The 33rd UJNR Aquaculture Panel Symposium

# Ecosystem and carrying capacity of aquaculture ground

- for sustainable development of aquaculture and stock enhancement -

Seikai National Fisheries Research Institute, NAGASAKI
2-3 November 2004

Organizers
Satoru Toda (NRIA), Osamu Matsuda (Hiroshima University)
Shusaku Kadowaki (Kagishima University) , Hisashi Yokoyama (NRIA)
Junya Higano(NRIA), Makoto Yamasaki(SNFRI)

## Keynote of the symposium

The role of the fisheries industry as a supplier of healthy food for human has become more important in recent years. Marine aquaculture and stock enhancement have been developed and can now compensate the reduced productivity of the wild catch.
Aquaculture creates impacts on the surrounding environment and ecosystem in various ways. Intensive feeding fish-farming often results in adverse effects on both the fish farm itself and the ecosystem beneath and around the fish farm through changes such as oxygen deficiency, generation of hydrogen sulfide, and blooms of harmful plankton. On the other hand, non-feeding aquaculture and stock enhancement of seaweeds and shellfish potentially prevent eutrophication by removing nutrients and particulate organic matter from the surrounding water. The integration of fish farming with non-feeding aquaculture is therefore a useful approach to mitigation of the environmental problems associated with marine aquaculture.
To achieve sustainable development of aquaculture, we need to deepen our understanding of the environmental problems associated with aquaculture activities, especially their effect on the ecosystem and carrying capacity of aquaculture ground. In this symposium we would like to discuss future perspectives of sustainable and responsible aquaculture, particularly in regard to the natural environment and ecosystem, methods of managing aquaculture grounds, and new approaches to integrated aquaculture management.

# The 33rd UJNR Aquaculture Panel Symposium
# Ecosystem and carrying capacity of aquaculture ground
### -for sustainable development of aquaculture and stock enhancement-

## Symposium Agenda

**<u>Tuesday November 2, 2004</u>**

**Session 1. Environment and ecosystem around aquaculture ground**

**(1) Environment and ecosystem in coastal sea (Chairs: C. Yarish and K. Takayanagi)**

13:15 Ariake Bay-Present Conditions of Fisheries and Research for Restoration-
Tokimasa Kobayashi（Seikai National Fisheries Research Institute)

13:45 Effects of Resuspended Sediments on the Environmental Changes in the Inner Part of Ariake Bay
Katsuhisa Tanaka（Seikai National Fisheries Research Institute)
Masashi Kodama (National Research Institute of Fisheries Science)

14:05 Observation on behavior of the large suspension feeding bivalve *Atrina pectinata lisckeana* under natural conditions
Kengo Suzuki, Setuo Kiyomoto and Yuichi Koshiishi（Seikai National Fisheries Research Institute)

14:25 Physical Mechanism for Dense Algal Bloom in the East China Sea and A Potential Model Management System
Changsheng Chen (University of Massachusetts-Dartmouth), Mac Rawson (University of Georgia)

14:45 Coffee break

**(2) Carrying capacity in stock enhancement ground (Chairs: B. Hard and Y. Koshiishi)**

15:05 Appropriate release number of juvenile red spotted grouper into nursery reef and fishing port habitats
Shigenobu Okumura (Yashima Station, National Center for Stock Enhancement, Fisheries Research Agency)

15:25 An appropriate stocking size of juvenile Japanese flounder, *Paralicthys olivaceus*, in consideration of carrying capacity.
Yoh Yamashita (Kyoto University)
Yutaka Kurita (Tohoku National Fisheries Research Institute)

**(3) Biogeochemical cycling around aquaculture area (Chairs: R.I.E Newell and J. Higano)**

15:45 Carrying Capacity and Management of Oyster Culture in U.S. West Coast Estuaries

Paul G. Olin (University of California )

16:05 Impacts of oyster cultures on nitrogen budgets in Hiroshima Bay, the Seto Inland Sea of Japan

Kenji Tarutani (National Research Institute of Fisheries and Environment of Inland Sea)

16:25 Carrying capacity models for bivalve mollusc aquaculture: consideration of food limitation for growth versus ecosystem ability to process excrement

Roger I. E. Newell (University of Maryland Center for Environmental Science)

**<u>Wednesday November 3, 2004</u>**

9:00 Microbial activity and community structure in a net cage aquaculture area

Tomoko Sakami and Katsuyuki Abo（National Research Institute of Aquaculture）

Kazufumi Takayanagi（Seikai National Fisheries Research Institute）

9:20 Effect of effluents from a new fish farming site on the benthic environment

Takashi Tanigawa and Azumi Yamashita (Ehime Prefectural fisheries Experimental Station)

Yoshitsugu Koizumi (Ehime Prefecture Uwajima Regional Office)

9:40 Coffee Break

**Session 2. Methods of managing aquaculture ground (Chairs: C.-S. Lee and S. Toda)**

10:00 A New 4-Dimensional GIS for assessing Fish Mariculture Operations and Impacts

Dale Kiefer, Frank J. O’Brien, (System Science Applications), J.E. Jack Rensel (Rensel Associates Aquatic Science Consultants)

10:20 Assimilative capacity of fish farm environments as determined by benthic oxygen uptake rate: Studies using a numerical model

Katsuyuki Abo and Hisashi Yokoyama (National Research Institute of Aquaculture)

10:40 Macrobenthos, current velocity and topographic factors as indicators to assess the assimilative capacity of fish farms: Proposal of two indices

Hisashi Yokoyama (National Research Institute of Aquaculture)
Misa Inoue (Mie Prefecture Kihoku Branch Office, Department of Agriculture, Fisheries, Commerce and Industry)
Katsuyuki Abo (National Research Institute of Aquaculture)

11:00 Ecosystem-based Management and Models in Sustainable Management of Coastal Aquaculture

Mac Rawson (The University of Georgia), Changsheng Chen (University of Massachusetts-Dartmouth), DaoRu Wang (Hainan Marine Development, Planning and Design Institute), Charles Yarish (University of Connecticut), MingYuan Zhu (The First Institute of Oceanography, State Oceanic Institute), James B. Sullivan (NOAA, Gray's Reef National Marine Sanctuary)

11:20 Zero Impact Offshore Mariculture in the Pacific Northwest U.S

J. E. Jack Rensel (Rensel Associates Aquatic Science Consultants), John R. M. Forster (Forester Consulting Inc.), Dale A. Kiefer (University of Southern California), Dana L. Woodruff (Battelle Marine Sciences Laboratory)

**Session 3. Environmental management by integrated system (Chairs: J. McVey and S. Kadowaki)**

13:15 Direct payment system to promote the appropriate management of aquaculture grounds

Yasuji Tamaki (National Research Institute of Fisheries Science)

13:35 An AIP Workshop: "*The Role of Aquaculture in Integrated Coastal Management: An Ecosystem Approach*"

Cheng-Sheng Lee (The Oceanic Institute)

13:55 *Ulva sp.* and *Undaria undarioides* culture for reduction nitrogen and phosphorus from fish culture area in Wakayama Prefecture, Japan

