease.
Notification	The procedure by which the Competent Authorities, State, tribal, and other appropriate regulatory authorities are informed of the finding of a notifiable pathogen.
OIE Code	The most current edition of the International Aquatic Animal Health Code of the Office International des Epizooties.
OIE Diagnostic Manual	The most current edition of the Diagnostic Manual for Aquatic Animals of the OIE.
Pathogens of regional significance	The causative infectious agents of diseases of significance listed in this plan or designated as such for a zone within the United States. A specified pathogen of regional significance may be present in a host without clinical disease.
Pest	Parasite, parasitoid, predator, or fouling agent.
Population	A group of aquatic animals of the same species residing together within the same zone. The group must have a similar history of exposure to diseases/pathogens of significance.
Prevalence	The total number of infected aquatic animals expressed as a percentage of the total number of aquatic animals in a lot or population at one specific time.
Quarantine	Maintaining aquatic animals in containment to prevent exposure of the aquatic animals or effluent from the containers to other animals or the environment; Isolation of the organism in a department approved facility.
Reference laboratory	A laboratory identified by the competent authorities of the government or OIE as capable of conducting tests confirming the identity of a specific pathogen.
Regulated finfish pathogens	The pathogens which, upon initial detection that has been pathogen-free for three or more years, require immediate notification to the authorities who will, in turn, notify the state veterinarian of the detection:

Risk Assessment	The process of identifying and estimating the risks associated with the movement of aquatic animals or aquatic animal products and evaluating the consequences of taking those risks.
Risk	The probability of an adverse event occurring that involves aquatic animal health or public health, or is of economic importance (such as a disease outbreak), and the magnitude of the event or harm that would result.
Shellfish	All aquatic invertebrates except insects.
Specific Pathogen-Free Water (SPF Water)	Well, spring, or treated water demonstrated to be free of pathogens of significance diseases notifiable to the OIE.
SPS agreement	The Agreement on the Application of Sanitary and Phytosanitary Measures, WTO.
Surveillance	A systematic series of investigations of a given population of aquatic animals to detect the occurrence of disease or pathogens for control purposes, and which may involve testing tissues or fluids from aquatic animals in the population.
Suspect	A susceptible aquatic animal population or individual animal, or the parents of the aquatic animal in question, that have been exposed to a notifiable pathogen due to the presence of the infectious agent in cohorts, or via horizontal exposure due to the presence of the disease/pathogen in other aquatic animal populations or vectors within the zone.
Terminal quarantine facility	A department-approved quarantine facility where imported aquatic invertebrates are held for public display or research purposes only, with minimal risk that the organisms will be released or that untreated quarantine facility holding waters will commingle with state waters. The operation plan of the quarantine facility must be approved by the department prior to the introduction of any organisms. At the conclusion of the public display or research, the organisms held in quarantine shall be destroyed and all waters and waste disinfected and disposed of using methods approved by the department
Transfer	Any movement of aquatic animals or their larvae, eggs, or gametes between or within a zone, including any movements between culture facilities, watersheds, or designated zones.
Watershed	Geographically distinct river basins that have separate entrances to marine and/or estuarine areas. A watershed may include one or more primary river systems.
Zone	A portion of one or more countries comprising an entire catchment area from the source of a waterway to the estuary, more than one catchment area, part of a catchment area from the source of a waterway to a barrier, or a part of coastal area, or an estuary with a precise geographical delimitation that consists of a homologous hydrological system.
Zoning	Identifying zones for disease control purposes.

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<u>Web-based Resources</u>

- http://aquanic.org/publicat/state/il-in/as-503.htm Fish Farmer's Guide to Understanding Water Quality
- http://rfdp.seafdec.org.ph/publication/manual/

- http://www.enaca.org/modules/mydownloads/singlefile.php. The Asia Diagnostic Guide to Aquatic Animal Diseases or ‘Asia Diagnostic Guide'
- http://www.enaca.org/NACA-Publications/Manual-of-Procedures.pdf
- http://www.fao.org/DOCREP/005/X8485E/x8485e06.htm The "Beijing Consensus and Implementation Strategy"
- http://www.oie.int/eng/normes/fcode/A_summry.htm Aquatic Animal Health Code (2006)
- http://www.oie.int/eng/normes/fcode/en_chapitre_1.1.1.htm
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- http://fdcc.nfrda.re.kr (in Korean)
- http://china-fisheries.net (in Chinese)
- http://www.chinafish.net (in Chinese)
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2 TECHNICAL GUIDELINES FOR THE DEVELOPMENT OF A TRAINING COURSE IN MARICULTURE TECHNIQUES: Towards Sustainability

2.1 INTRODUCTION

Aquaculture industry in the Yellow Sea and all other regions is facing with more problems today than ever before. Issues like **diseases**, **low productivity and environmental pollution** are acknowledged impediments for sustainable development of aquaculture. Environmental protection and remediation is the most effective way to resolve this problem. **Policymaking and enforcement** are also important in keeping the industry on the right track. The blind development of aquaculture is sometimes the result of shortage of guidelines. Therefore, guidelines should be carefully prepared and propagated through the proper education and extension system.

