Preface

In November 2006, the 35th Japan-US Joint Meeting of UJNR (U.S.-Japan Cooperative Program in Natural Resource) Aquaculture Panel was held in National Research Institute of Aquaculture in Minami-ise, Mie Prefecture. Through the long history of UJNR, Aquaculture Panel has contributed to development of aquaculture researches of both countries by means of various cooperative activities, i.e. the exchange of scientists, the exchange of literatures and promoting joint research projects. It is understood that the Aquaculture Panel is one of the most active UJNR panels by both countries. Further positive action is expected to the UJNR Aquaculture Panel for a solution of the varied problems presenting in aquaculture of both countries.

The present special issue of Bulletin of Fisheries Research Agency is the proceedings of the 35th UJNR Aquaculture Panel Symposium "Building Sustainable Food Supplies through Aquaculture, Wild Stock Enhancement, and Habitat Management" which is held in accordance with the 6th UJNR five-year plan.

Development of aquaculture in harmony with the environmental conservation of coastal and freshwater ecosystems is extremely important for stable supplies of aquatic products, and the issue has been globally a common theme. It is my great pleasure that the present UJNR proceedings containing high quality papers of the selected American and Japanese aquaculture scientists will help integrating aquaculture and fisheries technologies to optimize value from coastal resources, zoning for aquaculture, use of biotechnology in aquaculture and effects on natural population, and improvement of public perception.

Finally I would like to express my sincere gratitude to the colleagues involved in the UJNR Aquaculture Panel for their efforts to prepare and organize the symposium. I also would like to deeply thank the editorial board members for publishing the proceedings.

Hiroshi Nakano
Chair of UJNR Aquaculture Panel
Director General
National Research Institute of Aquaculture
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The 35th Scientific Symposium of the UJNR Aquaculture Panel

Building Sustainable Food Supplies through Aquaculture, Wild Stock Enhancement, and Habitat Management

National Fisheries Research Institute of Aquaculture, Mie
November 13th-14th, 2006

Key note of the symposium

The role of aquaculture in stabilizing food supplies has been globally important, while production based on capture fisheries has become depressed due to the decline of wild resources. Since the sustainable use of resources in the exclusive economic zone (EEZ) was made an obligation by the United Nations Convention on the Law of the Sea, aquaculture technology R&D aimed to maintain sustainable production while preserving coastal environments and ecosystems have become the common issues to the US and Japan.

The UJNR Aquaculture Panel has discussed various science and technologies as follows: 1) algae and filter feeders aquaculture, 2) crustacean aquaculture and pathology, 3) ecosystems and carrying capacity of aquaculture grounds, and 4) finfish aquaculture in accordance with the 6th 5-years Plan (2002-2006). During the last year of the plan, how to achieve sustainable fisheries production and food supplies through aquaculture and stock enhancement was explored among aquaculture scientists as well as socio-economists and member of governmental sectors, while summarizing discussions covering previously developed aquaculture technologies.

In the present symposium, the following issues were discussed in order to promote the future sustainability of the fisheries community and fisheries industry by means of aquaculture and stock enhancement.

1. Aquaculture technologies harmonized with coastal ecosystems to realize sustainable production
2. Sustainable stock enhancement technologies harmonized with the ecosystem
3. Environmental conservation and mitigation technologies for sustainable use of aquaculture grounds
4. Sociological and economic measures for sustainable development and use of coastal resources

Key Categories: Integrating aquaculture and fisheries technologies to optimize value from coastal resources, zoning for aquaculture, use of biotechnology in aquaculture and effects on natural population, improvement of public perception

Program

Monday, November 13th, 2006 Registration 12:30-14:00

NRIA tour for guests · 13:00-14:00
Opening remarks (Yasuji Sakai, Japan Panel Chair) · · · · · · · · · · · · · · · · · 14:00-14:10
Aim of the symposium (Kazumasa Ikuta) · 14:10-14:15
Keynote presentation (Moderators: Kunihiko Fukusho & Conrad Mahnken)
· 14:15-15:00
An Overview of the US/Japan UJNR Aquaculture Panel: Past, Present and Future
James P. McVey

Break · 15:00-15:20

Session Ⅰ. Aquaculture technologies harmonized with coastal ecosystems to realize sustainable production (Moderators: Cheng-Sheg Lee & Takao Yoshimatsu)

1. Recent Progress in Closed Recirculation Seed Production System for Environmental Preservation in Japan · 15:20-15:45
   Yoshihisa Yamamoto
2. Utilization of Waste *Porphyra* Products as Eco-friendly Feed Ingredients · 15:45-16:10
   Tsuyoshi Sugita
3. The Relationship between Growth of Cultured Red Sea Bream (*Pagrus major*) and Method of Farming · 16:10–16:45
   Takashi Uede
4. Manila Clam and Pacific Oyster Culture in Isahaya Bay- For the Sustainable Production in Stressful Environment- · · · · · · · · · · · · 16:35–17:00
   Junya Higano

Tuesday, November 14th, 2006 Registration 8:30- 9:30

Keynote presentation (Moderators: Charles E. Helsley & Satoru Toda)
Recent Attempt towards Environmental Restoration of Enclosed Coastal Seas:
Ago Bay Restoration Project Based on the New Concept of *Sato-Umi*
· 9:30-10:15
Osamu Matsuda

Break · 10:15-10:35

Session Ⅱ. Environmental conservation and mitigation technologies for sustainable use of aquaculture grounds (Moderators: Thomas A. Flagg & Hisashi Yokoyama)

1. The Role of Aquaculture in Integrated Coastal Management · · · · · · 10:35-11:00
   Charles E. Helsley
2. New Technology for Developing Biologically Productive Shallow Area in Ago Bay
   · 11:00-11:25
   Hideki Kokubu

3. Stable Isotope Analyses of the Trophic Structure of Macrobenthos on an Artificial Tidal Flat Developed Using Sediments Dredged from Pearl-oyster Farms in Ago Bay · 11:25-11:50
   Yuka Ishihi

Announcements · 11:50-12:00
Lunch · 12:00-13:00

Session Ⅲ. Conservation of biodiversities and ecosystems for sustainable use of aquatic resources (Moderators: William Fairgrieve & Hiroyuki Sudo)

1. Introduced Species and Aquaculture · 13:00-13:25
   Cheng-Sheng Lee
2. Countermeasures against Alien Fish (Largemouth Bass and Bluegill) in Lake Biwa · 13:25-13:50
   Atsuhiko Ide
3. Conservation Aquaculture Approaches for Hatchery Reform · · · · · · 13:50-14:15
   Thomas A. Flagg
4. Environmental Standards for Marine Aquaculture in the United States; Minimizing Negative Interactions of Escaped Farm Fish and Natural Populations · · 14:15-14:40
   Conrad Mahnken

Break · 14:40-15:00

Session Ⅳ. Sociological and economic measures for sustainable development and use of coastal resources (Moderators: Kazumasa Ikuta & James J. Sullivan)

1. Accounting for Economic Risk and Uncertainty in Offshore Aquaculture: A Case Study of Korean Rock Bream Production · · · · · · · · · · · · 15:00-15:25
   Douglas Lipton
2. Economic Evaluation of Various Roles and Functions of Propagation and Aquaculture · 15:25-15:50
   Yasuji Tamaki
3. Risk and Risk Management for Feed and Seed for Carnivorous Marine Fish Aquaculture · 15:50-16:15
   Michael B. Rust
4. Ecological Risk Assessment of Marine Fish Aquaculture in the Coastal Zone · 16:15-16:40
   William Fairgrieve
5. The Measures for Sustainable Marine Aquaculture in Japan · · · · · · · · 16:40-17:05
   Ikuo Takeda

General discussion (Moderators: Panel members) · · · · · · · · · · · · · · · · 17:05-17:30

Closing remarks (Robert Iwamoto, U.S.A. Panel Chair) · · · · · · · · · · · · · · 17:30-17:40

An Overview of the US/Japan Natural Resource's Panel on Aquaculture: Past, Present and Future.

James P. McVey*

Background: The United States Japan Cooperative Program in Natural Resources (UJNR) was initiated by a proposal made during the Third Cabinet-Level Meeting of the Joint United States-Japan Committee on Trade and Economic Affairs in January 1964. An aquaculture panel was formed in 1969 and was charged with exploring and developing bilateral cooperation. In addition to the aquaculture panel, their were other programs on desalination of seawater, toxic microorganisms, air pollution, energy, forage crops, national/park management, mycoplasmosis, wind and seismic effects, protein resources, forestry and several joint panels in marine research, development and utilization.

The First Joint Meeting of the U.S.-Japan Cooperative Program in Natural Resource's Panel on Aquaculture was held in Tokyo, Japan, on October 18-19 and 29, 1971

Dr. Atsushi Furukawa and Mr. William N. Shaw, were elected co-chairmen for the Meeting and were accompanied by Robert Hiatt, Robert Wildman Harvey Willoughby, A. Crosby Longwell, John Glude and Cornelius Mock on the US side and Yoshio Hasegawa, Yukimasa Kuwatani, Shunzo Suto, Hiroshi Kan-no, Tomoo Hayashi and Masaru Fujiya on the Japan side. This meeting included presentations by both sides and a week long field trip to see aquaculture site in Japan. The Japan presentations were on marine cultivation in Hokkaido, seaweed mariculture, freshwater culture, shellfish culture, finfish culture in Japan. The US presentations were on Penaeid shrimp larval culture, Sea Grant research, mollusc culture in S. Atlantic, Gulf and Pacific NW, genetics of American oyster, and freshwater fish culture.

A second meeting of the Aquaculture Panel was held in the United States in Washington, DC and Seattle, Washington in 1972. Dr. Furukawa and William Shaw remained the Chairs and they identified Nutrition and Pathology as issue of mutual concerns and scientific exchanges were planed on these topics.

These early meetings established the general format for conduct of the UJNR technical exchange that we have followed throughout the 35 year history of the program. Meetings are alternated between the two countries on an annual basis with a two day symposium and then a field trip for the delegations to view the research facilities and observe the industry. During this time there is adequate opportunity for individual scientists to talk with one another regarding topics of mutual interest and to identify joint research projects. These projects can be supported in a formal way under the UJNR structure or arranged between cooperating institutions, both Federal and academic.

Since that time 35 years ago there have been annual meetings alternating between our two countries on a broad range of topics:

- 71 Overview papers of Japan and US
- 72/73 Pathology and Nutrition
- 74 Pathology
- 75 Nutrition
- 76 General Discussion FAO meeting
- 77 Marine Algae
- 78 Marine Fish
- 79 Freshwater and Marine overviews
- 80 Crustaceans

2009年8月10日受理（Received. August 10. 2009）
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- ・81 Molluscan Aquaculture
- ・82 Salmon Enhancement
- ・83 Reproduction, maturation and seed production
- ・84 Environmental Quality
- ・85 Innovative Advances Bio/Engineering
- ・86 Marine farming and Enhancement
- ・87 Genetics
- ・88 Marine Ranching
- ・89 Reproductive Physiology
- ・90 Disease
- ・91 Nutrition
- ・92 Environmental Management
- ・93 Interactions of Cultured and Natural Species
- ・94 Biological Control of Salmon and Advanced Tech
- ・95 Water Effluent & Quality, Fish and Shrimp
- ・96 Biodiversity and Aquaculture
- ・97 Nutrition and Technology Development
- ・98 Goals and Strategies for Breeding
- ・99 Spawning and Maturation
- ・00 Pathogenic Organisms/Stock Enhancement
- ・01 Ecology of Aqua species/stock enhancement
- ・02 Aquaculture and Stock Enhancement Algae/ Filter feeders
- ・03 Pathology of Crustaceans
- ・04 Ecosystem Carrying Capacity/Sustainable Development
- ・05 Aquaculture Stock Enhancement

These topics were identified in a series of five year plans and we have just completed the sixth five year plan with this, the 35th meeting of the UJNR Aquaculture Panel. Studying the flow of topics over time there are trends that follow the development of the industry in both Japan and the US.

During the first five years of our cooperation there was an emphasis on understanding the issues in each country and formulating a plan for the best areas of cooperation. The first two meetings were spent on providing overviews of national research activities and identifying two research topics: nutrition and pathology, that were important to both parties. These themes were discussed in the next two meetings and then, in 1976, Japan hosted the strategic United Nations Food and Agriculture Organization (FAO) meeting on world aquaculture that served to focus world attention on the issue of aquaculture and set the course of research for the next decade. The UJNR met as part of the FAO meeting and I had the honor of attending that meeting as a young scientist just starting his career.