Hazime Kimura (Wakayama Research Center of Agriculture, Forestry and Fisheries), Masahiro Notoya (Tokyo University of Marine Science and Technology)

14:15 The growth, N, P uptake rates and photosynthetic rate of seaweeds cultured in coastal fish farms

Yuuki Kitadai and Shusaku Kadowaki （Kagoshima University）

14:35 The Bioremediation Potential of Economically Important Seaweed in Integrated Aquaculture Systems with Finfish

C. Yarish (University of Connecticut), G. P. Kraemer (State University of New York), J. Kim (University of Connecticut), R. Carmona (University of Connecticut), C. D. Neefus (University of

New Hampshire), G. C. Nardi (GreatBay Aquaculture LLC), J. J. Curtis (Bridgeport Regional Vocational Aquaculture School), R. Pereira (University of Connecticut), M.Rawson (University of Georgia)

14:55 Coffee break

15:15 Model Management Plan to Optimize Production of Marine Tropical Systems
James P. McVey (National Sea Grant College Program), Dallas Alston, Alexis Cabarcas (University of Puerto Rico)

15:35 New approach for the integrated aquaculture management from the view point of multi-functional role of fisheries and aquacultures
Osamu Matsuda (Professor Emeritus, Hiroshima University)

# Ariake Bay - Present Conditions of Fisheries and Research for its Restoration -

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Ariake Bay is a nutrient enriched productive sea located in western Kyushu and its area is about 1700 square kilometers. The bay is geomorphologically semi-enclosed, being connected to the East China Sea through the narrow Hayasaki-Seto Strait. The bay environment is strongly influenced by the environmental conditions of the East China Sea. The main features of the bay are tidal flats, a large tidal range and enriched with nutrients. The tidal flats cover about 20,000ha along the coast of the bay. Fast tidal currents and strong vertical mixing have been observed in the bay due to the large tidal range (the maximum is about 6m) and shallow water depth. Such a mixing process promotes oxidative decomposition of organic matter in the bottom layer and brings the regeneration of nutrients up to the surface from the bottom. This nutrient cycling provides a high productivity and has prevented bottom-water hypoxia in the inner part of the bay.

However, COD, a well-used environmental parameter for fisheries grounds, is gradually increasing, implying the deterioration of the bay environment. The transparency has also been increasing. The area of muddy sediment has extended to the western part of the bay, where the sediment was formally sandy. The total number of the occurrence and the days of appearance of excessive algal blooms are rising. Furthermore, higher water temperature than normal years has been continuously recorded in recent years.

The tidal range has become smaller, resulting from a decrease of the area of the tidal flats especially during neap tides. Moreover, hypoxia is formed in the inner part of the bay from summer to fall and the concentration of dissolved oxygen falls drastically especially during neap tides.

The catch of bivalves was large and the major part of the fisheries in the bay. The amount of the catch reached more than 80,000 tons in the late 1970s. Since then, however, the production of short-necked clam (*Ruditapes philippinarum*), jack-knife clam (*Sinonovacula constricta*) and pen shell (*Atrina pectinata*) has been diminishing. The catch fell to the level of 30,000 tons early in the 1990s, and it has further fallen to less than 20,000 tons in recent years. Mass mortality due to hypoxia was reported. The predation by ray, which inhabitats generally in southern waters, has also reported to be causing serious damage to the bivalve stocks.

The production of cultured *Porphyra* (Nori) has been increasing since 1960's, and it reached 1,500 million sheets in 1970, 2,700 million sheets in 1980, 3,500 million sheets in 1990, and it reached the maximum of 4,400 million sheets in 1999. However, discoloration of cultured *Porphyra* was widespread in the winter of 2000-2001, damaging the *Porphyra* production. The discoloration was thought to be caused by a shortage of nutrients as a result of the unusual environmental conditions such as a large amount of precipitation in the fall, longer daylight hours far exceeding normal years and repeated occurrence of atypical algal blooms. The production was only 2,300 million sheets in that year, the lowest in the past 25 years.

In addition, other commercially important fishes and crustaceans are caught in the bay. However, their share in the total catch is small and the amount of catch has never exceeded 20,000 tons. Annual fluctuation is relatively small and a gradual declining tendency has also been noticeable in the 1990s.

The bivalve catch and *Porphyra* production are undoubtedly the main fisheries production in the bay, but the production is not stable. Therefore, it is an important issue to restore the bivalve resources and to maintain the steady production of *Porphyra*. Additionally, it is required to improve the habitat environment, especially the water and sediment quality. It is known that the improvement of sediment quality can be achieved by irrigation and/or covering by sand. We are investigating the effectiveness and long-term persistence of these methods and also trying to develop more effective techniques to restore the sediment environment.

We are also investigating the formation mechanisms of hypoxia in order to find where hypoxic conditions will form, when they will form, how large an area it will affect, what will trigger hypoxia, and how to eliminate it. Other related research includes the development of techniques to prevent harmful effects of excessive algal blooms on cultured *Porphyra* as well as to predict an outbreak of excessive algal blooms. We also have strong research programs on seeds for release including fish and shellfish, breeding of high-temperature, low-nutrient resistance *Porphyra* in order to restore fisheries resources and to maintain sustainable fisheries in Ariake Bay.

# Effects of Resuspended Sediments on the Environmental Changes in the Inner Part of Ariake Bay

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Turbidity, *in situ* fluorescence of phytoplankton pigments and dissolved oxygen concentration were monitored and their relationships to tidal variations investigated in the inner part of Ariake Bay. Turbidity during spring tides showed large short-term (6-24hrs) variations due to the tidal resuspension of bottom sediments. The phytoplankton biomass increased from neap tides to before spring tides, because of the higher nutrient availability in the surface low salinity water caused by the stratification and the higher transparency due to the low turbidity. While, during the spring tides, the increase of phytoplankton biomass was restricted by the low light availability due to the turbid water caused by the resuspended sediments, strong mixing with offshore water and possibly flocculation of phytoplankton with the resuspended sediments. During the neap tides in summer, large scale hypoxia was also observed in the offshore area of mud flats, where resuspended sediments accumulate on the surface sediments. These observations indicate that the recent reduction of tidal currents is one of the contributing factors to the decrease of resuspension of the bottom sediments and increase in hypoxic areas within the bay.