With the aid of a comprehensive policy framework, aquaculture can be safely managed to ensure sustainable and productive future. The international cooperation can catalyze sustainable development in the sector by providing a cohesive, integrated and coordinated response in the regional sectors. The first is the education and training in this response for the sustainable development of aquaculture industry. Study on carrying capacity, environment remediation and polyculture techniques have all contributed to enhance productivity, as well as protect the environment. Although **Technology improvement** of each individual cultivar species is vital for aquaculture; however, listing up wide variety of aquaculture procedures and methods are beyond the scope of this manual.

Other factors that support a sustainable aquaculture include the establishment of easily accessible **information system**, and **public awareness** of the importance of harmonized development of economy, social culture and the environment.

Further investments in education and training are essential to build the knowledge, skills and attitude towards sustainable aquaculture. We need paradigm shift from the conventional aquaculture practice to the systematic aquaculture under the ecosystem based aquaculture management, which is only possible through education and training of all people involved in the sector.

Human capacity development can be made more cost-effective and responsive to needs through: using participatory approaches to curriculum development; improving co-operation and networking between agencies and institutions; multidisciplinary and problem-based approaches to learning; and use of modern training, education and communication tools, such as the internet and distance learning, to promote regional and inter-regional co-operation and networking in the development of curricula, exchange of experiences and development of supporting knowledge bases and resource materials; and providing a balance of practical and theoretical approaches to train farmers and provide more skilful and innovative staff to industry.

It is recognized that the industry is in a dynamic phase, with research and development leading to a better understanding of what constitutes best practice from a commercial production as well as an environmental performance standpoint. However, the provisions put forward in the sustainable development represent what is considered current best practice and provide a minimum performance benchmark. Industry is encouraged to make improvements on the environmental performance set out in the sustainable aquaculture development. When there are significant advances in best practice, the aquaculture development will be reviewed to reflect those advances. To achieve the sustainability of the future aquaculture industry, the environmental concern is moved to foremost in the near future. Therefore, the current culture system in the coastal area could not persist. We need to develop a different paradigm for the coastal aquaculture industry. In the coastal waters, the seaweed-integrated aquaculture and polyculture could be the only possible way and the concept of polyculture should be applied to all aquaculture practices. Some self-pollution producing fed aquaculture should move to offshore area. The only left choice is land-based aquaculture system which should not discharge effluent with closed recirculation system.

In this manual the general concept of three culture methods, polyculture, Recirculating Aquaculture Tank Production Systems and offshore culture, which are leading to the sustainability of the aquaculture is considered. The individual cultivar culture methods and specific apparatus are not presented in detail. The mission of this manual is to establish a firm faith in the support of the sustainable aquaculture to the participants. With this determined will, the mentors educate and develop a highly skilled workforce, through practical education and training, that will support competitive and sustainable aquaculture industries. Education and training programs may include intensive courses, customized training, field trips, and teacher workshops.

2.2 CONVENTIONAL METHODS APPLIED IN YS REGION OF CHINA AND KOREA: BRIEF REVIEW OF CURRENT GENERAL AQUACULTURE METHODS OF MARINE FARMED ORGANISMS

2.2.1 Pump Ashore/Land-based Culture

Land-based marine aquaculture systems have several advantages. Technology is rapidly advancing in this field and the cost of equipment, such as chillers and pumps, is decreasing. A land-based system allows the water quality to be controlled more easily via filtration. The weather has a lesser impact on land-based systems and animals than on those exposed to the elements like offshore cage culture. Compared to net pen systems, land-based systems can diminish the risk of disease introduction to the natural waterways. Finally, there is little to no effluent produced in a recirculations system, which is especially important to maintain the integrity of the natural environment. However, there are several drawbacks for pump ashore systems. Coastal land is expensive. Energy costs are high to run pumps, motors, chillers, heaters, etc. If a facility is located further inland there are higher costs associated with pumping the water further. There are also high overhead, labor, and capital costs associated with this type of system. Despite the obstacles, there have been successes and opportunities to develop land-based culture systems. Onshore tank farms in Tasmania and South Korea have had success growing flatfish; however salmonid onshore tank farm production has not been profitable. [1]

2.2.2 Submerged Line Culture

Submerged line culture is often the preferred method for culturing bivalve species such as mussels and oysters. Some aquaculturists describe the greatest advance in oyster culture has been to move the oysters off the bottom so sediment will not impact their ability to filter feed. Oyster culture is often performed using longline, rack, and tube culture methods. The advantage of submerged line culture is that the animals are suspended in the water column and are able to obtain food

1 http://hmsc.oregonstate.edu/projects/msap/system.html#Anchor-47857

(plankton) more easily. In addition, submerged line has advantages over on-bottom culture since siltation and exposure to benthic animals is reduced. (Photo by James P. McVey)

2.2.3 Net Pen Culture

Net pens are often used for many finfish culture. There is increasing interest to convert net pens from salmon culture to other finfish culture.