During the next five year period the UJNR symposiums tended to focus on culture of different phyla and species, i.e. marine fish, algae, crustaceans, mollusks, salmon. These discussions allowed us to look at the life histories of these groups as well as the technical and husbandry aspects of their culture.

During the next ten year period we continued to discuss the basic disciplines underlying the industry needs and we saw the appearance of marine biotechnology as applied to aquaculture. This advanced technology used for diagnosis of pathogenic organisms, control of endocrine processes for reproduction, and genetic manipulation of marine species has been an important part of our technical exchange. It was during this period that serious questions about environmental issues related to aquaculture started to be asked and the 1984 meeting focused on this topic.

Starting in 1992 we held a series of meetings related to environmental issues:

- ・92 Environmental Management
- ・93 Interactions of Cultured and Natural Species
- ・94 Biological Control of Salmon and Advanced Tech
- ・95 Water Effluent & Quality, Fish and Shrimp
- ・96 Biodiversity and Aquaculture

These meetings helped define the key issues relative to environmental concerns about aquaculture. These issues were being discussed by scientists around the world and by the media and the press. It was during this time period that the rise of Non Government Organizations (NGO's) concerned about environmental matters turned their attention to aquaculture issues. The UJNR Aquaculture Panel helped to bring science to these issues and I believe helped both countries to define the research needed to provide solutions. It is very important to have the view of more than one country when looking at broad issues as individual countries have different public views of any developmental technology. This will become more apparent during the discussion that comes later in this paper.

From 1997 to 2003 we see the topics turning back towards the disciplinary subjects of genetics, pathology, nutrition, endocrinology and biotechnology. This time period corresponded to a leveling off of aquaculture production in both countries as well as a sharp decline in wild fishery production. Increased imports were needed in both Japan and the US to meet public demand. Supply of seafood shifted to more imports than domestic production and the economics associated with seafood changed accordingly. Prices fell.

The most recent meetings, 2004 and 2005, as well as this meeting entitled "Building Sustainable Food Supplies through Aquaculture, Wild Stock Enhancement and Habitat Management", are adjusting to the shift of world opinion about the need to manage coastal resources in a more holistic manner. Many are attempting to move towards ecosystem-based management or integrated coastal management and away from single species management for seafood and living resources. In 2005 Japan and the US participated in a meeting with China, Korea, Viet Nam, Canada and representatives from Chile, European Union, Taiwan and Malaysia to discuss the role of aquaculture in ecosystem based management. This will be discussed later in this paper.

Significant Accomplishments:

- Approximately 530 oral presentations at Symposia evenly distributed between both countries as determined through 32 published Proceedings.
- Thousands of scientists and students attending symposia and meetings.
- Exchanges of scientists, students and scientific information between Federal, Provincial, and academic institutions. A perusal of UJNR documents indicates that the US sent a minimum of 104 scientists to Japan and Japan sent 327 scientists to the US during our cooperation to date.
- Aquaculture is being integrated into the new paradigm of ecosystem-based management for seafood supplies in several countries.
- Creation of UJNR websites in both countries that are updated periodically to provide information on the science and accomplishments of UJNR

This list of accomplishments does not take into account the increased cultural understanding between our two countries, the formulation of long term friendships between scientists, the broadening of understanding of world issues, the establishment of career lines or focus for young scientists.

Status of Marine Aquaculture in the US and Japan:

It is important to put this flow of research and discussion into context with the status of the aquaculture industry in our two countries. Attached are graphs showing the growth of production of marine aquaculture in our respective countries during 1970 to the present. I have not included freshwater aquaculture statistics in order to simplify the analysis and reflect the primary focus of US/Japan cooperation.

In 1970 Japan had marine aquaculture production of approximately 550,000 tons compared to the US production of about 130,000 metric tons (Figure 1)(FAO statistics 2006). Japan had a fairly broad range of species that they were producing including mollusks, finfish, crustaceans and algae while the US production was mainly in mollusks. Over the course of the 70's decade Japan's production increased dramatically to nearly 900,000 tons while US production of mollusks actually declined to about 100,000 metric tons. This decline was probably due to loss of habitat and increases in disease in molluscan stocks.

In the 1980's Japan's marine aquaculture production increased to nearly 1,300,000 tons and US production rose slightly back to pre-1970 levels of about 130,000 (Figure 2). The rise of US production corresponds to increased shellfish production resulting from improvements in hatchery supply of commercial mollusks and the initiation of coastal shrimp and salmon farms in some states.

During the 1990's (Figure 3) both the Japan and US marine aquaculture production leveled out at the levels realized at the end of the 1980's. There appeared to be a slight decline in Japan's production by the end of the decade and the US remained essentially level around 130,000 metric tons.

During the last four years of the statistics available from FAO, Japan has again declined slightly in its marine aquaculture production while the US, for the first time, has moved up from 130,000 metric tons of production to over 200,000 metric tons in 2004(Figures 4 and Table 1). During this time period the value of marine aquaculture production in Japan was a little under $4 billion while the US production moved from $94 million

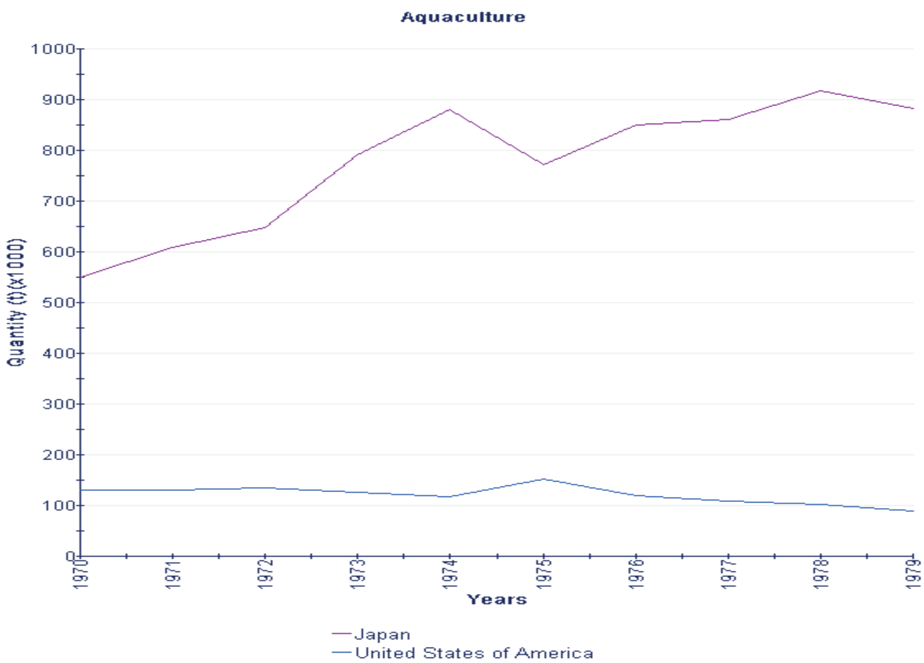

Fig. 1. 1970's Marine Aquaculture Production.

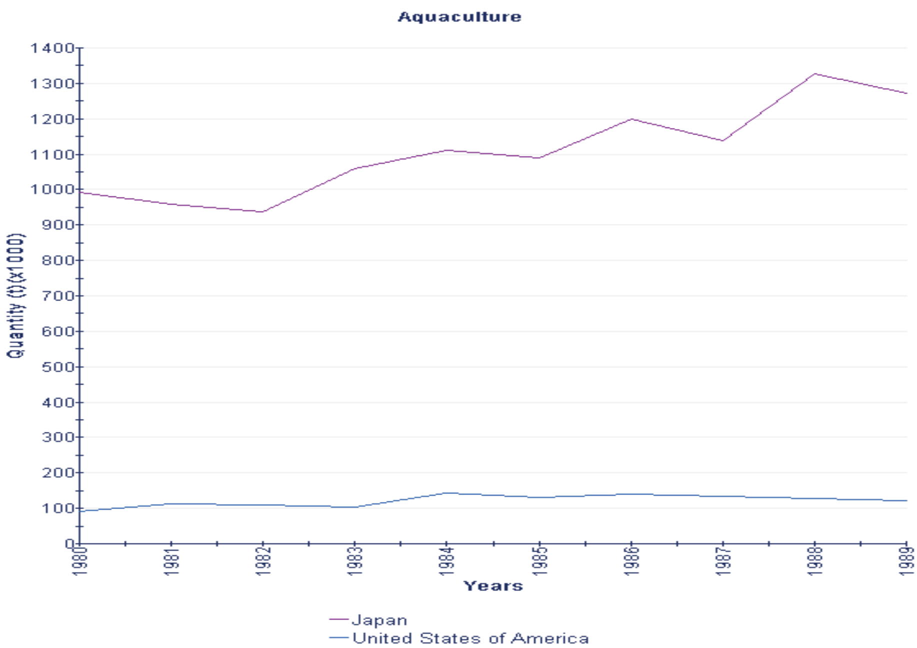

Fig. 2. 1980's Marine Aquaculture Production.

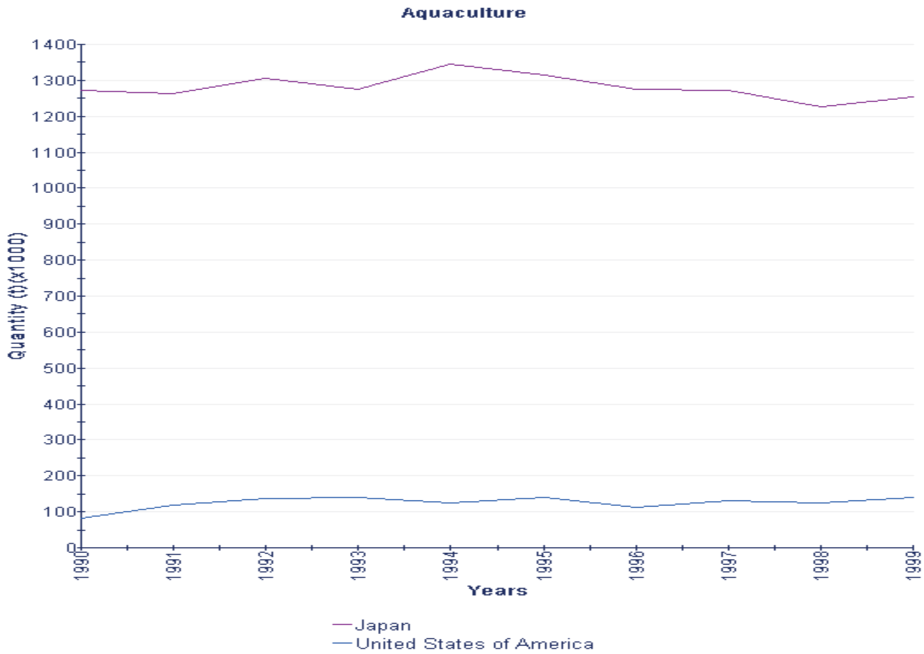

Fig. 3. 1990's Marine Aquaculture Production.

to $191 million or a doubling over the four year period (Figures 5 and Table 2). This increase for the US appears to be a result in a dramatic increase in mollucan production as well as the initiation of a marine finfish industry.

Significance of FAO statistics:

- Marine Aquaculture is a significant part of Japan's seafood supply and economic well being but has not expanded in last decade.
- Marine Aquaculture is a very small part of US seafood supply and is just starting to expand.
- The ten fold difference in production and value in marine aquaculture between the US and Japan may be attributed to differences in public perceptions and traditions, regulatory and policy structures, and timing relative to environmental issues among other factors.
- Possible factors influencing the stagnation of Japanese marine aquaculture production and the prolonged low production of US may be: response to competition from cheap seafood imports making the economics of aquaculture difficult, competition over limited space and resources in coastal zones, and concern over environmental impacts,
- The shift from self sufficiency in seafoods to importation of cheap seafoods has had a profound effect on both countries production and value of seafood. These observations, which represent my personal opinions, help set the stage for this years UJNR symposium.

UJNR 2006 Symposium Topic: Building Sustainable Food Supplies through Aquaculture, Wild Stock Enhancement and Habitat Management

This topic implies a holistic look at seafood production that includes aquaculture, fisheries, habitats and the coastal communities that depend upon these resources. We have a range of presentations from both US and Japanese scientists that will examine these issues and hopefully add to our understanding of these critical relationships.