# Observation on behavior of the large suspension feeding bivalve *Atrina pectinata lisckeana* under natural conditions

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The Pen shell (*Atrina* sp.) is a large, suspension feeding bivalve and is also one of the most important species in shellfish fisheries in Ariake sound. However, pen shell production has been decreasing since the 1960's. In a recent survey, mass mortality of the Pen shells was observed in the fishing grounds. Some environmental factors such as the development of a hypoxic water mass, and increase in muddy bottom area have been blamed on the decline of the Pen shell. The possibility of disease has also been discussed. Despite intensive research, the mechanism for the decrease in pen shell resources remains unclear. The Pen shell is also an important species for its ability to construct benthic fauna. When Pen shells are predominant the subtidal seafloor, they usually make dense beds. Their filtration and biodeposition may affect the composition of the benthic fauna and environmental condition. Therefore, the Pen shell is important as a key species in the subtidal benthic community in Ariake sound. However, there have been few ecological studies of the Pen shells in Ariake sound.
To evaluate the effect of environmental change on the Pen shell, we conducted research on the valve movement of the Pen shell which is an indicator of their activity. In the laboratory experiments, we found two patterns of valve movement recorded under aerobic conditions. First, the multi close-open action and second the single close-open action. The multi close-open action is characterized by a series of close-open actions which repeat at intervals of less than 30 seconds. This action appears during the burrowing behavior of the Pen shell. The single close-open action is characterized by a close-open action which occurs at intervals of more than 4 minutes. This action occurs during vomiting behavior. Single close-open action occurred more frequently under hypoxic conditions and the high frequency of this action was associated with creep-out behavior. The result of a laboratory experiment showed that the valve movements represent the state of the Pen shell. We developed two types of instruments to measure the valve movement of Pen shells under field conditions. One is a wire-communication type for the region close to shore and the other is an underwater type for the offshore region. Measurements were performed from May 19 to June 30 2004 on tidal flats near Konagai and from Aug. 24 to Sep. 8 at the subtidal station off Ohura. Measurement on tidal flats revealed a distinct emersion effect. Pen shells were slightly closing their valves and motionless during the emersion. This type of motionless period did not appear when they were submerged. Measurement at the subtidal station revealed burrowing behavior after transplantation and unusual single open-close actions during storms.

# Physical Mechanism for Dense Algal Bloom in the East China Sea and A Potential Model Management System

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Abstract

Harmful algal blooms ("red tides") occur primarily in a confined region on the inner shelf off the Changjiang River in the East China Sea during May-August. The areal extent of these blooms has increased dramatically in the last decade, and is thought to be associated with the rapid increase in nutrient supply via the Changjiang River. Our recent studies have identified three areas of high chlorophyll-a concentration in this region: the near-surface Changjiang plume with high dissolved oxygen and pH, the thermocline above Taiwan Warm Current (TWC) water, and near the bottom north of the Zhoushan Island complex, an area of strong sediment deposition from the Changjiang River with low dissolved oxygen and pH. These results imply that the formation of phytoplankton blooms is controlled by a complex interplay of physical, geological, biological, and chemical processes associated with the Changjiang discharge, sediment deposition, and TWC intrusions. The predicted increase in nutrient loading in the Changjiang River due to further economic development of Shanghai and reduction in sediment discharge due to the Three Gorges dam suggest that this part of the East China Sea could become an ecosystem disaster, with possible downstream contamination of Korea and Japan, unless the nutrient loading from Shanghai and surrounding cities and aquaculture activities along the coast are reduced.

# Appropriate release number of juvenile red spotted grouper into nursery reef and fishing port habitats

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Three release experiments were carried out to assess the appropriate release number of red spotted grouper, *Epinephelus akaara*, juveniles into artificial nursery reefs and a fishing port. Six nursery reefs, 3.6 × 3.6 m wide 1.6 m high each containing 6 test units filled with mesh pipes each with a string of scallop shells, were installed on the bottom off Shiraishi Island, central Seto Inland Sea, Japan in July 2000. Artificially reared juveniles, 67.6 ± 7.0 mm in total length, were released into the reefs on 16 October 2001. The densities of released juveniles were arranged at three levels, 500 fish per reef, 1000 fish per reef and 2000 per reef and each density level tested at 2 reefs. A test unit was salvaged from each nursery reef three times to estimate the number of residual fish. At the first salvage operation one week after the release, the estimated mean residual fish number and retention rate of the 500 fish released reefs, 1,000 released reefs and 2,000 released reefs were 198 fish (40%), 444 (45%) and 624 (31%), respectively. Similarly the figures were 93 (19%), 165 (17%) and 267 (13%) at the second salvage one month after the release. At the final salvage operation four months after the release, they were 78 (16%), 66 (7%) and 84 (4%), respectively. The numbers of residual fish in the reefs were directly proportional to the numbers of released fish until one month after release; however the numbers of residual fish were nearly even among the three levels and retention rates were inversely proportional to the released number at four months after release. These results indicate that releasing 2,000 fish per reef is effective to retain a large number of released fish in a reef for a month; and releasing 500 fish is efficient to obtain a high retention rate at four months after release. Thus the appropriate number of released fish should be determined depending on the duration spent in the nursery reef. Release experiments into a fishing port were carried out in Ishima West Port which is shallow (2 – 4 m) and small (4500 $m^2$) located in central Seto Inland Sea, Japan. A total number of 15,000 artificially reared juveniles (69 mm, mean total length) were released into the port on 13 October 1998. Recapture operation took place 16 days after the release using 16 fishing traps (60 × 45 × 20 cm) in the port. Total number of recaptured fish was 6 and catch per unit of effort (CPUE) was calculated as 0.38 (6 fish per 16 traps). A total number of 1,500 juveniles (109 mm) were released into the same port on 11 November 1999. Recapture operation was similarly conducted using 20 traps 28 days after the release. Only one fish was recaptured at that operation and CPUE was 0.05 (1 / 20). Although these operations were experimental and the calculated figures were estimates, CPUE seemed to be directly proportional to the number of released juveniles. The retention rate may be fixed unrelated to the number of released fish within the limits of 1,500 – 15,000 fish per port.

# An appropriate stocking size of juvenile Japanese flounder, *Paralichthys olivaceus*, in consideration of carrying capacity

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Japanese flounder *Paralichthys olivaceus* is a major coastal commercial fish. The total catch of the flounder is stable between 6,500 and 8,400 tonnes in the last decade. It is also one of the major target species of stock enhancement in Japan. A total of 30 million juveniles are released every year. Economic return rate (amount of catch / cost of stocking) can increase to 2.5 in the case appropriate releasing techniques are applied. Stocking size is one of the most important techniques to be considered as well as the size at release and the timing of release. We applied an ecophysiology model to predict the growth of juvenile Japanese flounder and to evaluate an appropriate stocking size under the criterion that released fish, as a competitor of wild one for food, do not restrict the growth of wild fish. This model consists of 5 compartments (i.e. wild flounder, released flounder from hatchery as a competitor, other competitors, mysids as a main food item, predators) and includes various physiological responses to varying environments (mainly temperature) and ecological interactions (i.e. prey-predator relationship and competition for food) among these compartments. The predicted growth of both wild and released flounders until 65 days after stocking (9 November) well agreed with the observed ones at Ohno Bay, a small shallow sandy area up to 10 m deep in the northwest of Japan. Wild flounder would reach to 141 mm in TL on 9 November without any released flounder, while in fact they grew only to 109 mm. The model explained that the standing biomass of mysids decreased because the amount of predation on mysids by both wild and released fish exceeded the production which was controlled by temperature and abundance of mysids themselves, and that led to the restricted growth of wild flounder. An appropriate stocking level below which release of hatchery-raised flounder would not retard the growth of wild one was predicted as 49,000 individuals while actual stoking level was 76,300.