Finding a suitable and permittable site to use net pens is one of the major limitations for net pen culture. In addition, environmental and economic concerns associated with net pens have fostered research into alternative technologies and systems.

2.2.4 Challenges for Developing Aquaculture Systems

It is often expensive to find solutions to technical problems associated with marine aquaculture. There are often high costs associated with initial investment of equipment and labor followed by high costs for feed and continuous maintenance.

The high costs associated with aquaculture systems has forced the industry to explore cost-cutting technology. For example, researchers are interested in collaborating with organizations that create waste heat (e.g. power plants and natural gas companies) to reduce the cost of heating water via electricity.

Through both lecture and hands-on laboratory sessions, participants will learn about:

- Fish production systems (ponds, flow-through, net pens, and recirculating aquaculture technology) commercially used throughout the world
- Various components and functions of fresh and salt water recirculating aquaculture systems
- Integration of hydroponics and recirculating aquaculture systems
- Interdependence of food science, horticulture and fishery biology in aquaculture
- Nutrition of various fish (herbivores, omnivores, and carnivores)
- Characteristics and management of solid and liquid wastes
- Issues associated with the discharge of wastewaters into public receiving waters
- Treatment of sick fish
- Recognizing the early stages of disease
- Sampling skin and gill tissue
- Performing a necropsy

2.3 Sustainable Mariculture techniques

2.3.1 Polyculture (Modified from G. LUTZ)

Goal and concept

The underlying goal of polyculture involves increasing productivity by more efficiently utilizing ecological resources within an aquatic environment. This type of aquaculture is accomplished (or attempted) by stocking species with different feeding habits and different habitat preferences (say, benthic vs pelagic). Stocking two or more complementary species can increase the maximum standing crop of a pond by allowing a wider range of available foods and pond volume to be utilized.

The concept of polyculture is by no means new. Chinese aquaculturists have been combining complementary species of carps and other species in production ponds for centuries. One of the earliest descriptions of this practice from the “modern” times can be found in Lin’s (1940) account of “Fish Culture in Ponds in the New Territories of Hong Kong.”

Currently a great deal of emphasis is placed on responsible marine aquaculture practices worldwide. One concept that is currently being examined is polyculture or integrated aquaculture. This is the idea of growing finfish, shellfish and marine plants together for the benefit of all crops and the environment.

Principles

In some situations, aquatic species that might be expected to occupy different ecological niches within a pond actually end up competing for resources. To make the most of polyculture, a grower needs to ascertain and maintain some optimal balance between the different species present, in order to maximize harvestable production. This often requires some trial and error, as well as some fine tuning for site-specific conditions: additional production is of little use if it does not represent a marketable product.

In traditional forms of polyculture, waste products of primary species and the natural productivity they foster provide the basis for production of supplemental species. In recent years, polyculture has begun to regain attention as a possible means to increase efficiency in aquaculture production systems, and to reduce environmental impacts caused by excess nutrients.

The polyculture technique is based on nutrient recycling which combines, in the right proportions, the cultivation of salmon (fed aquaculture) with that of mussel (organic extractive aquaculture) and kelp (inorganic extractive) aquaculture for a balanced ecosystem management approach. This approach takes into consideration the operational limits within the farm tenure, as well as food safety guidelines and regulations. Mussels are filter feeders and are used to extract the fine particulate wastes from fish cages, like the nutrient-rich food pellets that are not consumed by the fish, while the macro algae absorb dissolved inorganic waste created by the fish farm.

Polyculture is an approach that uses the mussels and kelp to recycle the nutrients and can lead to "greener" aquaculture practices through the reduction in waste products in the marine environment and possible sedimentation on the ocean floor. Additional benefits also include a decreased risk of algal blooms and cloudy water. The culture of various species could also lead to economic gains for fish farmers.

Their internationally acclaimed research has focused on growing various organisms from different levels in the food chain (i.e. kelp, a form of seaweed, and blue mussels) alongside Atlantic salmon sea cages. The theory is that the growing of multiple species will provide a more balanced ecosystem approach and a more economically efficient industry.

Practices

Most polyculture systems developed to date involve freshwater fishes. While combinations of carp have been popular in Chinese polyculture for hundreds of years, many other freshwater finfish lend themselves to this practice, and polyculture is nothing new in countries such as India and Israel. Over 40 years ago, Yashouv (1958) described how the addition of supplemental tilapia to carp ponds in Israel resulted in augmented production. The previous year, Pruginin and Kitai (1957) described the use of mullet as a complementary species to boost yields from Israeli carp ponds.

Alikhuni (1957) described polyculture of the Indian carps Catla catla ("Catla," a plankton feeder), Labeo rohita ("Rohu," an omnivore), and Cirrhina mrigala ("Mrigal," also an omnivore). Typical stocking rates at that time were roughly 1,000 fish of each species per acre, although commercial growers tended to stock a slightly higher portion of Cirrhina. While this stocking rate might have seemed high at the time for fish producers in North America or Europe, Lin (1940) described one fish culture pond in Hong Kong that yielded 'fairly satisfactory' harvests at a combined stocking rate of well over 12,000 fish per acre.