This years UJNR meeting will build upon a multi-lateral meeting held with several key countries, mentioned earlier, that was attended by UJNR leadership last year in Hawaii entitled: The Role of Aquaculture in Ecosystem Based Management, This meeting came up with several products that add to this overall discussion, these are:

- Guiding Principles for Marine Aquaculture
- Coastal Managers' Considerations for Aquaculture and Integrated Coastal Management

- Requirements for Models used in Managing Coastal Aquaculture
- Country Scenarios for Ecosystem Based Coastal Aquaculture

We expect the publication of these products in book form in the next year and they can be added to the publication of the Proceedings of this meeting as we continue to look at aquaculture in coastal environments.

Questions for the Future:

Looking at the past 35 years of the United States and Japan Aquaculture Panel activities in combination with the analysis of aquaculture production in our respective countries as well as recent meetings and discussions on this year's topic I would like to offer several questions that might guide some of our discussions:

➢ How do developed countries develop their own aquaculture industry in the face of cheaper imports?

➢ How does large scale aquaculture integrate with fisheries and coastal communities in the coastal zone of developed countries?

➢ How do environmental concerns limit aquaculture development?

➢ What regulatory and financial changes need to be made to develop the aquaculture industry

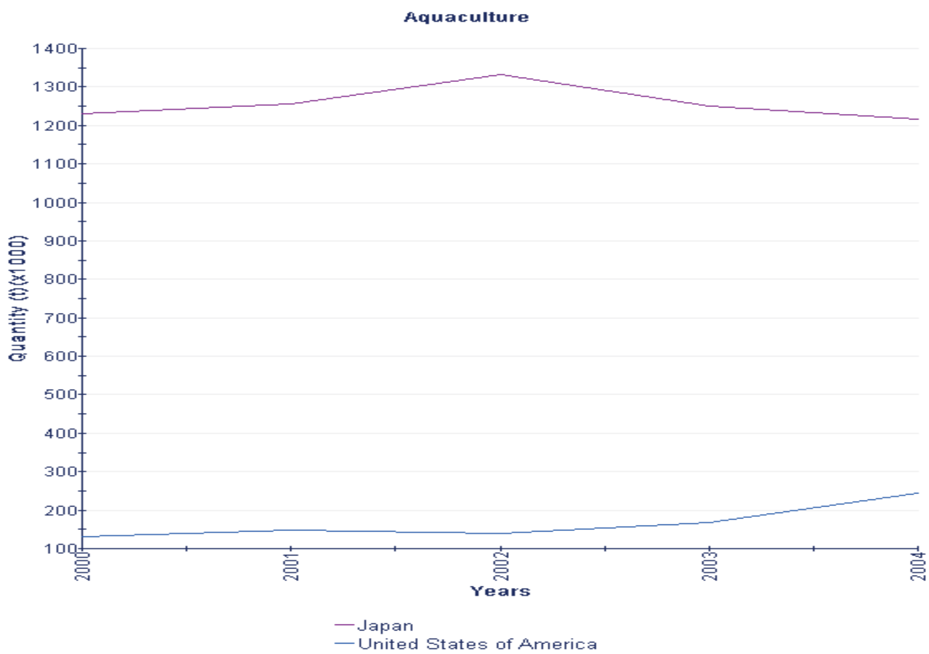

Fig. 4. 2000-2004 Marine Aquaculture Production.

Aquaculture: Quantity (t)

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Land Area	Ocean Area	Environment	Species	Scientific name	2000	2001	2002	2003	2004
Japan	Marine waters	Marine	Aquatic plants	Aquatic plants	528 574	511 448	557 951	477 705	484 389
			Marine fishes	Marine fishes	245 566	252 173	260 382	264 710	252 674
			Crustaceans	Crustaceans	2 086	2 004	1 778	1 824	1 818
			Molluscs	Molluscs	433 629	468 851	495 725	485 221	451 223
		Sub-total Marine			1 209 855	1 234 476	1 315 836	1 229 460	1 190 104
	Sub-total Marine waters				1 209 855	1 234 476	1 315 836	1 229 460	1 190 104
Total Japan					1 209 855	1 234 476	1 315 836	1 229 460	1 190 104
United States of America	Marine waters	Marine	Crustaceans	Crustaceans	2 163	3 564	4 026	4 577	4 731
			Marine fishes	Marine fishes	0 .	0 .	0 .	0 .	1 362
			Molluscs	Molluscs	105 689	122 463	121 717	145 979	221 717
		Sub-total Marine			107 852	126 027	125 743	150 556	227 810
	Sub-total Marine waters				107 852	126 027	125 743	150 556	227 810
Total United States of America					107 852	126 027	125 743	150 556	227 810
Grand total					1 317 707	1 360 503	1 441 579	1 380 016	1 417 914

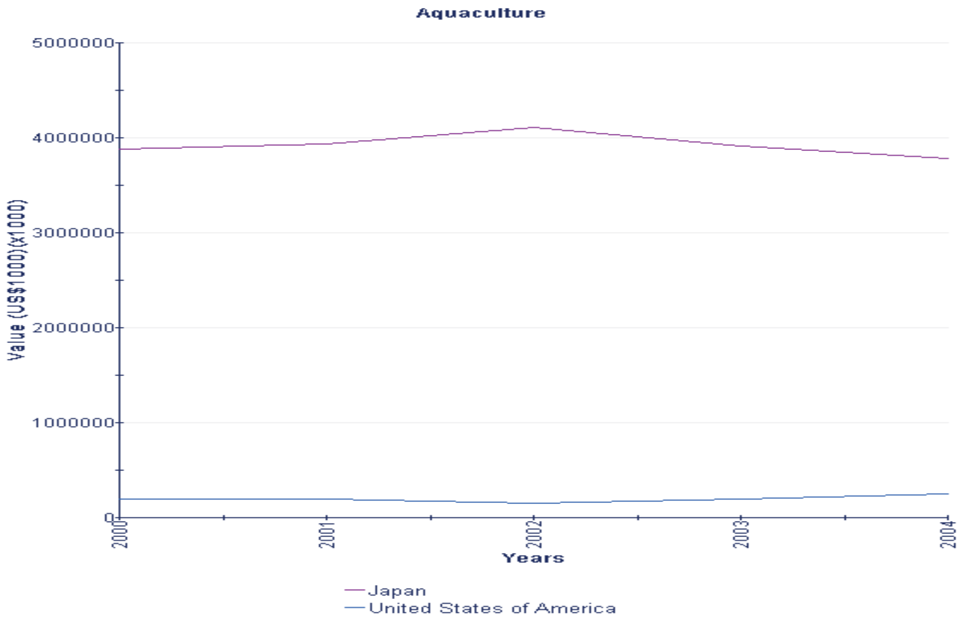

Fig. 5. 2000-2004 Marine Aquaculture Value.

Aquaculture: Value (US$1000)

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Land Area	Ocean Area	Environment	Species	Scientific name	2000	2001	2002	2003	2004
Japan	Marine waters	Marine	Aquatic plants	Aquatic plants	1 132 793	1 099 083	1 206 075	1 021 294	1 036 728
			Crustaceans	Crustaceans	13 559	13 026	11 557	11 856	11 817
			Marine fishes	Marine fishes	2 019 604	2 058 042	2 102 470	2 103 228	2 001 269
			Molluscs	Molluscs	652 536	705 368	746 416	730 257	679 077
		Sub-total Marine			3 818 492	3 875 519	4 066 518	3 866 635	3 728 891
	Sub-total Marine waters				3 818 492	3 875 519	4 066 518	3 866 635	3 728 891
Total Japan					3 818 492	3 875 519	4 066 518	3 866 635	3 728 891
United States of America	Marine waters	Marine	Crustaceans	Crustaceans	14 514	27 407	27 095	23 205	20 958
			Marine fishes	Marine fishes	0 .	0 .	0 .	0 .	6 292
			Molluscs	Molluscs	79 984	93 239	98 073	120 929	164 352
		Sub-total Marine			94 498	120 646	125 168	144 135	191 603
	Sub-total Marine waters				94 498	120 646	125 168	144 135	191 603
Total United States of America					94 498	120 646	125 168	144 135	191 603
Grand total					3 912 990	3 996 165	4 191 686	4 010 769	3 920 494

site last updated: Jan 1 1970

sector while protecting the environment?

➢What is the future of offshore technologies?

➢What predictive models and monitoring techniques will be necessary for situating and managing aquaculture in coastal areas

➢What genetic guidelines will be necessary for safe-guarding natural fishery stocks relative to aquaculture

➢How can we capture and recycle marine proteins and obtain alternative proteins and oils from both land and ocean for aquaculture diets

➢What diagnostic tools and disease treatments are appropriate for sustainable aquaculture

In closing, I would like to reflect on some additional FAO information that deals with the needs of the future:

· In 2006, FAO's "The State of World Aquaculture" reported that world aquaculture is now contributing 45.5 million tons (43%) of fish supply. The world will need 40 million tons more by 2030 based on present per capita consumption. Catches in the wild have leveled off and the only hope for meeting future demand is through farming. Imports of seafood by developed nations have reached 33 million tons valued at $62 billion.

These statistics show how far we have come and how far we have have to go! Aquaculture production is now nearly equal to wild fisheries production and the combination of the two equal our seafood supply. The loss of habitat, declining water quality in our coastal areas, the declining fisheries around the world, the limited amount of marine protein available for aquaculture feeds, the limited amount of space available for aquaculture in nearshore environments, presents great challenges to future production.

Working together the US and Japan have made great strides in providing aquaculture science and technology for developing world aquaculture. Technologies developed through our joint efforts are being used throughout the world and have helped lead to the increased production recorded in FAO statistics.

I anticipate that our cooperation will continue for a long time to come and the professional relationships and friendships that have evolved over the past 35 years will form the base of future endeavors.

Recent Attempt towards Environmental Restoration of Enclosed Coastal Seas: Ago Bay Restoration Project Based on the New Concept of *Sato-Umi*

Osamu MATSUDA*

Abstract Since the present status of the enclosed seas along the coast of Japan is more or less "damaged" or "deteriorated" mainly due to prolonged impact of human activities, environmental restoration followed by rehabilitation of the natural ecosystem is one of the most important subjects to be tackled from the view point of both environmental conservation and living resource management. Ago Bay is one of the deteriorated areas especially from the viewpoint of aquaculture grounds in Japan. Although the bay is known to be a world-famous cradle of pearl culture, conditions of the bay in terms of sediment quality, dissolved oxygen and harmful algal blooms have deteriorated during the long history of pearl culture. The ongoing "Environmental Restoration Project on Enclosed Coastal Seas" in Ago Bay mainly deals with restoration of deteriorated tidal flats and seagrass beds and also development of environmental forecasting technology based on environmental monitoring and modeling. Since the project conducted under the collaboration program of the Japan Science and Technology Agency with industries, academies and public services includes not only scientific and technological studies but also components of environmental education, environmental management and wider cooperation with varieties of stakeholders, it can be a model of environmental restoration and management of enclosed coastal seas. The outline of the project as well as its present status and future perspective is introduced with particular emphasis on the new concept of *Sato-Umi*, which in Japanese means coastal sea under the harmonization of sustainable wise use with conservation of appropriate natural environment and habitat conditions. An automatic monitoring system to monitor water quality has been established and real time observation data are open to the public through the Internet. Varieties of restoration methods for damaged shallow environments and habitats with the use of environment friendly technology based on the concept of *Sato-Umi* is being developed and applied in this project.

Key words: environmental restoration, environmental monitoring, enclosed coastal sea, Ago Bay, pearl culture, Sato-Umi

Introduction

Since the present status of the enclosed seas along the coast of Japan is more or less "damaged" or "deteriorated" mainly due to prolonged impact of human activities, environmental restoration followed by rehabilitation of the natural ecosystem is one of the most important subjects to be tackled from the viewpoint of both environmental conservation and living resource management. Among 88 officially designated enclosed coastal seas in Japan, Ago Bay is one of the deteriorated areas especially from the viewpoint of environmental quality and aquaculture grounds. Although the bay is known to be a world-famous cradle of pearl culture, environmental conditions in the bay in terms of sediment quality, dissolved oxygen in bottom water and occurrence of harmful algal blooms have deteriorated during the long

2009年8月10日受理（Received. August 10. 2009）
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history of pearl culture spanning more than 100 years. Ago Bay is located in Ise-Shima National Park, Mie prefecture, the central part of Japan and the enclosed topography of the bay surrounded by deeply indented rias-type coastline protects the intrusion of ocean waves from the sea and provides an adequate place for pearl culture.