# Carrying Capacity and Management of Oyster Culture in U.S. West Coast Estuaries

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The Pacific oyster, *Crassostrea gigas* is the most widely cultured shellfish in the world with a harvest in 2002 of 4,216,300 metric tons valued at $3,488,385 USD. In the Pacific Northwest, oysters are grown in estuarine and near shore waters in the states of Washington, California, Oregon and Alaska. Washington State is the dominant producer with production in 2004 expected to be 35 million kg. California, Oregon and Alaska follow with projected 2004 production of 3.2, 2.3, and 0.1 million kg respectively. With the exception of Washington State where private ownership of intertidal oyster beds is typical, oyster growers generally lease land from state agencies. Management agencies in each state issue permits that approve specific growout techniques, culture species, and production levels. Recently, there have been concerns raised about the environmental interactions of aquacultured species and the potential impacts they may have on coastal ecosystems. For filter feeding bivalve shellfish these concerns include potential changes in water quality parameters such as dissolved oxygen, nutrient levels, turbidity, suspended sediments, organic particulates, and transmittance. Cultured shellfish can also influence the diversity and abundance of fish and invertebrates in surrounding waters and in nearby benthic communities. The complex three dimensional habitat created by cultured shellfish is colonized by a wide variety of vertebrate and invertebrate fauna that interact with organisms in adjacent waters. The degree to which cultured shellfish impact coastal ecosystems is of great concern to natural resource managers who must represent the interests of fishermen, recreational users and the public, while protecting marine resources. In the most extreme case, the biomass of shellfish cultured in a given area may exceed the natural carrying capacity resulting in a decrease in primary productivity with the potential to negatively impact organisms at multiple trophic levels. To determine the carrying capacity of coastal waters is a complex process that involves models with inputs that include variables such as cultured shellfish biomass, feeding rates, primary productivity, nutrient levels, light, temperature, currents, suspended particulates, microzooplankton, mesozooplankton, macrozooplankton, benthic meiofauna, and benthic macrofauna. The complexity of these models and the expensive data collection necessary to populate them, coupled with the dynamic conditions in coastal estuaries and little evidence that carrying capacities are being exceeded, are such that carrying capacity is not generally not an issue that is addressed by agencies that manage shellfish growing waters on the U.S. West Coast. In most cases, the nutrient rich waters of the Eastern Pacific support primary productivity that provides ample food for both cultured and wild shellfish. There are however, anecdotal reports of reduced growth observed in some localized embayments in Puget Sound that shellfish growers attribute to excessive filter feeding by cultured shellfish. Different management strategies employed by Pacific States will be compared and discussed in relation to the carrying capacities of west coast estuaries.

# Impacts of oyster cultures on nitrogen budgets in Hiroshima Bay, the Seto Inland Sea of Japan

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Hiroshima Bay, where located in the western part of the Seto Inland Sea of Japan, has a long history of pacific oyster (*Crassostrea gigas*) culture and produces about 60% of oyster production in Japan. The bivalves not only filtrate particulate materials but also regenerate and mineralize materials in the water column. Therefore, high population density of oyster in the modern culture system should play a significant role on the material cycle in Hiroshima Bay. In the present study, the impact of oyster culture on the nitrogen budget was demonstrated for the northern Hiroshima Bay. In addition, we also evaluated nitrogen removal efficiency from the bay by harvesting the cultured oysters. The output from a simple two-layer box model and nitrogen measurements in the bay over a 1 year period were used to estimate the nitrogen budget in the northern Hiroshima Bay. The input from rivers was the major nitrogen source to the bay and accounted for about 60% of the total dissolved inorganic nitrogen input. Dissolved inorganic nitrogen comprised a great part of total nitrogen input to the bay from rivers. On the other hand, dissolved organic nitrogen accounted for 60% of the annual average of nitrogen standing stock in the bay, suggesting that the biological production is high within the bay. Actually, the annual average of the phytoplankton production rate was very high. Estimated filtration rate of cultured oyster suggested that the filtering activity of oyster culture is highly significant in considering the nitrogen cycle in Hiroshima Bay. In addition, the amount of nitrogen harvested as oyster products was about 0.9 ton N $d^{-1}$, which is about 5% of daily nitrogen input from rivers to the bay. The removal rate through oyster harvesting is five times higher than that by fishing activities, suggesting that oyster culture plays a significant role on the recycling of nitrogen from Hiroshima Bay to the land.

# Carrying capacity models for bivalve mollusc aquaculture: consideration of food limitation for growth versus ecosystem ability to process excrement

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Abstract

Successful commercial production of suspension-feeding bivalves molluscs, such as oysters and mussels, requires knowledge of the stocking density at which intraspecific competition for food reduces growth rates. Obtaining such information for open-water cultivation sites is difficult, however, because food availability varies with rates of phytoplankton production, water currents affect "food flux" through the grow-out sites, etc. In an effort to integrate these complex environmental variables there are ongoing efforts to develop "carrying capacity" models that can be used as predictive tools. Often the emphasis in these models is estimating the standing stock at which production is maximized without negatively affecting growth rates. Such an emphasis means that other important aspects of ecosystem carrying capacity, such as the ability of the culture site to process the excrement produced by the animals, may not be adequately modeled. Future carrying capacity models need to be more fully integrated ecosystem models that consider all aspects of the interactions between the cultivated animals and the ecosystem. Such models should be parameterized to quantify other benefits of culturing suspension-feeding bivalves, such as their ability to exert top-down control on phytoplankton stocks, reduce turbidity, and enhance nutrient removal. These secondary benefits can have economic value to the aquaculturists as part of polyculture systems, environmental remediation, and nutrient trading schemes.

# Microbial Activity and Community Structure in a Net-pen Aquaculture Area

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Excess organic matter production from net-pen aquaculture farms operated in open water causes serious seawater pollution. To develop sustainable aquaculture systems we need to consider the mechanisms of organic matter cycling. Microbial communities have very important roles in cycling organic matter in seawater. To elucidate how microbial communities are affected by aquaculture activities, we examined the bacterial activity and community structure annually in a red sea bream aquaculture area and a neighboring, non-aquaculture, reference area in Gokasho Bay, Japan.

The bacterial activity parameters examined – abundance, production rate, and extracellular hydrolytic enzyme activity – were always higher in the aquaculture area than in the reference area, and these differences were most pronounced in surface waters in summer. The annual mean bacterial abundance and production rate in the aquaculture area were $4.7 \times 10^9$ cells $L^{-1}$ and 82 mg C $m^{-3}$ $day^{-1}$: about 1.4 and 3.5 times, respectively, those in the reference area. The annual bacterial production per unit area was estimated at 608 g C $m^{-2}$ $y^{-1}$, which was about 1% of the annual fish food input to fish farms (on a raft-area basis; 57 kg C $m^{-2}$ $y^{-1}$). The annual mean extracellular leucine aminopeptidase (LAP) activity (which represents proteolytic activity) in seawater in the aquaculture area was about twice that in the reference area. On the other hand, the activity of β-glucosidase, which represents polyhydrocarbon degrading activity, in the aquaculture area was about five times that in the reference area, indicating that, overall, β-glucosidase activity was promoted more than LAP activity. These microbial activity parameters were positively correlated with the organic matter concentrations in the water, suggesting that input of organic matter from the fish farms to the surrounding waters promoted microbial activity.