In recent times, Chinese scientists have applied modern analyses to evaluate various polyculture combinations and practices in their country. A province-by-province study by Chen et al. (1995) indicated that the traditional Chinese classification of provinces into high-, medium- and low-productivity regions is supported by production data. A key difference emerged between productivity classifications, related to stocking combinations: filter-feeding fish dominated polyculture stocking schemes in low-output areas, while active feeders such as grass, black and common carp dominated high-output ponds. Indeed, studies by Yang et al. (1994) indicated that on average, the production of 100 kg of grass carp results in production of an additional 19 kg of filter feeding fish and 15 kg of omnivorous fish.

Synergism is often seen in polyculture systems. That is, some species actually perform better in the presence of other species. Freshwater prawns are a good example. When certain fish species (those that do not have a particular appetite for prawns, such as tilapia [Martino and Wilson 1986]) are stocked with M. rosenbergii, their feces serve as a substrate for bacterial growth, which in turns provides additional nourishment for the prawns. Cohen and Ra'anan (1983) and Wohlfarth et al. (1985) reported in two separate studies that when stocked with tilapia and various Chinese carps, prawn growth and survival were influenced only by stocking rate, not by the species of fish co-stocked with them, nor by fish stocking rates or feeding regimes.

Polyculture is not just a freshwater concept, and it can incorporate many species besides just finfish. Joseph (1980) reported on mixed culture of milkfish, mullets, and two species of marine shrimp (P. indicus and P. monodon) in coastal ponds. Total production of 2986 kg per ha per year resulted from a single stocking/multiple harvesting management scheme. Hu et al. (1995) described mixed culture of shrimp and oysters in shrimp ponds in China. Compared with typical monoculture practices, shrimp yields improved by 30%, while oyster meat yields were increased by 20.3%.

Brackishwater polyculture has been practiced for many years in Hawaii, and was probably an important management strategy for ancient Hawaiian fishponds. Wyban (1982) described a “modern” approach to brackishwater polyculture in Hawaii involving the combined stocking of mullet, milkfish, aholehole, red tilapia, samoan crab, and threadfin. Bwathondi (1985) discussed the potential for combined rabbitfish and oyster culture in floating cages in Tanzania. Ekenam (1983) proposed innovative polyculture schemes to utilize native clams and water snails in Nigeria.

Occasionally, polyculture allows for behavioral characteristics of certain species to be used (or mitigated). In a very interesting set of studies, Nortvedt and Holm (1990, 1991) reported on “duoculture” of Atlantic salmon and Arctic charr. Given a certain salmon density, addition of charr increased the mean salmon size significantly. The mechanism for this improvement proposed by the authors was decreased aggression between Atlantic salmon, as a result of interference due to the presence of charr, reducing the number of salmon:salmon aggressive interactions.

<u>Problems</u>

One problem with polyculture wherever labor costs are relatively high involves handling and sorting species at harvest. Unless species are physically separated, say, in floating cages, this will always be a problem.

Another problem with polyculture involves overlap of food or habitat preferences among species, or even downright antagonism. Brummett and Alon (1994) indicated that although growth of redclaw crayfish was not adversely affected by the presence of tilapia in polyculture, tilapia growth, reproduction, and food conversion were significantly impacted by redclaw.

Perhaps the biggest problem facing the expansion of polyculture in modern aquaculture involves acceptance by producers and consumers. Many of the species that have lent themselves to polyculture systems up to now are not considered “high- value” among consumers in the more lucrative Western markets. Additionally, in many cases the best candidate species for a polyculture system may not be native to the area in question, resulting in reduced consumer acceptance, not to mention regulatory and legal issues.

Fish farmers are often not willing or prepared to adopt polyculture. Ghosh et al. (1993) reviewed the knowledge and application of polyculture by fish farmers in West Bengal. They found that the majority of producers did not fully understand the principles or potential of polyculture, and that those who did apply the technology often did so only to a limited extent. In a previous study in the same area, Bhaumik et al. (1992) indicated that although up to 61% of fish producers practiced some form of polyculture, only 11% appeared to have adopted recommendations relating to stocking combinations and management practices.

Promise

Species combinations for polyculture are sometimes developed with the intent of improving water quality. The use of filter feeding and bottom feeding carps has provided this benefit in Chinese polyculture ponds for centuries, but in recent times other approaches have also been evaluated, including bivalve culture.

As early as 1968, Swingle reported on the use of the freshwater mussel Lampsilis to improve water quality in bass/ bluegill sportfishing ponds. In 1991, Shpigel and Blaylock reported that production of Pacific oysters in effluents from a marine fish culture pond reduced nutrient levels sufficiently to allow for a 50% water re-use rate. Lin et al. (1992) estimated that production of 2000 kg of mussels in effluent from an intensive shrimp culture pond system resulted in removal of approximately 2116 kg of solid organic matter from the effluents, allowing the re-use of effluents for shrimp production. In 1993, Hopkins et al. illustrated the potential for oysters and clams to improve water quality in shrimp production ponds.