The "Environmental Restoration Project on Enclosed Coastal Seas" conducted in Ago Bay during 2003-2007 under the collaboration program of the Japan Science and Technology Agency (JST) with industries, academies and public services mainly deals with restoration of deteriorated tidal flats and seagrass beds and also the development of environmental forecasting technology based on the real time environmental monitoring and modeling. The central organization for implementation of this project is the Mie Industry and Enterprise Support Center (MIESC) and the Mie Prefecture Science and Technology Promotion Center (MPSTPC) has full administration responsibilities. Since the project includes not only scientific and technological studies but also includes components of environmental education, environmental management and wider cooperation with varieties of stakeholders, it can be a model of environmental restoration and management of small scale enclosed coastal seas.

This paper outlines the project as well as the present status and future perspective with particular emphasis on the new concept of *Sato-Umi*, which in Japanese means coastal sea under the harmonization of sustainable wise use with conservation of appropriate natural environment and habitat condition. In this project, varieties of restoration methods for damaged shallow environments and habitats with the use of environment friendly technology based on the concept of Sato-Umi are developed and applied. Compared with deteriorated coastal environments, Sato-Umi is able to provide higher biological diversity for habitat and higher biological productivity for living resources. These characteristics of *Sato-Umi* are also suitable sites for demonstrating multi-functional roles of fisheries.

Outlined framework of the environmental restoration project

The bay is a typical enclosed coastal sea, connected to the Pacific Ocean with a very narrow and shallow entrance (Figure 1). The environmental quality of the bay, in particular of the sediments quality, has deteriorated in conjunction with the continuation of pearl culture and development of the coastal area. Therefore, in the project, attempts are being made to improve the natural self-purification capability in the shallow areas of the bay by constructing functional tidal flat and seagrass beds that contribute to the enhancement of both the biological diversity and biological productivity of *Sato-Umi*. At the same time, sustainable aquaculture system is also developed to build a new ecosystem based management of pearl culture. The project consists of following two themes.

Theme 1. Integrated restoration of coastal environment and ecosystem to establish a regional model of *Sato-Umi*. In Ago Bay, deteriorated sediments with COD values higher than 30 mg/g dry sediment have been dredged up as an administrative measure for environmental improvement. In order to make use of the dredged sediments rich in organic matter accumulated at the bottom of the bay, technology for dewatering dredged sediment was developed and the treated sediments were applied as raw material to construct functionally improved artificial tidal flat and seagrass beds. The function of tidal flats and seagrass beds were quantitatively evaluated from the viewpoint of material cycling, self-purification, biological diversity and biological productivity in order to establish a reliable method for constructing functional tidal flats and seagrass beds. In addition to the development of technology to make the best use of dredged sediments, practical methods for environment friendly pearl culture were also developed.

Theme II. Development of an automatic environmental monitoring system and environmental forecasting technology. An automatic monitoring system to monitor water quality has been established in Ago Bay and the

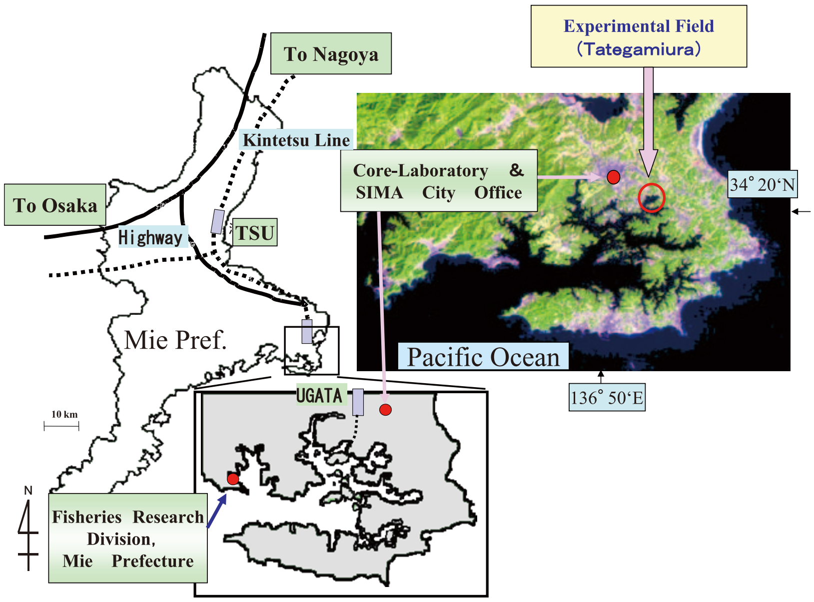

Fig. 1. Location of Ago Bay and its outline showing the enclosed topography and rias-type coastline.

real time observation data are open to the public through the Internet. An ecosystem model is also being developed. By combining these two tools, construction of a system that can forecast environmental changes in water quality is being developed.

New technology for developing biologically active tidal flats

Sediment eutrophication and the frequent occurrence of oxygen-deficient water at the bottom layer has caused the destruction of the benthic ecosystem and hence a decrease in biological activity in recent years. As a result of multi-spectrum aerial picture analyses, it was found that approximately 70% of the tidal flat and shallow areas had been decreased by land reclamation and other artificial environmental transformation along the coast of Ago Bay (Figure 2). Therefore, one of the major causes of environmental deterioration is considered to be reduction of shallow coastal areas, including tidal flats and seagrass beds that originally provided shallow areas with natural purification capability. In this context, the present Ago Bay Restoration Project aims to enhance the natural purification capability and to recover better material circulation around the shallow areas. New technology has been developed for constructing functional artificial tidal flats using muddy dredged sediment which contains rich organic matter but has always been treated as useless material in Ago Bay.

We set up the six experimental tidal flats in which the mixing ratio of dredged sediment with original sandy sediment in the area was changed stepwise (Figure 3). Sediment quality and benthic species on experimental tidal flats have been monitored for three years. The following results were obtained from the field study: 1) The number of benthic species in the experimental tidal flats constructed by muddy dredged sediment increased after six months (Figure 4), and 2) The suitable range of sediment quality on tidal flats for macrobenthic species was found to be 3-10 mg/g dry sediment for COD and 15-35% for mud content ratio (i.e. silt and clay content ratio). These results indicate that macrobenthic species decreased not only when organic matter and mud content was too high but also when organic matter and mud content was too low in the sediments. Accordingly, artificial tidal flat material mixed with muddy dredged sediment rich in organic matter and natural tidal flat sediments provides better conditions for the habitat of the benthic species than a conventional construction method of a tidal flat that uses clean sand.

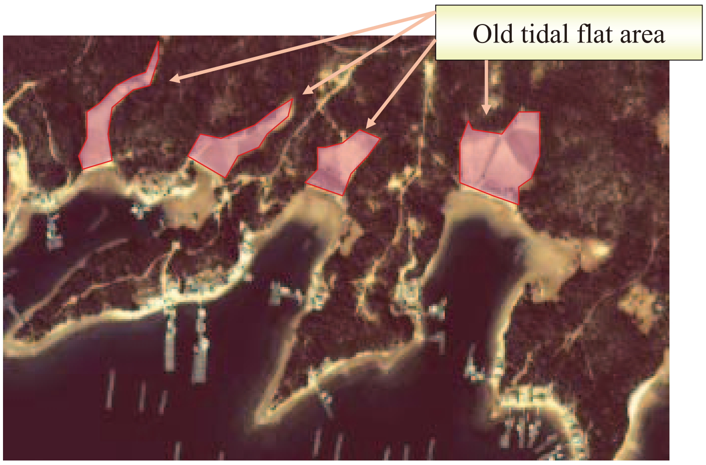

Fig. 2. An aerial photograph in which transformation of shallow coastal areas to reclaimed land (shaded area) are shown.

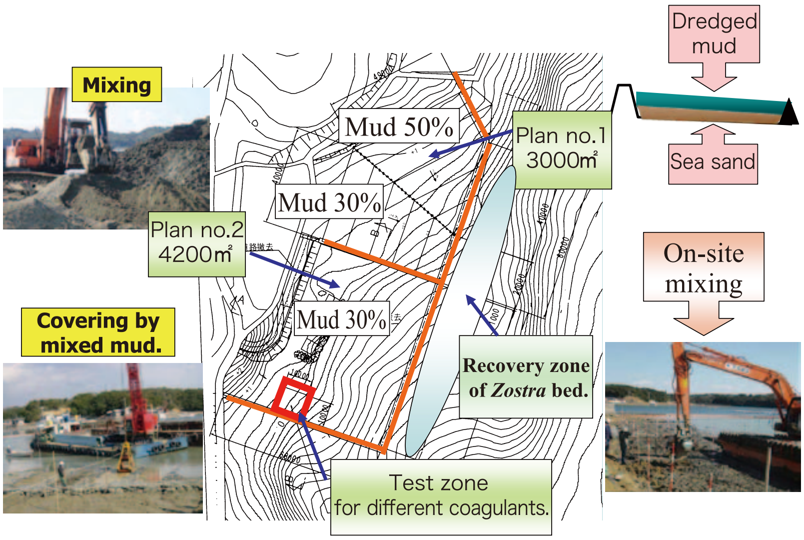

Fig. 3. Sketch of the experimental site and scenes of construction at Tategamiura where new technology for tidal flats and *Zostera* beds were developed.

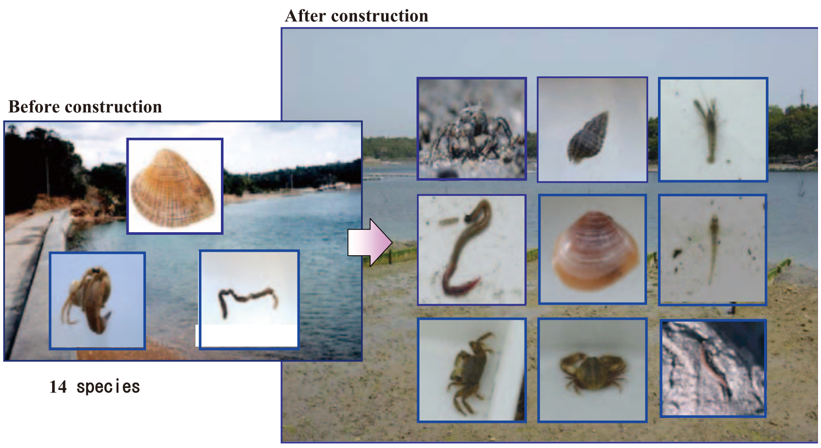

Fig. 4. Schematic display on the effects of tidal flat enrichment by dredged sediment in which species numbers and the biomass of macrobenthos increased.

Technology development for dewatering dredged sediments and its application

In Ago Bay area, dredged sediments have so far been placed in confined disposal sites but recently, acquisition of disposal sites is becoming difficult and the cost of land development is rising. Therefore, emphasis is shifting toward utilizing these materials for beneficial application in the marine environment. One of the main obstacles to treat dredged sediment is its extremely high water content. In order to overcome this problem, treatment by appropriate coagulants followed by dewatering are necessary to harden the dredged sediments for easy handling. A new technology to which the name Hi-Biah-System (HBS) was given, was developed in the project to perform this operation. Main components of HBS are: main stock tank, coagulant chamber, reactor, and dewatering system. Continuous flow operation can be achieved through a fully automatic system. Different coagulants were tested to check their abilities to form larger and more stable flocks. After coagulation and following the dewatering process, water content of the original sediments was remarkably reduced. Treated sediment cakes were applied in many ways for constructing different types of artificial tidal flats (Figure 5).

Another application of HBS is to provide suitable bases for seagrass beds that were prepared mainly from dredged sediments treated with a coagulant (Aquarefine: ARP), then mixed with different hardeners to be used as a bed for eelgrass (*Zostera marina* Linnè) germination. Hardeners used in this study were Gypsander, polyvinyl alcohol (PVA). Eelgrass germination and propagation were closely observed for almost six months. Data show high germination rates in the samples treated with hardeners compared with the ones without treatment. For original sandy sediments that were used as control samples, low germination rate was observed presumably due to the particle size and lack of organic matter. Leaf area index (LAI) for eelgrass germinated both in the control and dredged sediments without treatment were less than that for samples treated with ARP and other hardeners.

Bivalves are widely used as bio-indicators of heavy metals and other pollutants in coastal areas, since bivalves are well known to concentrate these contaminants, providing a time integrated indication of environmental contamination. Therefore, safety of treated sediments with different coagulants was checked through the growth of short necked clams in the prepared artificial tidal flats.