We examined bacterial community structure in seawater by using a PCR–denaturant gradient gel electrophoresis (DGGE) method based on 16S-rRNA gene fragment fingerprinting. Since the level of leucine aminopeptidase activity was closely correlated with the particulate organic matter concentration, the bacterial community was separated into two categories, particle-associated (>1 µm) and free-living (<1 µm). In the free-living bacterial community, the number of DGGE bands (which corresponded to bacterial species) ranged from 2 to 12, and the DGGE profiles were similar in the aquaculture area and in the reference area. However, some bands identified as representing alpha and gamma proteobacteria were observed only in the aquaculture area from spring to autumn. In the particle-associated bacterial community, the number of DGGE bands was less than in the free-living one, and most of the bacteria were identified as cyanobacteria. However, in summer, when the particle-associated bacterial community had high hydrolytic enzyme activity, bands identified as representing the *Cytophaga–Flavobacterium–Bacteroides* group, most isolates of which have the ability to degrade biomacromolecules, were detected in the aquaculture area, together with those of alpha and gamma proteobacteria. These results suggest that the variation in bacterial activity was related to bacterial community structure and that aquaculture activity affects the bacterial community in seawater, both quantitatively and qualitatively.

# EFFECT OF EFFLUENTS FROM A NEW FISH FARMING SITE ON THE BENTHIC ENVIRONMENT

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In relation to improvement of the environment around fish (red seabream and yellowtail) farms in Shitaba Bay, Uwajima, Ehime Prefecture (Japan), about half of fish cages were shifted from the inside (ca. 40m depth) to the outside (60m depth) of the bay during May-November 2001. We investigated the spatio-temporal variability of the benthic environment at the newly established fish farm site, by analyzing the sediments at both the new (outside) and the former (inside) farm sites before and after the shift of fish cages. For example, the organic matter load from the new farm was measured to determine the assimilative capacity of the benthic ecosystem.

Acid volatile sulfides (AVS-S) of sediment at the center of the new farm were 0.028mg/g･dry weight in February 2001 without fish cages. As soon as the fish cages were set, AVS-S drastically increased (0.106 mg/g･dry weight in July) and reached 0.256 mg/g･dry weight in November when the fish cage shift had been completed. Moreover, AVS-S continued to increase and reached its maximum (0.455mg/g･dry weight) in April 2002. However, it remained at ca. 0.3-0.4mg/g･dry weight thereafter. Although AVS-S increased also at the edges and surrounding areas of the new site, concentrations were lower than those at its center. AVS-S decreased at areas over 50m distance from the edges. Total nitrogen (TN) and total phosphorus (TP) of sediment at the new farm site were slightly higher than concentrations observed in a pearl farm and a non-farming site (as reference sites). TP was ca. 50% of that in the former farm site, while no marked difference of TN was detected between the two sites.

From data on the amount of feed sold, production and feeding amount to cultured fish for some cages, about 50% (5,000t as dry weight) of the total amount of feeds sold by the fisheries cooperative association was consumed in the new farm site in 2002. These feeds may be reflected in the total organic carbon (TOC), TN and TP flux caught using sediment traps set at 5m depth above the bottom, which were equivalent to or more than the concentrations at the former farm site.

Thus, it was suggested that the AVS-S increase was largely due to effluent of organic matters (uneaten food, fecal and urinary wastes) from fish farming activities closely linked with the shift of fish cages, and the effect of the loaded organic matter on the benthic ecosystem was low in areas more than 50m away from fish farming site. These findings indicate that the adoption of a periodic shift of fish cages and a fallow system (periodic suspension of fish farm activities) is effective to facilitate the recovery of polluted sediment.

# A New, 4-Dimensional GIS for assessing Fish Mariculture Operations and Impacts

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We have developed a simulation model to assess the effects of a commercial, marine fish farm that could be placed in the Strait of Juan de Fuca, Washington State. The model was imported into a marine GIS software called EASy (Environmental Analysis System). This software provides a 4-dimensional framework (latitude, longitude, depth, and time) to run simulation models as well as to analyze field measurements as graphical and statistical outputs. Although many species of farmed, marine fish can be "introduced" into the model, salmon was selected for this simulation since its growth and metabolism is been extensively studied. This virtual, salmon farm consists of 3 components: a 3 dimensional circulation model, a plankton model that provides a description of the response of plankton to nutrient and oxygen perturbations caused by the farm, and a growth and metabolic model of salmon.

The circulation model is a simple finite element description of the movement of water and suspended and dissolve materials caused by advection and turbulent dispersion. Such circulation is described in terms of a box model in which materials flow across the 6 interfaces of each rectangular element of the 3-dimensional array. Turbulent dispersion was parameterized as an exchange coefficient whose value was some fraction of the speed of advective flow.

The plankton model describes the cycling by plankton of nitrogen and oxygen within each element of the array- both within the farm and the surrounding waters. The outputs of this model consist of a time series of the concentrations of dissolve inorganic nitrogen, oxygen, phytoplankton, and zooplankton. The "master" cycle described the transforms of nitrogen between three compartments, inorganic nitrogen, organic nitrogen in phytoplankton, and organic nitrogen in zooplankton.

The inputs to the fish farm model are the dimensions and location of the farm in the array, daily feed ration, the average weight of fish, and the density of fish. The outputs consist of a time series of the average rates of growth, nitrogen excretion, and respiration. The rates of growth, respiration, and excretion are functions of the average weight of fish, the feed ration, the ambient temperature, oxygen concentration within the farm, and advective flow. The system of equations that describe the metabolism of the fish were obtained by fitting functions to the data found in the extensive literature on the growth and respiration of *Salmo salar* (Atlantic salmon) and

*Onchorhynchus nerka* (sockeye salmon).

The model indicated that there is no significant ecological concern in deploying such a farm within the study zone of the Strait of Juan de Fuca. This is to be expected given the fact that tidal currents are strong in the region and nutrient concentrations are sufficient to saturate the growth rate of phytoplankton. On the other hand, the model clearly indicates that the growth rate of the salmon are much influenced by environmental parameters such as current velocity, water temperature, and oxygen concentration. The model may be validated by reference to numerous upstream and downstream measurements of dissolved oxygen and nitrogen concentration, conducted in either the state of Maine and Washington State.

# Assimilative Capacity of Fish Farm Environments as determined by Benthic Oxygen Uptake Rate: Studies Using a Numerical Model

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In Japan, overstocking of aquaculture pens has led to a deterioration in the environmental conditions of aquaculture grounds. To promote improvements in the environmental quality of aquaculture grounds and maintain suitable conditions for stable aquaculture production, the “Law to Ensure Sustainable Aquaculture Production” was established in 1999. The law determined an environmental criterion for ensuring sustainable aquaculture production based on the capacity of sediments to assimilate organic wastes from fish farms. This criterion considers the relationship between benthic oxygen uptake (BOU) rate and organic matter loading rate; the maximum value of the BOU rate relative to the organic matter loading is regarded as an indicator of the phase of maximum biological mineralization. A value of acid volatile sulfide (AVS-S) content of the sediment corresponding to the maximum BOU is defined as the standard value. Recent studies, however, have suggested that it is difficult to detect the maximum (peak) BOU and to determine the standard value through *in situ* investigations. The practical applicability of this criterion therefore needs to be re-examined scientifically. To do this, we developed a three-dimensional numerical model, which takes advection, dispersion, sedimentation, and decomposition of organic matter from fish farming systems into account. By using simplified geometry, we simulated changes in benthic quality and BOU as functions of variations in the organic matter loading rate. The numerical simulations revealed that it was indeed difficult to estimate the maximum BOU and determine the standard value through *in situ* investigations, because the estimations were greatly influenced by water exchange rate and oxygen supply. We suggest that our numerical model should be used instead of *in situ* investigations for the practical application of the criterion. We also applied this model to an examination of the environmental quality of existing fish farms in a basin. The model proved to be an effective tool for evaluating the assimilative capacity of the fish farm environment and for suggesting appropriate spatiotemporal uses of aquaculture grounds.