Polyculture is not just about more production. It's also often about more profits. Polyculture is often of greatest benefit in extensive or moderately-intensive fish production. For the same reasons, it may be difficult to adapt to modern industrial-scale fish and shellfish farming. But, just as economics, regulatory policies, and social consciousness will eventually force the adoption of more fuel-efficient vehicles, aquaculture will be faced with similar pressures to improve efficiency and reduce environmental impacts in the coming decades. Polyculture, with its natural emphasis on increased utilization of water and nutrients, will almost certainly play an important role in this process.

Current status of polyculture in the YS LME region

Specialists from both countries are well aware of the importance of the polyculture. The Weihai fisheries officials strongly recommend the seaweed aquaculture should be increased up to 70% of the cultured area basis to get the sustainable development of the Weihai area. The east coast of China in the YS LME area, the authorities recommend to increase seaweed culture with other fed culture. In the west coast of Korea, they already have some guidelines for the polyculture, the practical activities are not popular and the scale is not prominent. The difference of this may be caused by the geographical and hydrographical difference in the coastal region and cultured species.

Although, the current situations of both sides are different, the concept of polyculture should be applied to get the sustainability of the aquaculture industry. Otherwise, the aquaculture industry should be transferred to the offshore or changed to the intensive land based closed circulation aquaculture system.

In the future, the system "polyculture (integrated) aquaculture" should be encouraged and given the highest priority especially among the culture systems of intensive culture of marine fish in raceways, semi-intensive culture of marine fish in ponds, shrimp culture in ponds (Neori et al., 2004).

In Korea, the National Fisheries Research & Development Institute (NFRDI) has already established guidelines for polyculture (Chung et al., 2002). Examples of existing polyculture systems include the sea squirt (Halocynthia roretzi) and Undaria pinnatifida or Laminaria japonica for the southeastern coastal area; abalone (Haliotis discus hannai) and Laminaria japonica or Hizikia fusiformis (actually now considered a species of Sargassum) in the midwestern coastal area; short-necked clams (Ruditapes philippinarum) or surf clams (Mactra veneriformis) and Porphyra tenera for the southwestern coastal area; and oyster (Crassostrea gigas) and sea squirt (Halocynthia roretzi) or blue mussels (Mytilus edulis) for the southern coastal area.

Seaweed-integrated aquaculture systems have been proposed as a means to develop environmentally sound aquaculture practices and resource management through a balanced coastal ecosystem approach (Chopin et al., 2001). Adding seaweed-integrated aquaculture into polyculture systems might have economic value as well (Jones at al., 2001). In Korea, the principal candidate macroalgal genera for aquaculture are Porphyra, Laminaria, and Undaria. Thus, the selection of seaweed species for seaweed-integrated aquaculture systems must take into consideration both their economic value and their capacity for bioremediation of nutrient-rich effluent.

2.3.2 Recirculating tank production system

To facilitate sustainable aquaculture in the region through: (a) reinforcing within the aquaculture industry the need for a commitment to environmental sustainable practices and a duty of care for the environment in which the industry is located; (b) ensuring environmental factors are considered in site selection for the optimum siting of new aquaculture enterprises; (c) ensuring environmental factors are considered in the planning, design and operation of all aquaculture enterprises.

The purpose of the recirculating aquaculture tank production system is to promote economically and environmentally sustainable land-based aquaculture by providing guidance for responsible aquaculture practices. Land based aquaculture facilities for ponds, tanks, hatcheries, raceways, farm dams and fishouts may include facilities for:

- holding, breeding, harvesting and purging of stock
- associated facilities for the preparation or storage of feed
- processing, manufacturing, packaging or distribution of products
- administration, laboratory, storage and maintenance facilties
- waste management
- water extraction, storage, reticulation and recirculation systems
- transport facilities including access
- any related tourist or fishout activities.

Recirculating systems for holding and growing fish have been used by fisheries researchers for more than three decades. Attempts to advance these systems to commercial scale food fish production have increased dramatically in the last decade. The renewed interest in recirculating systems is due to their perceived advantages, including: greatly reduced land and water requirements; a high degree of environmental control allowing year-round growth at optimum rates; and the feasibility of locating in close proximity to prime markets.

Recirculation systems are becoming increasingly popular as they provide a predictable and constant environment for growing fish. Recirculation systems also occupy very little area and require little water consumption compared to other forms of aquaculture. Recirculation systems can be expensive to purchase and operate. For this reason it is usually only economically viable to farm high value species in these systems. Cost of production is generally lower for larger producing systems. The principal behind recirculation systems is relatively simple however it is important to note that their construction involves some level of technical expertise if they are to succeed. When selecting a supplier or consultant, a potential grower should check their track record for the construction of the recirculation system, after sales service in technical and husbandry advice and ensure that the system will produce the tonnage of fish that has been originally specified by the supplier.

Unfortunately, many commercial systems, to date, have failed because of poor design, inferior management, or flawed economics. This publication will address the problems of managing a recirculating aquaculture system so that those contemplating investment can make informed decisions.