Five different experimental tidal flats were prepared with use of; ARP, Pellets, Gypsander,

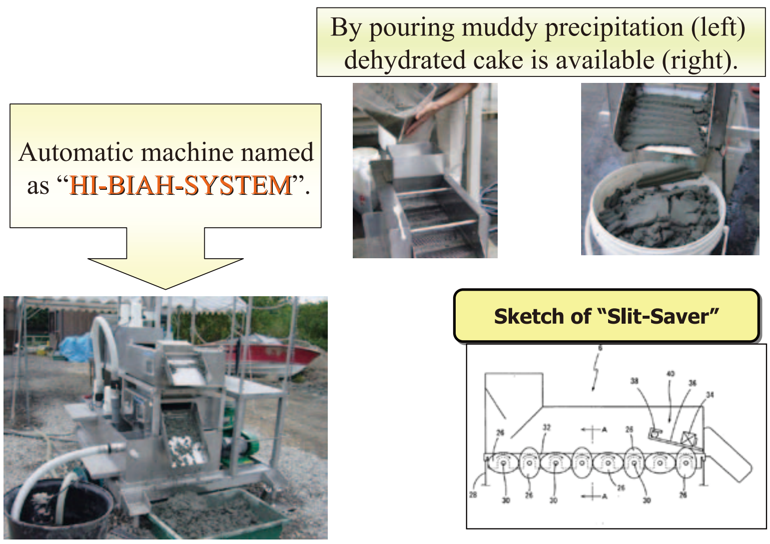

Fig. 5. Appearance of the automatic dewatering system of dredged sediment and scenes of dewatering processes.

Ecorton, and sand only (without treatment). On each flat, 200 short-necked clams were deployed inside stainless steel cages covered with nylon net. After three months of deployment, sampling was carried out to monitor mortality, length, height, growth, and heavy metals in the clam tissues. Maximum mortality was obtained with control flat (16%), whereas minimum mortality was obtained with Pellets (0%). Reasonable growth, which exceeed 50% from the original values, was observed for the clams in the different flats. Heavy metals were measured by ICP-MS. Although heavy metals in general showed a little increase after three months of deployment, the concentrations were below the level of international harmful standards.

Development of a new method for recovering *Zostera* bed

Zostera marina Linnaeus is widely distributed in the temperate zone of the northern hemisphere. It grows in calm and inner coastal areas and forms a dense populations called *Zostera* beds or *Zostera* zones on sandy or muddy bottoms. This seagrass bed performs a major role as a primary producer in the coastal ecosystem and serves coastal fish and other animals with an important nursery and spawning ground. In Japan, Z. *marina* had long been distributed in almost all coastal regions, but since the 1950s the beds have decreased drastically. So, not a few recovering programs of *Zostera* bed have started since the 1960s in various regions for conservation of the coastal environment and the propagation of fishery recourses. Several effective methods for recovering the beds have been developed, but the methods are generally complicated and sometimes very difficult for routine use by local people because of the need for special instruments or technologies and considerable SCUBA diving effort. In this project, a simple, convenient and effective method named the *Zostera* mat system that is applicable to local fisherman, was developed.

Reproductive shoots of *Zostera* with developing seeds were collected from late spring to summer and were put in mesh bags for promoting maturation of seeds in sea water for about a month. Fully matured seeds were preserved under low temperatures of 0-4℃, which promoted germination. In late autumn when water temperature decreases to less than 20℃, the seeds begin to germinate. The *Zostera* mat system to sow seeds for growing the plants was developed. The size of the mat is 50x50 cm and is 2 cm in thickness and about 1.2 kg in weight. The mat is constructed with four layers; those are iron net of 4 cm mesh, jute net of 2 mm mesh, jute fiber mat of 5 mm in thickness and iron net of 4 cm mesh. Seeds were sowed between jute mesh net and jute fiber mat. Then, many bases were connected with cotton ropes in a row at intervals of 50 cm. Thus, the bases were easily settled on the sea bottom continuously on the straight line from a small boat. Many seeds germinated after a month, and grew up after three months. We set 250 and 400 bases of *Zostera* mat in 2004 and 2005, respectively. Growth patterns and seasonal changes in density of *Zostera* on the bed were surveyed. Optimal and upper limit temperatures for germination and growth of this plant were also studied in the laboratory (Figure 6).

Several advantages of the *Zostera* mat proved are as follows. When seeds germinate, seedlings can make root in the jute mat which helps seedlings attach tightly to the bottom. By connecting *Zostera* mat with ropes in a row, it is easy to set many bases on the sea bottom without any kind of diving effort. Fisherman can do all the procedures, such as collecting mature plants, promoting maturation of seeds, preserving seeds, sowing seeds on the bases and deploying the bases on the sea bottom without special instruments and the use of difficult techniques. This base is made only of natural materials such as jute fiber and cotton ropes, i.e. environment-friendly resources.

Automatic environmental monitoring system

The automatic monitoring system in Ago Bay consists of five sets of the automatic water quality observation stations (WQOS) and two sets of the automatic flow observation stations (FOS). One of the WQOS placed at the bay mouth collects information closely related to open sea, while the rest of the WQOS are established in the center

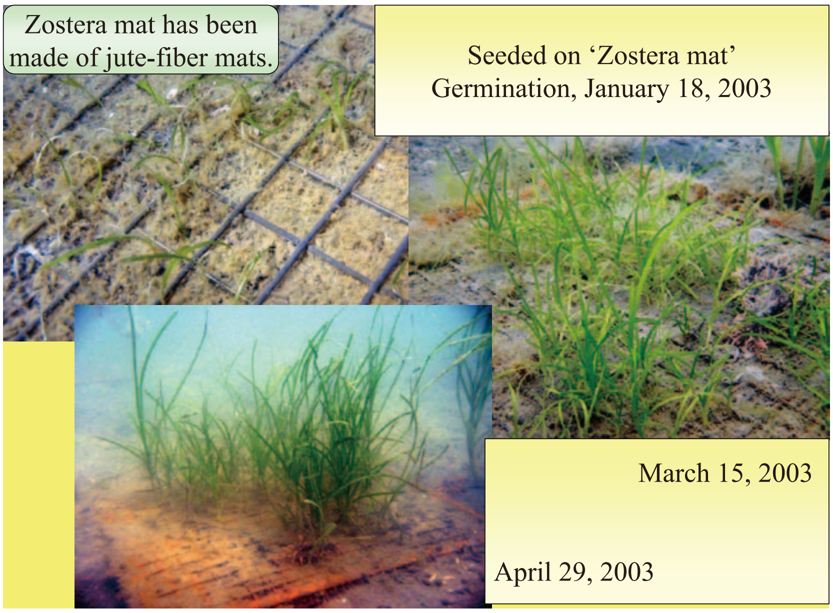

Fig. 6. Photographs showing the application of *Zostera* mats on which *Zostera* marina germinated and grown.

and inner parts of the bay to get information on the bay. The two FOS are established in line on the transverse section just inside the bay mouth.

The observation items of the WQOS are water temperature, salinity, chlorophyll fluorescence, dissolved oxygen and turbidity. The detector unit, in which the observation sensors are installed, goes up and down with a winch on the floating platform, and acquires the data for every water depth. In order to prevent biofouling, the detector unit is hauled up and is exposed to the air during the time between operations and goes down into water only during the time of measurement. This significantly reduced the frequency of maintenance and contributed to raise the time of operation. The WQOS has already been operated for more than three years, and attained an high operation rate of 90-95%, including the system stops at the time of typhoon attacks. The FOS consists of the seabed installation type ADCP and an acoustic modem that performs communication with the floating platform. The wireless communication system began to work in November 2005, however, the two ADCP had already been collecting data since July 2003. The analysis of the recorded data showed the effectiveness of the FOS to predict the variation of water quality in the bay (Figures 7 and 8).

The observation data of the WQOS and the FOS are transmitted to the Core Research Laboratory of the project at one hour intervals, using a cellular-phone network, and the data processed with the personal computer of the laboratory are immediately distributed to the Internet through the Web server. The homepage is actively accessed not only by researchers but also by pearl culture fishermen; consequently, it contributes to advertising the significance of the project to local residents (Figure 9).

Another objective of the environmental monitoring system is a short-term prediction of water quality. The observation data are used as the input data and the numerical simulation model under development is expected to perform the task. The dynamic behaviors of water quality in the bay have begun to be disclosed by the environmental monitoring system.

Development of hydrodynamic and ecosystem model for Ago Bay

Three different models are under development. They are a three-dimensional hydrodynamic model, a water quality model and a sedimentation model. The hydrodynamic model has characteristics that the vertical grid interval shrinks toward the sea surface. This aims at improvement of

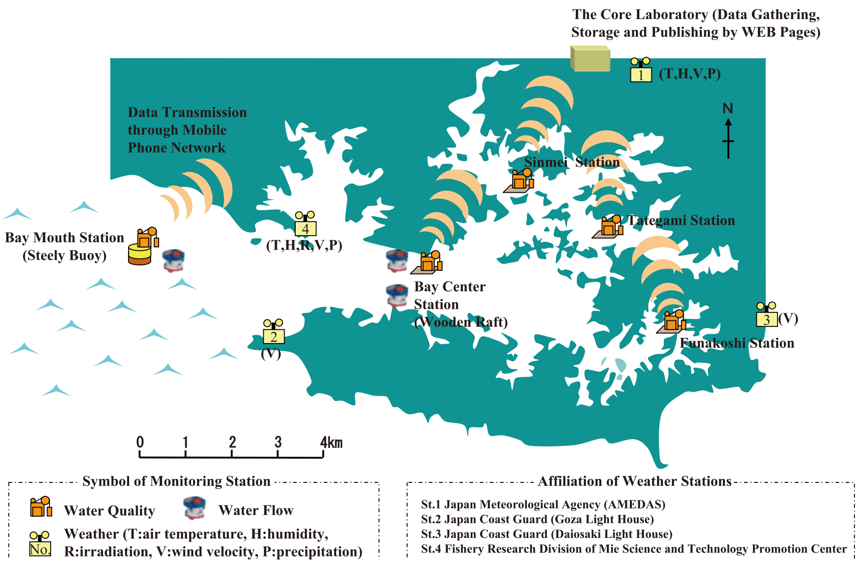

Fig. 7. Automatic environmental monitoring system of Ago Bay.

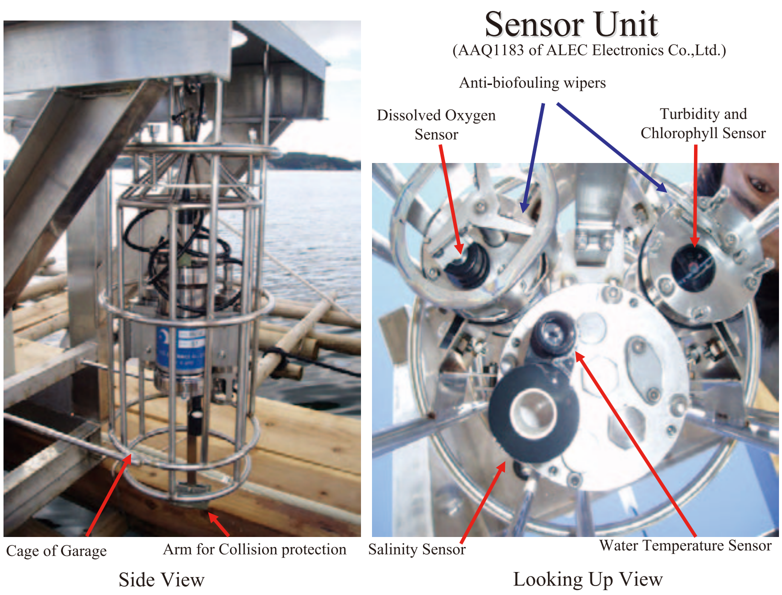

Fig. 8. Photographs showing the structure of a sensor unit.

computational accuracy of salinity, which has a strong vertical gradient near the sea surface. According to the analyses already done, the river plume that spreads on a sea surface was clearly captured, and density stratification in summer season was reproduced quite accurately. Since the nutrient inflow from the land area is conveyed by the river plume, the models are also expected to improve the accuracy of water quality calculation.