# Macrobenthos, current velocity and topographic factors as indicators to assess the assimilative capacity of fish farms: Proposal of two indices

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In order to assess the assimilative capacity of fish-farm environments, and to provide site selection guidelines, surveys of the bottom environments and macrobenthos were conducted in fish farms in Kumano-nada, Pacific coast of central Japan (Yokoyama et al. 2002a, b, 2004). In this review, these results are summarized, and requisites for determining the limit of the maximum fish production are discussed from a standpoint of the assimilative capacity. An index, "ED" (Embayment Degree), which is calculated from topographic factors, was devised. Six assemblages of the macrobenthos were recognized on the basis of cluster analysis. These assemblages were classified into three groups: a group characteristic of a healthy zone, a group characteristic of a cautionary zone, and a group characteristic of a critical zone. These groups had their own areas in a gradient of ED versus fish production, suggesting that the variation in macrobenthos and environmental factors found in the study area was attributable to the area's topography and aquacultural activities, and that the environmental conditions are predictable from ED and fish production. ED can be used as a simple indicator for the site selection, however, it is unknown whether this index is applicable to other localities. Therefore, another index, "ISL" (Index of Suitable Location), which is calculated from the current velocity and water depth at the farm site, was proposed. Current velocities under fish-farm cages were measured using plaster balls at 20 stations to obtain values for the calculation of ISL. The healthy, cautionary and critical zones, were also arranged regularly in a gradient of ISL and fish production. Values of biotic and abiotic factors were found to be changed along this gradient. These findings indicate that ISL is also an effective indicator of the assimilative capacity. ISL, which incorporates factors that are more direct variables that control the waste dispersal and loading and oxygen supply, can be of a wider application to assess the assimilative capacity of fish farms under a variety of topography.

# Ecosystem-based Management and Models in Sustainable Management of Coastal Aquaculture

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The complex process of ecosystem-based management to be successful requires management tools that can integrate the physical, chemical and biological processes. The modeling tool must function at multiple scales, be easily understood by non-scientist and above all be reliably predict manage alternatives. It must address specific questions about bays, lagoons or coastal oceans without loosing the ability to predict the cumulative consequences to large marine ecosystems.

This presentation discusses the concept of ecosystem modeling and focuses on two examples representing small and medium scale semi-enclosed marine ecosystems using a modified coastal ocean circulation model (Blumberg and Mellor 1987). Xincun Lagoon in southeast Hainan Island is a 21.97km$^2$ (~ 6 km X ~ 4 km) with a maximum depth of 10.6 m and 120 m wide outlet to the South China Sea. Xincun City, a major fishing port of ~ 15,000 people is on one shore of lagoon and the other shore is a wildlife reserve. The adjacent lagoon experienced a dramatic growth up to 230 ha of fish pen aquaculture in the 1996 followed by a catastrophic decline. The natural circulation in the lagoon combined with increased oxygen demand that was created by the fish pens was the likely reason for the disaster. Reducing the number of fish pens (33 ha) and the advent of a pearl and macroalgae culture resulted in a more sustainable aquaculture industry and environment. Data indicated that the surface water quality did not exceed China's National Water Quality Standards, but the pens were responsible for an estimated 5,000 tonnes of organic pollutants. Fish pens reduced bottom water and sediment quality. Low quality bottom water also flowed in and out of fish pen area with the tides, because of the slow turnover time (up to 90 days). Further analysis indicated that macroalgae culture on racks and seagrasses acted a nutrient scubbers and could play an important role by reducing ecosystem

risk of less desirable algal blooms (Rawson, *et al.* 2002).

The medium scale modeling experiment was conducted on Jiaozhou Bay that is a shallow bay of ~ 400 $km^2$ with an average depth of 7 m and maximum of 50 m. The adjacent city is Qingdao, which is one of China's largest ports and has a population > 2 million people. During the period of this study the bay contain three areas of scallop aquaculture pens. Simulation experiments with two pen stocking densities (12 individual $m^{-3}$ and 24 individuals $m^{-3}$) indicated that scallops dramatically decreased the concentration of phytoplankton in the culture areas. However, the impact of scallop culture was on nutrient concentrations were small (Chen, et. al 1999).

A new management model system has been developed under the fund of the Georgia Sea Grant Program based on the unstructured grid, finite-volume coastal ocean model (FVCOM: Chen et al., 2003). This system provides powerful management tool that allows aquaculture to be integrated into the broader context of coastal and large marine ecosystem management. Fed aquaculture does create pollution, but aquaculture is rarely the only pollution source. We must address the issue of aquaculture's contribution to pollution and find practical solutions to these complex problems.

# Zero Impact Offshore Mariculture in the Pacific Northwest U.S.

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Finfish mariculture has existed in the Pacific Northwest for over thirty years, benefiting from good growing conditions and a practical, science-based, state regulatory system. All existing commercial salmon farms in Washington State meet or exceed rigorous government performance standards. However, the industry is small and static; permitting begins locally where shoreline residents have opposed new mariculture sites inshore. The Strait of Juan de Fuca (the “Strait”) is a large area with sparse development and many advantages for mariculture. This U.S. NOAA-OAR sponsored study quantified conditions, probable impacts and possibilities for finfish culture in the Strait.

We conducted a literature review of hydrographic conditions in the Strait to contrast to the physiological requirements of candidate species. Field sampling in the 20 to 40m depth range included far field circulation studies, current and wave height/frequency, nutrient and algal sampling and other studies in three different regions. Results were compared to existing, inshore fish farms nearby. To model effects, we constructed a simulation model and incorporated it into a new, 4 dimensional GIS software (EASy: Environmental Analysis System). The model accounts for growth and metabolic oxygen demands of caged fish and includes the response of algae to nutrients and grazing. It indicates no probable adverse effect of large fish farms in the Strait. We expect the model will be useful in other coastal regions where oxygen or nutrient sensitivity of algal stocks to a developing offshore mariculture industry is a potential concern (e.g., semi-tropical, tropical areas).

Microalgal growth stimulation as a result of fish culture will not occur; the area is naturally replete with dissolved inorganic nitrogen (~10-30 μM). Fish-killing harmful algae were rarely observed and then only in sparse numbers, matching past experience. Tidal current velocities average near 0.3 m/s with extreme velocities of 1 m/s. These flow rates are suitable for larger fish in pens but demand use of modern offshore cages and revised management techniques. No permanent benthic sedimentation will occur in the studied areas due to strong currents. Ocean swell is sometimes moderate in the nearshore western Strait, grading to minimal in the eastern end. Wind waves are usually moderate.