Circulating water in ponds is an effective tool in destratification that improves oxygen levels throughout the pond and increases microbial oxidation of organic matter. Pond recirculation system technology is relatively new with many potential designs. Key to the systems is mechanical water circulation (pumps, aerators, or circulators) within a pond or pond/raceway combination.

Several potential advantages include:

- reduced water use and production effluent
- improved water quality
- easier accessibility to fish from raceways
- increase in species diversity
- increased sustainability

Several possible **disadvantages** of these systems include:

- need to pump or mechanically move water
- higher fish production costs compared to open pond culture due to increased pumping costs
- unproven economic feasibility in some cases

Recirculating pond systems will continue to develop in the future as water reuse becomes more important. Despite the positive impact on water quality, there has been little research to show that pond recirculating systems have significantly greater fish production over traditional open pond aquaculture.

Specific design criteria will vary depending on individual site, production objectives, and regulatory requirements. Farmers should carefully consider the costs and benefits prior to developing a pond recirculating system.

The followings provide the reader with a brief outline of recirculation systems and their management. (http://www.pir.sa.gov.au/factsheets)

The principle behind recirculation

Recirculation systems occupy a very small area and allow the grower to stock fish at high densities and produce high yields per unit area. Recirculation systems are very intensive and therefore require a high level in management of stock, equipment and water quality. Thus it is important to have an understanding of the principles of recirculation systems if the system is to be managed effectively.

A recirculation system is essentially a closed system and involves fish tanks and filtration and water treatment systems. The fish are housed within tanks and the water is exchanged continuously to guarantee optimum growing conditions. Water is pumped into the tanks, through biological and mechanical filtration systems and then returned into the tanks. Not all water is 100% exchanged however as it is difficult to ensure that all waste products are converted or removed by the treatment process. Most culture systems recommend at least 5% to 10% water exchange rate per day depending on stocking and feeding rates.

The followings are brief summaries of the recirculating system which have been distributed through the Southern Regional Aquaculture Center

- Losordo et al. (1998) Recirculating Aquaculture Tank Production Systems: An Overview of Critical Considerations (SRAC Publication No. 451)
- Masser et al. (1999) Recirculating Aquaculture Tank Production Systems: Management of Recirculating Systems (SRAC Publication No. 452)
- Losordo et al. (1999) Recirculating Aquaculture Tank Production Systems: A Review of Component Options (SRAC Publication No. 453)
- Rakocy et al. (1992) Recirculating Aquaculture Tank Production Systems: Integrating Fish and Plant Culture (SRAC Publication No. 454)
- Lazur and Britt (1997) Pond Recirculating Production Systems (SRAC Publication No. 455)

Recirculating systems have developed to the point that they are being used for research, for ornamental/tropical fish culture, for maturing and staging brood fish, for producing advanced fry/fingerlings, and for producing food fish for high dollar niche markets. They continue to be expensive ventures which are as much art as science, particularly when it comes to management. Do your homework before deciding to invest in a recirculating system. Investigate the efficiency, compatibility and maintenance requirements of the components. Estimate the costs of building and operating the system and of marketing the fish without any return on investment for at least 2 years. Know the species you intend to grow, their environmental requirements, diseases most common in their culture, and how those diseases are treated. Know your potential markets and how the fish need to be prepared for that market. Be realistic about the money, time and effort you are willing to invest while you are in the learning curve of managing a recirculating system.

The above publications have outlined the major components and options used in recirculating aquaculture production systems. These are by no means complete listings, new technologies are continually being developed. One should not attempt to simply link the components discussed here and expect to have a properly operating system. Any system you buy should be the result of years of development, with each component properly sized and integrated for optimal performance. When reviewing your options, always seek the assistance of a knowledgeable, experienced person, one who has designed a currently operating and economically viable recirculating fish production system.

Finally, design the system with an emergency aeration system, backup power sources, and backup system components. Monitor water quality daily and maintain it within optimum ranges. Exclude diseases at stocking. Perform routine diagnostic checks and be prepared to treat diseases. Reduce stress whenever and however possible. STAY ALERT!

The above publications have outlined the major components and options used in recirculating aquaculture production systems. These are by no means a complete listings, new technologies are continually being developed. One should not attempt to simply link the components discussed here and expect to have a properly operating system. Any system you buy should be the result of years of development, with each component properly sized and integrated for optimal performance. When reviewing your options, always seek the assistance of a knowledgeable, experienced person, one who has designed a currently operating and economically viable recirculating fish production system.

2.3.3 Offshore aquaculture

The future of aquaculture will likely be the development of large complexes of submerged net cages, anchored to the seafloor in deeper, offshore waters. Whether these ventures succeed in becoming sustainable depends, as with near-shore aquaculture, on the type of fish being farmed and how they are farmed.