The water quality model includes dynamics of plankton and nutrients, and the physiological characteristics of pearl oysters. Nineteen compartments are included in the model, which allows the competition of phytoplankton species between a diatom and a dinoflagellate. The concentration of carbon, nitrogen and phosphorus are carefully implemented in the model so that the computational results can be utilized in the investigation of material circulation. The sedimentation model also has 19 compartments and takes into consideration the circulation of carbon, nitrogen, phosphate, iron, manganese, sulfur and oxygen. It is one of the targets of the present study to couple the water quality model with the sedimentation model and to perform analyses that reproduce the existing phenomenon as correctly as possible.

To obtain basic data for the numerical models, oceanographic observations and experiments with the sediments have been conducted over three years. In addition to that, a biological experiment for developing a physiological model for pearl oysters has been conducted. The water quality data measured by the environmental monitoring system since September 2003 also created a huge data base. All of those data will be effectively utilized to complete the integrated Ago Bay model (Figure 10).

A short-term prediction of the water quality is planned in the project. The real time observation data of the environmental monitoring system is utilized and is read into the numerical models with use of the data assimilation technique. This will be tried after the completion of the development of the numerical models.

Closing Remarks

Results of the study and development of the technology during the course of the project including development of functional tidal flats, a new method for recovering *Zostera* beds, real time environmental monitoring systems and environmental forecasting technology to be established are expected to contribute to establish

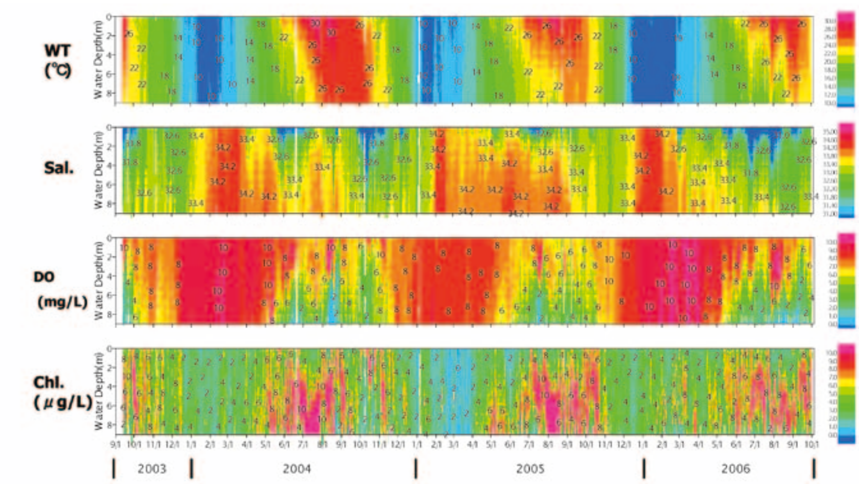

Fig. 9. Display of monitoring data during three years (water temperature, salinity, dissolved oxygen and chlorophyll from above) at Tategami Station.

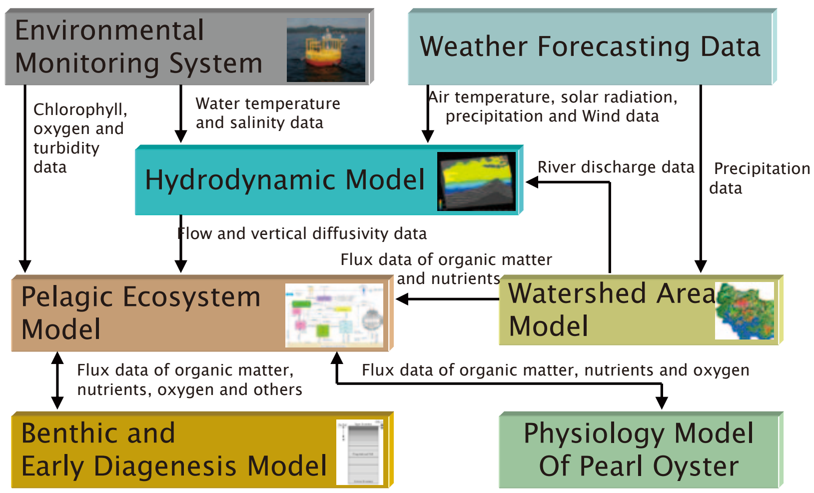

Fig. 10. Structure of prediction model by integration of the environmental monitoring system and other models being developed.

sustainable *Sato-Umi* through effective environmental restoration in the Ago Bay area. Recent attempts of environmental restoration in this area with broader cooperation among a variety of stakeholders can be a model of environmental restoration of small scale enclosed coastal seas with particular emphasis to environmental education for the next generation and sustainable environmental management by local people and local municipalities. The concept of *Sato-Umi* may help realize the motto of the project: "Better life through wise and sustainable use of coastal environments" in Ago Bay.

Acknowledgment

The author appreciates members of the project, in particular of Dr. Tadaya Kato, Professor Emeritus of Mie University, Dr. Miyuki Maegawa of the same university, Dr. Satoshi Chiba of Yokkaichi University, Mrs. Hideki Kokubu and Hiroyuki Okumura of Mie Prefecture, Dr. Dabwan Ahmed and Mr. Daizo Imai of Mie Industry and Enterprise Support Center, for providing valuable information and data.

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Utilization of Waste *Porphyra* Products as Eco-friendly Feed Ingredients

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Abstract We investigated the growth and hepatopancreatic enzyme activities in red sea bream, *Pagrus major*, fed diets containing waste nori, *Porphyra* spp. (red algae, purple laver) with different protein to fat ratios. Fingerlings of 10.1 g average body weight were fed for 10 weeks on the optimum fat and protein (11 and 55 %) control diet (CTD) and two higher fat and lower protein (19 and 42 % and 25 and 36 %, respectively) experimental diets (MFD and HFD). All diets were supplemented with 5 % waste nori. Weight gain, specific growth rate and feed efficiency in fish fed the CTD and MFD were higher than those in fish fed the HFD. Plasma total cholesterol, phospholipid, and free fatty acid concentrations and whole body crude fat content were increased as dietary fat level increased, whereas hepatopancreatic lipogenic enzyme activities (glucose-6-phosphate dehydrogenase, 6-phosphogluconate dehydrogenase, NADP-isocitrate dehydrogenase and NADP-malate dehydrogense) were decreased as the dietary fat level increased. Aspartate aminotransferase activity of the MFD group was significantly lower than the activity of the CTD group. These findings suggest that dietary fat content can be increased from 11% to 19% by supplementing 5% waste nori in fingerling red sea bream diets.

Key words: *Pagrus major*, *Porphyra*, eco-friendly fish feed, high fat low protein diet, hepatopancreatic enzyme activity

Introduction

In recent years, environmental pollution by nitrogen and phosphorus loading from fish farming has become a serious social problem. These pollutants are considered to originate mainly from fish meal, which is a main feed ingredient in fish feeds. Furthermore, the drastic decrease of feed-grade fish landings worldwide and increasing demand of formula feed production for aquaculture has made the market price of fish meal to increase. Therefore, from the viewpoints of environment and economics, dietary fish meal content should be reduced as much as possible.

The protein-sparing effects dietary of fat have been demonstrated with rainbow trout, *Oncorhynchus mykiss* (Takeuchi et al. 1978; Beamish and Medland 1986), yellowtail, *Seriola quinqueradiata* (Shimeno et al. 1980), Atlantic salmon, *Salmo salar* (Hillestad and Johnsen 1994), and Atlantic halibut, *Hippoglossus hippoglossus* (Aksnes *et al*. 1996), whereas no such effects were observed with tilapia, *Oreochromis niloticus* (Shimeno *et al*. 1993) or Japanese flounder, *Paralichthys olivaceus* (Kikuchi *et al*. 2000). In our previous report ofnfingerling red sea bream, *Pagrus major* (Sugita *et al*. 2007a), a protein-sparing effect by fat was not also found.

Nori, *Porphyra* spp. (red algae, purple laver) are commercially and culturally important species used widely as traditional Japanese food. Nori products contain high amounts of taurine, an important amino acid for the growth of marine fish, as well as minerals and vitamins. In recent years, occurrence of discolored nori with no commercial value

2009年8月10日受理（Received. August 10. 2009）
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(i.e., waste nori) has become a serious problem. Therefore, effective uses of the waste nori have been sought. There have been several studies on the use of various kinds of algae meal in fish feed (Stanley and Jones 1976, Tsai 1979, Appler 1985). It has been confirmed that a small amount of algae added to fish feed significantly improves growth, lipid metabolism, body composition, and disease resistance (Nakagawa and Kasahara 1986, Satoh *et al.* 1987, Xu *et al.* 1993, Mustafa *et al.* 1995). However, the supplemental effects of the waste nori on the growth and lipid metabolism have not been studied in red sea bream. We compared the growth and hepatopancreatic enzyme activities in red sea bream fed diets containing waste nori with different protein to fat ratios.

Materials and Methods

Experimental Diets

The formulation and proximate composition of the experimental diets are shown in Table 1. The control diet (CTD) contained 69% brown fish meal (BFM), 4.7% pollock liver oil (Riken Vitamin, Tokyo, Japan) and 10.5% gelatinized potato starch (Tokai Denpun, Shizuoka, Japan) as the main protein, fat, and carbohydrate sources, respectively. Medium fat and medium protein diet (MFD) and the highest fat and the lowest protein diet (HFD) contained 13.7 and 19.3% pollock liver oil. On the other hand, the BFM levels of MFD and HFD were reduced to 53 and 45%. The gelatinized potato starch content was reduced to 9% (MFD) and 5.1% (HFD). All diets were supplemented with 5% waste nori, which was supplied from Saga Prefectural Ariake Fisheries Research and Development Center, Koshiro, Saga, Japan. Krill meal was supplemented to all diets as a feeding stimulant. Chromium oxide was included as a marker for nutrient digestibility measurement. Cellulose was used as a filler. All the ingredients were thoroughly mixed, moistened by the addition of 35% water (w/w), and pelleted using a meat chopper (Hanaki Mfg Co., Ltd., Tokyo, Japan). Then the pellets were dried at 50℃ for 6 h and stored at -20℃ until fed to the fish.

Analytical nutrient and energy contents of the test diets are given in Table 1. The content of crude protein, crude fat and crude sugar in the CTD were 55, 11, and 11%, respectively, which are considered optimum (Furuichi *et al.* 1971, Yone *et al.* 1971, Yone 1976, Takeuchi *et al.* 1991). Crude protein contents were 42% in the MFD and 36% in the HFD, and crude sugar contents were 9% and 7%. On the other hand, crude fat contents were 19% in the MFD and 25% in the HFD. The phosphorus content in the CTD was 2.8%, and the content decreased as the dietary BFM level decreased (i.e., the dietary fat level increased), and the value was 2.4% (MFD) and 2.1% (HFD). Gross energy content in all diets ranged from 20.1-22.9MJ/kg.

Fish and Feeding Procedures

Fingerlings of red sea bream were obtained from the Kinki University Fish Nursery Center, Uragami, Wakayama, Japan and transferred to the Nansei Station of the National Research Institute of Aquaculture, Minamiise, Mie, Japan. The fish were initially stocked in two 500 L fiber reinforced plastic circular tanks, supplied with sand filtered and aerated sea water. The fish were fed a commercial feed (Kyowa Hakko Kogyo Co., Ltd., Tokyo, Japan) until they reached nearly 8.5 g. Then 20 fish of a similar size were selected and stocked in each of six 100 L plastic circular tanks with duplication for each dietary treatment. Seawater was supplied at a flow rate of 3 L/min, and the commercial feed was fed to the fish for another two weeks to acclimate them to the experimental conditions. The water temperature during the experiment was 19.0±1.7℃.

Just before the start of the feeding trial, the fish were weighed individually, and eight fish were randomly sampled from a surplus tank after being anesthetized in 0.01% 3-ethyl aminobenzoate methanesulfonic acid (initial fish). In the eight fish sampled, four were used for proximate whole body composition analysis. After taking blood from the other four fish, the hepatopancreas was taken for analyses of proximate composition and metabolic enzyme activity. After measuring the hematocrit, the blood was centrifuged at 4,000 x g for five minutes to separate the plasma. All samples were stored in a freezer at -80℃ until analyzed. The

Table 1. Formulation and proximate analysis of the experimental diets

Diets	CTD[1]	MFD[1]	HFD[1]
P/F[2]	55/11	42/19	36/25
Ingredient (% wet weight)			
Brown fish meal	69.0	53.0	45.0
Waste nori	5.0	5.0	5.0
Pollock liver oil	4.7	13.7	19.3
Gelatinized potato starch	10.5	9.0	5.1
Cellulose	–	8.5	14.8
Constant components[3]	10.8	10.8	10.8
Analysis (dry weight basis)			
Crude protein (N x 6.25 %)	54.5	41.6	35.7
Crude fat (%)	11.4	19.4	24.7
Crude sugar (%)	10.5	9.1	6.9
Phosphorus (%)	2.76	2.35	2.09
Gross energy (MJ/kg diet)	20.1	21.9	22.9

[1] CTD: control diet, MFD: medium fat diet, HFD: high fat diet.