Water temperatures range from 7 to 12˚C and should benefit candidate fish species such as black cod or halibut. From midsummer to fall dissolved oxygen concentrations are lower in the Strait due to oceanic upwelling with variance from hourly to annual time scales. Field surveys showed no detectable dissolved oxygen differences among survey locations in the Strait and nearby inshore fish farms, but sampling was limited considering the degree of variability. Summer water temperature was strongly and positively correlated to concurrent dissolved oxygen concentrations in our vertical profiles. Slightly but persistently lower sea surface temperatures were observed in satellite imagery for the central Strait region, and may be indicative of lower dissolved oxygen there. Therefore, eastern and western areas of the Strait may be marginally better for fish culture on this account. Reduced dissolved oxygen is mitigated by high delivery rates and minimal slack tide periods averaging only ~ one minute per day. Adverse environmental impacts from fish mariculture will be minimal or undetectable if properly planned and conducted in the Strait of Juan de Fuca.

# DIRECT PAYMENT SYSTEM TO PROMOTE THE APPROPRIATE MANAGEMENT OF AQUACULTURE GROUNDS

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Aquaculture occupies an important role in Japanese fisheries. And aquaculture plays various roles and functions through its activities and its existence as well as food supply. But it is becoming a problem in that leftover feed and excrement causes coastal environmental pollution. A subsidy system is already in place in the EU and U.S.A. to compensate for the decreased revenue and increased costs incurred by reducing environmental damage by agriculture. In this study, I consider a plan to apply a similar subsidy system to Japanese aquaculture.

## An AIP Workshop: *"The Role of Aquaculture in Integrated Coastal Management: An Ecosystem Approach"*

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The Aquaculture Interchange Program (AIP) was established in 1999 at The Oceanic Institute in Hawaii, via the funding support of the National Oceanic and Atmospheric Administration, to explore topics that address critical impediments to aquaculture development in the U.S. One of the most cost-effective methods to obtain new technology or information is through consultation with experts in the area of interest, especially for the U.S., where aquaculture is a new industry. Learning from the experience of other major aquaculture producing countries can help to accelerate the growth of U.S. aquaculture. Also, through information exchange, it is possible for aquaculture producing countries to standardize their operations in a sustainable manner. To date, AIP has conducted eleven international workshops to exchange culture technology among experts in a wide range of areas in the field, including reproduction, hatchery management, grow-out, health management, protein sources for aquafeed, live feed, and environmental concerns. The next AIP workshop will discuss on using aquaculture to balance the ecosystem.

The role of aquaculture production in supplying the world with seafood has increased annually during the past decades. As aquaculture operations expand, conflicts with other users of natural resources will arise. More and more aquaculture operations have to move to offshore. Widely-publicized criticism, however, of the negative impacts from cage aquaculture to the surrounding environment, regardless of its being based on scientific evidence or not, can hinder the development of the industry. Good stewardship in offshore aquaculture can help optimize the function and health of ecosystems (McVey, 2001; Stickney and McVey, 2002). Therefore, it is imperative to gather international experts to discuss practices that maximize the positive contributions of aquaculture to surrounding ecosystems. Forecasting the environmental effects of aquaculture through predictive and hydrological modeling is useful for selecting future aquaculture sites that contribute to a balanced ecosystem (Choo, 2001).

In additional to highlight the accomplishments so far and the access to those information, this presentation will discuss on the plan and expected outputs from our next workshop.

# *Ulva sp*. and *Undaria undarioides* Culture for Reduction Nitrogen and Phosphorus from Fish Culture Area in Wakayama Prefecture, Japan

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The amount of nitrogen and phosphorus are loaded from intensive fin-fish culture by metabolic extraction. We examined the balance of nitrogen and phosphorus loading and uptake by seaweed *Ulva sp*. and *Undaria undarioides* in fish culture cages. We used the cages (3×3×3m) at the fish culture area in Wakayama Prefecture, Japan. The cages cultured with red sea bream (*Pagrus major*) contained 225 individuals of 74.1g (mean weight) at 18-28ºC in autumn for 96 days, and 260 individual of 172.7g (mean weight) at 14-18ºC in winter for 89 days. The nitrogen content retained in fish body with feeds was 18.6% and the remaining nitrogen was loaded into the seawater. Phosphorus retained in fish body with feeds was 28.2% and remaining phosphorus was loaded into the seawater. It can be estimated that 25.0g nitrogen/day and 4.3g phosphorus/day were dissolved during autumn. In winter, almost the same nitrogen and phosphorus percentages (16.9%, 24.8%) were retained in fish body, and 83.1% nitrogen and 75.6% phosphorus was loaded into the seawater It can be estimated that 13.4g nitrogen/day and 2.4g phosphorus/day were dissolved in winter. Intakes of nitrogen (2.5g/g wet weight /day) and phosphorus (0.16g/g wet weight/day) by *Ulva sp*. were estimated from the result of growth rates in autumn. *U. undarioides* had 5.4g/g wet weight/day and 0.6g/wet weight/day nitrogen phosphorus intakes, respectively, from growth rates in winter time. Culture cage of *Ulva sp*. set adjoining red sea bream culture cages assimilated 10% of nitrogen and 3.7% of phosphorus excreted from cultured fish, yielding a load of 33kg of *Ulva* sp. in autumn. In winter, *U. undarioides* culture set in rope encircling Red sea bream culture cage assimilated 40.5% of nitrogen and 24.8% of phosphorus excreted from cultured fish, yielding a load 161kg of *U. undarioides*. The production seaweeds can be used as feed of top shell (*Turbo cornutus*) and abalone (*Notohaliotis sieboldi*) and as food for humans.

This study was done as part of an enterprise of Wakayama Prefecture Collaboration of Regional Entities for Advancement Technological Excellence and JST.