Case study and pilot scale farms of the University of New Hampshire

Project Goal

The overall goal of the project is to stimulate the further development of commercial aquaculture in New England, thereby increasing seafood production, creating new employment opportunities, and contributing to economic and community development. For the reasons given above, several faculty members at the University of New Hampshire, all of whom had extensive experience in aquaculture research, sought to further develop aquaculture in New England. To accomplish this goal, significant biological, technical and socio-economic issues needed to be resolved before aquaculture could become part of the solution to our fisheries crisis. Among the most significant of these issues was siting an aquaculture industry in New England. Because our inshore coastal waters are already heavily used for recreation, commercial fishing, and shipping, it was assumed that at least some aquaculture activities would need to take place in offshore areas where there would be fewer conflicts with existing user groups. The high energy (winds and waves) of such exposed locations present significant technical challenges in the design, testing and construction of aquaculture systems that are capable of surviving in these areas. In addition to these technical challenges, there are many biological, regulatory, social and economic problems to be solved.

The ocean beyond nearshore waters has long beckoned as a next area to be used for cultivation. One of the most frequently mentioned options for expansion of the mariculture industry is to move offshore into more open waters. Offshore mariculture presents a unique opportunity for sustainability

If such facilities are placed in offshore waters where circulation is excellent, and if the facilities are properly sized, no significant negative impact on local environmental conditions should occur. Thus offshore mariculture represents a next logical step in the development of the industry.

Careful attention to the density of offshore mariculture facilities within a given locale will ensure that the sustainability of the activity is maintained.

Advantages of offshore mariculture systems

Coastal regions throughout much of the world are becoming increasingly polluted. Mariculture facilities located in nearshore waters can be subjected to such pollutants as detergents, sewage, food-processing wastes, thermal effluents, trace metals, pesticides, and oil spills. Self-pollution – that is, the pollution of water used in mariculture by the wastes from the culture operation or those adjacent to it – has become a problem in some locations. The development of offshore mariculture facilities could alleviate many of the institutional, regulatory and environmental problems associated with coastal marine mariculture. Moving mariculture to offshore locations would avoid impacting the more environmentally sensitive nearshore areas of the coastal zone. And there might even be some benefits in terms of improved product quality

Offshore Aquaculture

In recent years, as more questions have been raised about the sustainability of some forms of coastal fish farming, the aquaculture industry and government agencies in the United States and elsewhere have begun looking to develop aquaculture operations in open ocean waters, including exposed state waters and those of the Exclusive Economic Zone (EEZ), a region of federal waters from the state boundary (usually 3 miles) out to 200 nautical miles offshore. In the United States, no regulatory regime exists for aquaculture in the EEZ and there is much confusion about the permitting, site selection, monitoring, and impacts of offshore aquaculture.

The Problem

Depending on how it's done and what species are farmed, offshore aquaculture development has the potential to cause many of the same problems as have been caused by some forms of nearshore aquaculture development. These include:

- Pollution from wastes such as particulate matter from fecal material and uneaten food, nutrients, and chemicals and drugs, such as pesticides, disinfectants, and antibiotics.
- Negative impacts on wild populations of fish through escapes of farmed fish and transfer of disease and parasites, as well as negative impacts on other wildlife through entanglements and harassment.
- Dependence on wild fisheries for feed inputs.
- Privatization of the oceans and negative interactions with other stakeholders.

The Causes

Offshore aquaculture operations are largely following the same model as nearshore fish farming, one of open feedlot style net-pen or cage systems. In this type of aquaculture there is no effective barrier between the farmed fish and the natural environment. As a result, waste materials are discharged directly into the surrounding environment and there is potential for escapes of farmed fish as well as negative interactions with wild populations of fish and other wildlife. Farming carnivorous species of fish can result in a net loss of fish protein since they require a protein-rich, high-energy diet. Commercially prepared feeds are given to these farmed fish, with much of the protein coming from fishmeal and much of the fat coming from fish oil, both obtained from wild fish, such as anchovy, sardine, and mackerel. To produce one ton of farmed carnivorous fish requires several tons of wild fish for feed. Offshore aquaculture will involve the leasing of sections of the oceans - a public resource - to individuals or corporations, as has happened with offshore oil and gas development. This could potentially lead to further erosion of the public trust in ocean resources and result in conflicts with other stakeholder groups, such as fishers, recreational boaters, and shipping traffic.

The Context

Under its marine aquaculture initiative, the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) has set targets of $5 billion worth of aquaculture production, 600,000 jobs, and $2.5 billion in goods and services by the year 2025. Much of the increased production is expected to come from offshore aquaculture, which has been touted by NOAA as having the potential to provide many benefits, including: stabilization of the trade deficit, creation of employment and economic development, and reduction of pressure on wild fish populations. The effect of offshore aquaculture development on coastal communities has not been researched, leading to questions about the government's claims of aquaculture as a jobs creator, especially since it will likely be a highly automated industry. In fact, in some areas with salmon farming, while production has increased greatly, employment actually has declined. There is also fear that an offshore aquaculture industry could have negative impacts on traditional commercial fisheries and the local communities they support.