[2] Crude protein : crude fat.

[3] 3.0% krill meal, 5.0% mineral mixture (Ogino et al. 1979), 1.5% vitamin mixture (Sugita et al. 2007a), 1.0% chromic oxide (chromic oxide : cellulose=1 : 1), 0.3% guar gum.

experimental diets were fed to the fish with an initial mean weight of 10.1 g to satiation, three times daily (0900, 1300, and 1700), six days per week for 10 weeks. At the end of the feeding trial, the fish were weighed individually, and seven fish per tank were sampled after one day starvation. In the seven fish sampled, four were used for whole body proximate composition analysis and the other three fish were used for analyses of plasma components and hepatopancreatic proximate composition and enzyme activity.

Another 38 fish (11.0 ± 0.3 g) were selected from the surplus tank and stocked in each of six 50 L tanks for fecal collection (Sugita *et al.* 2007b). Seawater was supplied at a flow rate of 4.5 L/min, and the commercial feed was fed to the fish for another seven days to acclimate them to the experimental conditions. Each experimental diet was fed to the fish to satiation twice in the morning. For the initial six days, the fish were acclimated to the diets and fecal samples were not collected. Feces excreted from 1730 on one day to 0830 the next day, were collected immediately prior to the next satiation feeding each day for six days, pooled, and freeze-dried. The water temperature during fecal collection was 19.0 ± 1.7℃.

Blood Component Analysis

Blood was taken using a heparinized syringe. Hematocrit was measured using microhematocrit tubes. After sealing, the tubes were centrifuged at 10,000 x g for 5 min. The contents of plasma glucose, triglyceride, total cholesterol and total protein were determined using an automatic analyzer (SPOTCHEM SP-4410, Arkray, Kyoto, Japan). Plasma free fatty acid (FFA) and phospholipid were measured using commercial kits (NEFA C Test Wako and Phospholipids C Test Wako, Wako Pure Chemical Industries, Ltd., Osaka, Japan) and free amino acid (FAA) was assayed using dinitrofluorobenzene (Goodwin 1968).

Chemical Component Analysis

Determination of moisture, crude protein, crude fat, and ash in the test diets; feces; whole fish; and hepatopancreas were assayed by 10 h drying at 110℃, semi-micro Kjeldahl method (N x 6.25), diethyl ether extraction, and 5 h heating at 600℃, respectively (Shimeno 1974). Crude sugar content in the diets was determined by measuring simple sugar liberated in boiling 1N sulfuric acid for 4 h, based on the phenol-sulfuric acid method (Shimeno

1974). Phosphorus contents of the diet, feces, and whole fish were determined using ammonium molybdate and ascorbic acid (Lowry and Lopez 1946). The gross energy content of the diets was measured using a CA-4PJ bomb calorimeter (Shimadzu, Kyoto, Japan). The chromium oxide contents of the diets and feces were measured using a spectrophotometer (UVmini 1240, Shimadzu) after the samples were hydrolyzed in nitric acid and perchloric acid (Furukawa and Tsukahara 1966).

Enzyme Activity Analysis

Hepatopancreas samples were homogenized with nine volumes of 3-morpholinopropansulfonic acid buffer (MOPS-buffer; 30 mM, pH7.0) using a Polytron (Kinematica AG, Switzerland, PTA 10S). The homogenate was centrifuged at 12,000 x g for 30 min at 4℃. The resulting supernatant was used to analyze the activities of the following enzymes: phosphofructokinase (PFK, EC 2.7.1.11), glucose-6-phosphatase (G6Pase, EC 3.1.3.9), fructose-1,6-bisphosphatase (FBPase, EC 3.1.3.11), glucose-6-phosphate dehydrogenase (G6PDH, EC 1.1.1.49), 6-phosphogluconate dehydrogenase (6PGDH, EC 1.1.1.44), NADP-isocitrate dehydrogenase (ICDH, EC 1.1.1.42), aspartate aminotransferase (GOT, EC 2.6.1.1) and alanine aminotransferase (GPT, EC 2.6.1.2). These enzyme activities were assayed by the methods described previously (Sugita et al. 2001, 2007a). Pyruvate kinase (PK, EC 2.7.1.40) activity was measured as the rate of NADH reduction (Moon and Johnston 1980). NADP-malate dehydrogenase (MDH, EC 1.1.1.40) activity was determined as the rate of NADP reduction (Ochoa 1995). The absorbance of samples during the measurements of enzyme activities was measured using UVmini 1240 spectrophotometer (Shimadzu) equipped with a thermo-controlled cell positioner CPS-240A (Shimadzu). All the enzyme activities were expressed as μmol of substrate or coenzyme converted per min per 100 g body weight.

Statistical Analysis

The effects of diet on growth, feed utilization, apparent digestibility and biochemical parameters were evaluated by one-way ANOVA and Fisher`s Protected Least Significant Difference test. A probability level of less than 0.05 was considered significant. The statistical analyses were carried out using the Stat View program (SAS Institute, Cary, North Carolina, USA).

Results

Apparent Digestibility

Table 2 shows the apparent digestibility of nutrients in the experimental diets in fingerling red sea bream. The apparent digestibility of crude protein was not significantly different among the dietary groups. The apparent digestibility of crude fat in fish fed the CTD and MFD was higher than the digestibility of the HFD. The apparent phosphorus absorption increased as the dietary fat level increased (i.e., the dietary BFM level decreased).

Growth and Feed Performances of Fish in the Feeding Trial

Growth and feed performance are presented in Table 3. Weight gain (WG), specific growth rate (SGR), and feed efficiency (FE) in fish fed the CTD and MFD were higher than those in the HFD

Table 2. Apparent digestibility of nutrients of the experimental diets in fingerling red sea bream (%)[1]

Diets	CTD[2]	MFD[2]	HFD[2]
P/F[2]	55/11	42/19	36/25
Crude protein	91.8±0.1	91.2±0.1	91.0±0.5
Crude fat	99.1±0.1[b]	99.1±0.1[b]	98.6±0.0[a]
Phosphorus	48.3±0.2[a]	56.2±1.5[b]	59.8±0.1[c]

[1] Values are mean ± SD of two samples. Values in the same row followed by the same letter are not significantly different (*P* >0.05).

[2] See the footnote of Table 1.

group. On the other hand, feed consumption rate was highest in the HFD group. Protein efficiency ratio (PER) and protein retention in the fat-rich diet (MFD and HFD) groups were higher compared with those of the CTD group. Phosphorus retention was not significantly different among the dietary groups.

Hematological Characteristics

Table 4 shows the results of hematological parameter analyses of fingerling red sea bream. Plasma FFA, total cholesterol and phospholipid concentrations increased as the dietary fat level increased. Plasma glucose, triglyceride, FAA and total protein concentrations were not different among the dietary groups. Hematocrit level was decreased as the dietary P/F decreased; however, it was not significantly influenced by dietary treatment.

Whole body and Hepatopancreas Composition

The whole body composition of the initial and the final fish for each diet are shown in Table 5. Moisture and crude protein contents decreased as dietary fat level increased, whereas crude fat content increased as dietary fat level increased. Ash and phosphorus contents were not significantly different among the dietary groups. Table 5 also shows the hepatopancreas composition of fingerling red sea bream. Hepatopancreatic crude protein and crude fat contents, and hepatosomatic index (HSI) was not significantly influenced by the dietary treatment.

Hepatopancreatic Enzyme Activity

The hepatopancreatic enzyme activities of the initial and final fish are shown in Table 6. The activities of G6Pase, FBPase, G6PDH, 6PGDH, ICDH, and MDH were the highest in the CTD groups, and those activities decreased as the dietary fat level increased. GOT activity of the MFD group was significantly lower than that of the CTD group, whereas GOT activity of the HFD group was not significantly different from that of

Table 3. Growth and feed performances of fingerling red sea bream fed the experimental diets [1]

Diets	CTD[2]	MFD[2]	HFD[2]
P/F[2]	55/11	42/19	36/25
Initial BW (g/fish)	10.10±0.02	10.10±0.01	10.12±0.01
Final BW (g/fish)	45.93±0.48	46.05±1.18	39.62±0.24
WG (%)[3]	355±5.7[b]	356±11.4[b]	292±1.9[a]
SGR (%)[4]	2.16±0.02[b]	2.17±0.04[b]	1.95±0.01[a]
Feed consumption rate (% BW/day)[5]	1.55±0.03[a]	1.57±0.00[ab]	1.62±0.02[b]
FE (%)[6]	112.8±2.5[b]	109.8±2.4[b]	97.4±1.8[a]
PER[7]	2.07±0.05[a]	2.64±0.06[b]	2.73±0.05[b]
Retention (%)			
Protein[8]	38.6±0.3[a]	47.1±1.0[b]	45.3±2.4[b]
Phosphorus[9]	38.7±4.8	41.8±0.1	44.4±4.0

[1] Values are mean ± SD of duplicate tanks. Values in the same row followed by the same letter are not significantly different (P >0.05).

[2] See the footnote of Table 1.

[3] Weight gain (WG) =100 x (final BW-initial BW)/initial BW.

[4] Specific growth rate (SGR) =100 x {ln(final BW) - ln(initial BW)}/rearing period (days).

[5] Expressed as 100 x feed intake/[{(initial BW + final BW)/2} x rearing period (days)].

[6] Feed efficiency (FE) =100 x (final BW - initial BW)/dry feed intake.

[7] Protein efficiency ratio (PER) =(final BW - initial BW)/dry feed protein intake.

[8] Expressed as 100 x {(final BW x final body protein) - (initial BW x initial body protein)} /(total feed intake x feed protein).

[9] Expressed as 100 x {(final BW x final body phosphorus) - (initial BW x initial body phosphorus)} /(total feed intake x feed phosphorus).

Table 4. Hematological characteristics of fingerling red sea bream fed the experimental diets [1]

Diets		CTD[2]	MFD[2]	HFD[2]
P/F[2]		55/11	42/19	36/25
	Initial[3]	Final		
Glucose (mg/100mL)	69	44±3	51±11	49±6
Triglyceride (mg/100mL)	77	86±15	76±3	125±34
FFA (mEq/L)[4]	0.30	0.22±0.02[a]	0.28±0.02[ab]	0.37±0.07[b]
Total cholesterol (mg/100mL)	166	163±16[a]	266±35[b]	255±39[ab]
Phospholipid (mg/100mL)	458	460±36[a]	674±47[b]	721±14[b]
FAA (mg/100mL)[5]	45.4	54.2±6.9	46.6±0.8	45.3±1.5
Total protein (g/100mL)	2.3	2.9±0.2	2.9±0.2	2.7±0.3
Hematocrit (%)	24.8	25.5±1.9	23.8±3.7	19.9±0.8

[1] Values are mean ± SD of duplicate tanks (3 fish/tank). Values in the same row followed by the same letter are not significantly different (*P* >0.05).

[2] See the footnote of Table 1.

[3] Average values of 4 fish.

[4] FFA, Free fatty acid.

[5] FAA, Free amino acid.

Table 5. Proximate composition of whole body and hepatopancreas of fingerling red sea bream fed the experimental diets

Diets		CTD[1]	MFD[1]	HFD[1]
P/F[1]		55/11	42/19	36/25
	Initial[2]	Final		
Whole body[3]				
Moisture (%)	75.9	71.6±0.4[b]	69.7±0.4[a]	69.2±0.0[a]
Crude protein (N x 6.25 %)	17.1	17.4±0.3[b]	16.9±0.1[ab]	16.2±0.2[a]
Crude fat (%)	2.4	5.7±0.6[a]	9.0±0.1[b]	9.6±0.1[b]
Ash (%)	4.9	5.0±0.0	4.8±0.2	5.0±0.1
Phosphorus (%)	0.97	0.92±0.07	0.88±0.01	0.94±0.04
Hepatopancreas[4]				
Crude protein (N x 6.25 %)	10.7	14.8±0.2	15.5±0.4	15.3±2.0
Crude fat (%)	4.3	5.6±1.3	7.5±2.1	6.2±1.1
HSI (%)[5]	1.30	1.37±0.02	1.31±0.19	1.25±0.04

[1] See the footnote of Table 1.