# THE GROWTH, N, P UPTAKE RATES AND PHOTOSYNTHETIC RATE OF SEAWEEDS CULTURED IN COASTAL FISH FARMS

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To improve the water quality in coastal *Seriola quinqueradiata* and *Pagrus major* farms throughout year, we cultured *Undaria pinnatifida* at 12～19ºC, *Laminaria japonica* at 13～26 ºC and *Ulva pertusa* at 17～28 ºC in the Yatsushiro Sea. The growth, N,P uptake rates and photosynthetic rate of seaweeds cultured were estimated.
The growth of the seaweeds cultured were identified and measured. Each of the seaweeds cultured was collected monthly and analyzed for N,P. The observed N,P uptake rates per the blade and thallus area($P_{N,P}$, mg N,P/$m^2$/day)of each seaweed cultured were calculated by the following formula: $P_{N,P} = (C_{N,Pt} - C_{N,P0}) \cdot \alpha / t$, where $C_{N,P0}$ is the N,P contents at the start of the experiment(mg N,P/g dry), $C_{N,Pt}$ is the N,P contents day $t$(mg N,P/g dry), α is the dry weight per the blade and thallus area, and $t$ is the cultivation days. The calculated N,P uptake rates of the seaweeds cultured were estimated from the dissolved inorganic nutrients concentrations, irradiance, and water temperature characteristics found at the fish farms. The photosynthetic rates of the seaweeds cultured were measured by the Winkler's method used light and dark oxygen bottles on fine day in the fish farm.
The maximum growth rates of the blade length of *U. pinnatifida* and *L. japonica* were 4.2 and 3.0 cm/day and maximum sizes reached to 182 and 250 cm in 2 m layer, respectively. The maximum growth rate of the thallus area of *U. pertusa* was 41 $cm^2$/day and maximum size approached to 640 $cm^2$. in 0.5 m layer. The maximum N, P uptake rates (Pm) of *U. pinnatifida* and *L. japonica* in blade and *U. pertusa* in thallus were 3.1, 2.9, and 3.6 mg N/$m^2$/day and 0.54, 0.43, and 0.19 mg P/$m^2$/day, respectively. Maximum Pm for *U. pinnatifida*, *L. japonica* and *U. pertusa* occurred at irradiances of 670, 720, and 730 $\mu$mol/$m^2$/s, respectively. The water temperature coefficients of N,P uptake rates by *U. pinnatifida*, *L. japonica,* and *U. pertusa* were 1.090, 1.071, and 1.076 for N uptake and 1.081, 1.084, and 1.062 for P uptake, respectively. The calculated values of N,P uptake rates of integrated dissolved inorganic nutrients concentrations, irradiance, and water temperature characteristics corresponded well with the observed values. The maximum gross oxygen production rates (Pm') of *U. pinnatifida* and *L. japonica* in blade and *U. pertusa* in thallus were 830, 750, and 6,390 mg $O_2$/kg wet/h, respectively.
The allowable volume of seaweeds cultured for N uptake to N load in fish farming area, and for oxygen production to oxygen consumption by a fish cultured in cage were estimated by using the Pm and Pm' values, respectively.

# THE BIOREMEDIATION POTENTIAL OF ECONOMICALLY IMPORTANT SEAWEED IN INTEGRATED AQUACULTURE SYSTEMS WITH FINFISH

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The value of cultivated, managed and wild harvested seaweeds exceed over $U.S. 6.0 billion with 87% of this value derived from aquaculture. The most valued of the maricultured seaweeds is the red alga *Porphyra*, or nori. It is a major source of food for humans throughout the world, although it is primarily cultivated in Asia (China, Japan and South Korea). Worldwide production is approximately 14 billion sheets, with an annual value of over $U.S. 1.8 billion. In addition to *Porphyra*, other edible seaweeds include *Gracilaria*, *Undaria*, *Laminaria* and *Caulerpa* with their collective value exceeding $U.S. 3.0 billion. Seaweeds are also the industrial sources of carrageenans (*Chondrus*, *Eucheuma* and *Kappaphycus*), alginates (*Ascophyllum*, *Laminaria,* and *Macrocystis*) and agars (*Gelidium* and *Gracilaria*). These important polysaccharides are used in the food, textile, paint, biotechnological and biomedical industries and have a global value of approximately U.S. $580 million. Seaweeds have significant value in agriculture as soil additives, fertilizers and seaweed meals with their value over $U.S. 20 million. The increasing demand for safe, healthy, and minimally processed foods is creating an opportunity for seaweed products as functional foods, nutraceuticals, and alternative medicinal products. There is now renewed interest in using seaweeds as nutrient removal systems in integrated aquaculture of finfish, shellfish and crustaceans. Nutrification of coastal waters as a result of anthropogenic activities is a worldwide phenomenon. The development of integrated aquaculture practices appears increasingly necessary to remedy the economic and environmental limitations of monospecific aquaculture whose sustainability is questionable. To address this pressing environmental issue, the bioremediation potential of several *Porphyra* species has been assessed for open water (*Porphyra*/salmon) and land-based (*Porphyra*/flatfish) systems. The bioremediation role of other seaweeds (*e.g. Kappaphycus*), acting as biological nutrient removal systems, and the mutual benefits for co-cultured organisms will also be illustrated. Properly planned integrated aquaculture systems will enhance the health of coastal waters and will benefit the aquaculture industry, which needs to move in new directions.

# Model Management Plan to Optimize Production of Marine Tropical Systems

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NOAA, the University of Puerto Rico Sea Grant College Program and other federal, state and private partners are proposing to develop model management plans suitable for tropical marine ecosystems. Recent advances in the development of offshore, submerged, marine aquaculture technology for island locations has provided a new tool for managing island coastal resources. In this paper we offer a new ecosystem-based management scenario using aquaculture to optimize value and function of tropical island ecosystems. Puerto Rico offers an excellent opportunity to unite several management plans while maintaining the flexibility to work with user groups to manage and optimize sustainable production from marine tropical systems. Puerto Rico has several examples of tropical ecosystems available for study ranging from the high energy coastlines found on the northeast coast to low energy, mangrove shorelines on the southwest coast. Coral reefs are prevalent in low energy areas. All Puerto Rico coastal communities have seen a decline in fishery resources and habitats leading to a decline in value from these resources and a new approach for coastal resource management is needed.

# New Approach for the Integrated Aquaculture Management from the View Point of Multi-functional Role of Fisheries and Aquacultures

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Supply of food, in particular of protein food has long been widely accepted as major role of fisheries and aquaculture for human society. However, recent growing concern on the global environmental issue and sustainable development is now making clear that fisheries and aquaculture also play important roles on material cycling between land and sea, monitoring of fishing environment and living resources, purification of pollutant through heterotrophic activities of organisms and food chain, environmental watching by fisherman, environmental education, ecotourism and so on. On this context, Science Council of Japan submitted a special report to the Minister of Agriculture, Forestry and Fisheries very recently (Aug. 2004) on the contents and evaluation of multiple roles and functions of fisheries and fishing communities, in which role on environmental conservation, role on formation of regional community, role on maintaining personal security, role on providing fields of education and many kinds of amenity were highlighted as well as the role of food supply. Responsible and sustainable aquaculture also can play important functional roles in many ways. As an example of possible new approach for the integrated aquaculture management from the view point of multi-functional role of aquaculture, present status and possible future direction of large scale oyster culture in Hiroshima Bay, Japan are examined, where very long experience of oyster culture, monitoring and management of paralytic shellfish poisoning are accumulated. Interdisciplinary investigation on the restoration of deteriorated Hiroshima Bay environment also started in April, 2004 by the prefecture government. For the future direction, integrated oyster culture management responsible for regional economy and employment are proposed with particular reference to safe and clean oyster meat supply, sea cucumber resource enhancement by raft oyster culture system, recovery of discharged N and P from land, environmental and red tide monitoring system, many varieties of recreation, seascape, eco-tourism and environmental education for especially younger generation. This proposed integrated oyster culture management should be involved in the more holistic environmental and ecosystem management by much variety of stakeholders as a part of integrated coastal management of Hiroshima Bay including watershed and land use management of Ohta River watershed which has strong influence on the biological productivity and diversity of the ecosystem in Hiroshima Bay.