NOAA has been drafting legislation to promote the development of offshore aquaculture. Among other things, the proposed National Offshore Aquaculture Act will provide streamlined permitting, long-term leases for offshore aquaculture development, and exemption from the Magnuson-Stevens Act, which will allow for foreign investment and leasing of U.S. waters as well as a weakening of fisheries management protections. Congressional introduction of the legislation, which has had little public input, is expected in 2004. Offshore finfish aquaculture operations most likely will include moored, surface operated systems with semi-submersible and fully submersible cages that are anchored to the bottom, but are accessible from the surface. Offshore farming of shellfish with rafts and longlines has not received much attention from government or industry, though it is potentially more environmentally friendly than raising carnivorous finfish. In the United States, there are currently no commercial aquaculture operations in the EEZ, though several small-scale research projects are investigating the feasibility of offshore aquaculture. Government and industry research collaborations are developing the technology needed for the industry to expand to open ocean areas including off the coast of the Northeast U.S and the Gulf of Mexico. Commercial facilities are currently in operation off the coast of Hawaii and Puerto Rico, though neither is located in federal waters. Industry advocates have promoted offshore aquaculture as a solution to environmental problems in and of itself and claim that strong currents in offshore waters could help dilute pollution. Other than a few studies on small-scale or pilot sites, however, very little research has been conducted on the environmental impacts of offshore aquaculture and little is known about the possible impacts from large-scale commercial facilities.

Recommendations

Given the lack of understanding of the potential environmental, social, and economic impacts, a precautionary approach is an appropriate guiding principle for future decisions regarding offshore aquaculture. Many issues should be addressed before offshore aquaculture proceeds, including: discharge of wastes, the amount of wildcaught fish used in feeds for farmed fish, escapement of farmed fish, disease transfer, use of non-native species, marine mammal conflicts, habitat loss, use of chemicals, and conflicts with other uses.

With the potential for expanded development of the EEZ, public participation in policy and regulatory decision making is needed to ensure that environmental, social, and economic impacts are adequately addressed in an open and transparent manner. Comprehensive public input is critical to developing a strong policy and regulatory framework for offshore aquaculture.

Case study of the Sea Grant Gulf of Mexico Offshore Aquaculture Consortium (OAC)

The Route to the Development of Socially, Economically and Environmentally Sustainable Offshore Aquaculture

The OAC Aquaculture Cage, moored 25 miles off the Mississippi coast, experiences numerous environmental conditions not usually found in other locations around the world, including exposure to wind and wave action from all directions, short/steep wave patterns, strong currents, seasonal anoxic conditions at depth, and periodic presence of a nepheloid layer. These unique environmental conditions have challenged the OAC to develop operational procedures to address these issues throughout its research efforts.[2]

Open-ocean aquaculture differs from its coastal water counterparts in many ways. One of the more significant factors is remoteness and the need for automated processes to perform functions normally completed manually in coastal aquaculture. Of these processes, feeding is most important and without cost-effective, reliable unmanned feeding systems, open-ocean aquaculture is commercially impractical.[3]

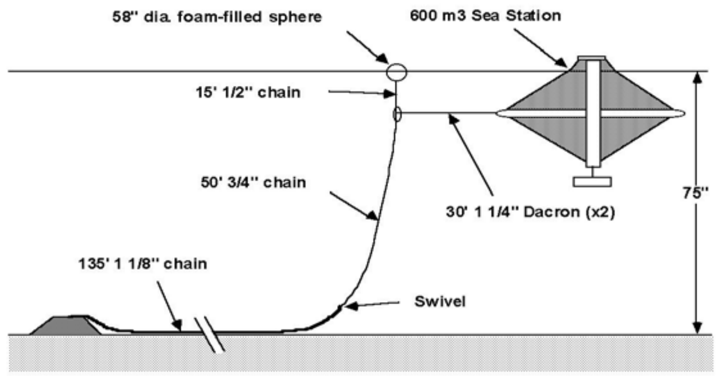
This facility provided sufficient workspace to assemble and stage the various cage and mooring components near the water. The octagonal rim is composed of eight flanged sections of steel pipe that are individually pressurized and sealed to allow floatation on the water surface. The assembled octagonal rim was hoisted to the water surface and towed to the distant offshore aquaculture site with the central spar buoy inside the rim, in a horizontal position on the surface during the towing operation.[4]

Aquaculture operating in fully exposed, hostile offshore environments requires innovative problem solving to consistently raise fish. Offshore aquaculture sites have no protection from the natural elements and may regularly experience poor sea-state conditions which could be amplified when deploying offshore

2 Feed Fish Offshore (http://www.masgc.org/oac/gallery05.html)
3 Deploy an Offshore Aquaculture Cage (http://www.masgc.org/oac/gallery01.html)
4 ...Change the Net Offshore (http://www.masgc.org/oac/gallery03.html)

aquaculture components using a large boat and boat crane. [5]

The ballast weight is a circular concrete block weighing approximately 3,200 kg for the OAC cage and having a toggle through its middle to attach it to the bottom of the spar buoy. In its proper position, the ballast weight provides necessary weight to maintain the cage in the water column and provide stability during high seas and wind. [6]



Mooring aquaculture cages in sheltered-water environments has almost entirely used multiple mooring anchors creating an array that holds the cages in a fixed position. Open-ocean aquaculture ventures experience decreased user conflicts, improved water quality, and a lack of established practices-all of which gives researchers considerable opportunities for innovation compared standard sheltered-water operations.

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