[2] See the footnote of Table 4.

[3] Values are mean ± SD of duplicate tanks (pooled samples, 4 fish/sample). Values in the same row followed by the same letter are not significantly different (*P* >0.05).

[4] Values are mean ± SD of duplicate tanks (pooled samples, 3 fish/sample). Values in the same row followed by the same letter are not significantly different (*P* >0.05).

[5] Hepatosomatic index (HSI) = 100 x hepatopancreas weight/BW. Values are mean ± SD of duplicate tanks (3 fish/tank).

Table 6. Hepatopancreatic metabolic enzyme activities of fingerling red sea bream fed the experimental diets[1]

Diets		CTD[2]	MFD[2]	HFD[2]
P/F[2]		55/11	42/19	36/25
	(μmol/min/100g body weight)			
	Initial[3]	Final		
PFK[4]	2.42	3.20±0.40	2.95±0.44	2.40±0.50
PK[4]	13.0	14.9±0.4	15.0±1.4	14.1±1.4
G6Pase[4]	5.69	8.54±0.36[b]	6.92±0.38[ab]	5.46±0.96[a]
FBPase[4]	5.54	5.42±0.04[b]	3.52±0.29[a]	3.34±0.36[a]
G6PDH[4]	23.1	41.1±0.2[c]	12.9±1.1[b]	8.4±1.0[a]
6PGDH[4]	9.4	19.6±0.1[c]	11.9±1.2[b]	6.9±0.4[a]
ICDH[4]	41.0	44.0±1.6[b]	35.7±2.6[a]	37.0±1.1[a]
MDH[4]	1.54	4.66±0.41[b]	1.65±0.06[a]	1.25±0.18[a]
GOT[4]	42.2	78.2±2.6[b]	58.0±0.5[a]	64.9±7.4[ab]
GPT[4]	20.3	22.1±0.7	19.9±6.0	24.1±0.2

[1] Values are mean ± SD of duplicate tanks (3 fish/tank). Values in the same row followed by the same letter are not significantly different (P >0.05).

[2] See the footnote of Table 1.

[3] See the footnote of Table 4.

[4] PFK: Phosphofructokinase, PK: Pyruvate kinase, G6Pase: Glucose-6-phosphatase, FBPase: Fructose-1,6-bisphosphatase, G6PDH: Glucose-6-phosphate dehydrogenase, 6PGDH: 6-Phosphogluconate dehydrogenase, ICDH: NADP-Isocitrate dehydrogenase, MDH: NADP-Malate dehydrogenase, GOT: Aspartate aminotransferase, GPT: Alanine aminotransferase.

the CTD group. The activities of PFK, PK, and GPT were not significantly different among the dietary groups.

Discussion

In our previous report on fingerling red sea bream (Sugita *et al*. 2007a), growth and feed performances decreased as the dietary fat level increased (i.e., dietary protein level decreased). Therefore, the authors concluded that fingerling red sea bream did not effectively utilize the high fat diet. In the present experiment, crude protein and crude fat contents of the experimental diets were similar to those in the previous experiment. However, growth and feed performances of the MFD group were equal to those of the CTD group. The difference between the present and previous experiments was just the waste nori diet supplementation. The present experiment clearly showed that supplemental waste nori enhanced the utilization of the higher fat and lower protein diet. Since dietary protein contents of MFD and HFD were lower than CTD, PER and protein retention of the MFD and HFD groups were higher than the CTD group. WG, SGR, FE and apparent crude fat digestibility were not different between the CTD group and the MFD groups, whereas those were lowest in the HFD group. These results suggest that waste nori supplementation can improve utilization of high fat and low protein diets to some degree in fingerling red sea bream. The supplemental effect was not observed in fish fed the high fat and low protein diet (HFD), because digestible energy intake for fish fed the HFD might have been reduced due to the decrease of apparent fat digestibility.

Lipogenic enzymes (G6PDH, 6PGDH, ICDH and MDH) play an important role in the generation of reduced form nicotinamide adenine dinucleotide phosphate (NADPH) for lipid synthesis in the liver (Kheyyali et al. 1989). In the present experiment, the activities of these enzymes significantly decreased in the MFD and HFD groups. On the other hand, the concentrations of total cholesterol, phospholipid and FFA in the plasma, and the content of crude fat in the whole body increased as the dietary fat level increased. These results indicate that the accumulated body fat components did not originate mainly from dietary protein and carbohydrate but from dietary fat. Similar depression in hepatic lipogenic enzyme activity and increase in fat deposition by a high fat and low protein diet was reported in yellowtail (Shimeno *et al.* 1980; Shimeno *et al.* 1981), carp *Cyprinus carpio* (Kheyyali *et al.* 1989), tilapia (Shimeno *et al.* 1993) and Japanese flounder (Kikuchi *et al.* 2000).

Although the GOT activity of the HFD group was not different from the CTD group, the activity of the MFD group was significantly lower than the CTD group. The response of GOT activity of the MFD group meant the depression of breakdown from protein to amino acid. These results suggest that protein-sparing effect by fat was demonstrated with fish fed the MFD but the effect was limited compared to the case in rainbow trout, yellowtail and so on as mentioned in the introduction. Judging from the growth performance and hepatopancreatic enzyme activities of the present experiment and our previous report (Sugita et al. 2007a), the dietary fat content can be increased from 11% to 19%; i.e., dietary protein content can be effectively reduced from 55% to 42%, by supplementing 5% waste nori in fingerling red sea bream diets.

Acknowledgements

This study was financially supported in part by the Fisheries Agency, Ministry of Agriculture, Forestry and Fisheries, Government of Japan.

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The Effect of the Methods of Farming on the Environment and Growth of Cultured Red Sea Bream, *Pagrus major*

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Abstract The environment of fish farming areas and aquaculture production are considered to be closely related. Therefore, to establish the efficient use of fish farming grounds, I conducted a research on the subjects in conjunction with the rearing of red sea bream.

The presence of waste feed is assumed to provide the majority of the total particulate nitrogen discharged. The primary cause of eutrophication of fish farming grounds is excessive loading of nitrogen and phosphorus. Therefore, reducing waste is an important countermeasure to excessive nitrogen discharge. The chemical characteristics of phosphorus are different from those of nitrogen. Therefore, different measures are required to reduce phosphorus discharges.

In addition, it is suggested that rearing fish at low density is good for the growth of red sea bream, though the accumulation of more data is necessary before a clear conclusion can be reached. Furthermore, mortality caused by *Edwardsiella* decreases when fish are reared at low density. Thus, low density rearing is thought to be effective in reducing disease problems.

Key words: aquaculture, feeding frequency, rearing density, red sea bream, waste feed

Introduction

Wakayama Prefecture is located in the southwest of Honshu Island, Japan. The main fisheries products are horse mackerel, mackerel, and cultured red sea bream. Cultured red sea bream, *Pagrus major*, ranks third in terms of level of production. The species is cultured in fish farming sites scattered along the coast of the prefecture. The aquaculture industry, which produces one quarter of the fishery products in the prefecture, is important in Wakayama. The production of cultured red sea bream reaches 80% of total aquaculture production. In the 1980s, the deterioration of the sedimentary environment and the frequent occurrence of the red tides were observed in Tanabe Bay. In addition, there was an increase in aquaculture production in the bay, which today is one of the largest aquaculture sites in the prefecture (Uede 2004a, 2004b).

Tanabe Bay is located in the central part of Wakayama Prefecture. The southern part of the bay is a tranquil region with a complex coastline comprised of five inlets and some small islands. The southern part of the bay is one of the largest fish farming sites with the primary target fish being red sea bream. The aquaculture of yellow tail started in the 1970s and that of red sea bream began in 1977. Production of both species increased every year, peaking in the latter half of the 1980s. Annual production decreased from the late 1980s, and has fluctuated between 1,000 and 2,000 annually since. Fluctuation in red tide, especially associated with total duration, and fish farming production reacted with each other from 1971 to 2001 (Uede 2004a), when there was a decrease in fish farming caused by a depression in fish value that began during the latter half of the 1980s, accompanied with reductuion in the duration of the red tide events (Uede 2004a, 2004b, 2008).

When the aquaculture production increased and peaked, the acid volatile sulfide (AVS) increased and the dissolved oxygen (DO) in

2009 年 8 月 10 日受理（Received. August 10. 2009）
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summer season decreased (Uede 2004a, 2006). An azoic zone appeared in the southern part, the most deteriorated area of the bay. However, improvements of AVS and DO were observed, when production began to decrease in the 1990s. There are significant relationships between aquaculture production and the two parameters: AVS as a sedimentary environment factor and the total duration of red tide events. Given the results presented, the environment of the bay and aquaculture production are regarded as being closely related (Uede, 2004a).

Aquaculture production should be controlled to harmonize with the surrounding ecosystem. Deterioration of the environment caused by the nutrient load discharged from aquaculture influences not only the productivity of aquaculture itself but many other values of the coastal environment as well (Brown *et al*. 1987, Weston 1990). For example, biodiversity, nutrition cycling, and the value for tourism are all affected.

To establish efficient use of fish farming grounds, I conducted a series of studies associated with the rearing of red sea bream. This paper describes the results of studies into the effects of farming methods on the environment and the growth of red sea bream.

Materials and Methods

Rearing Experiment I

The purpose of the rearing experiment was to demonstrate how much particulate carbon, nitrogen, and phosphorus originated from the discharge of fish feed and feces from the fish cages. The experiment was conducted with the apparatus illustrated in Figure 1 from October 31 to November 2, 2006. Red sea bream (55 individuals with mean body weight 105g) were distributed in the tank (Figure 1) and the particulate matter discharged was collected. The diet type given to red sea bream was extruded pellets commercially available. The pellets were give to the fishes so that no waste feed as mach as possible. Sampling was conducted 0.5, 3, 6, 24, and 48 hours after feeding, at which times water temperature was measured at the inflow. The settled particulate matter was collected by filtering the bottom water (100 liters) through a 229 μm mesh nylon net. One liter of water that passed through the net was passed through filter paper (GF/C) to collect the fine particulates. The particulates in the outflow water were collected in the nylon net during the intervals between sample collections. The collected particulates were weighed after desiccation at 90℃. Total carbon and nitrogen levels in the

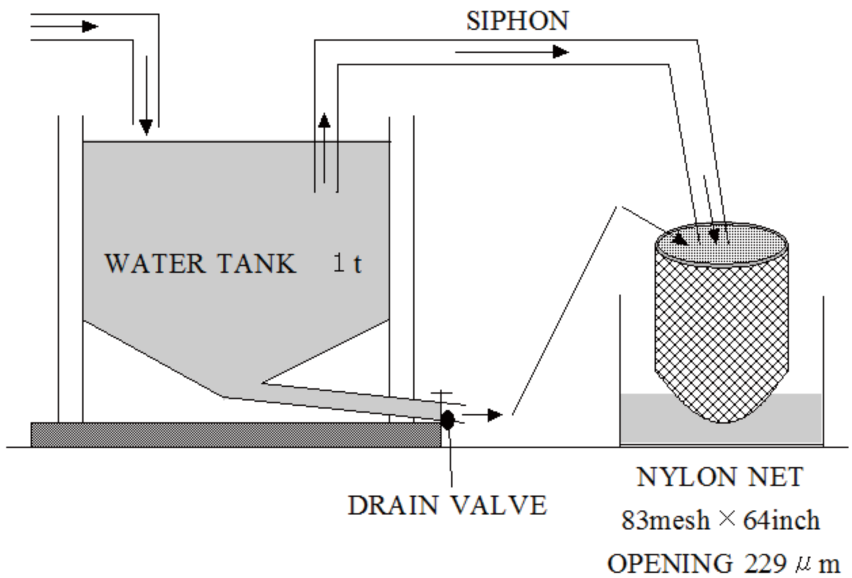

Fig. 1. Diagram of the experimental apparatus used to measure particulate compound discharged of carbon, nitrogen and phosphorus. Arrows indicate the flowing of sea water.

samples were determined with an elemental analyzer (Valio EL, Elementar). Total phosphorus was measured by the wet degradation method (The Japan Society for Analytical Chemistry 1987, Japanese Industrial Standard Committee 1998) The introduction and discharge of particulate carbon, nitrogen and phosphorus were calculated from the data collected.

Rearing experiment II

The organic load caused by rearing red sea bream is related closely to the amount of food offered. Therefore, the feeding rate is thought to be an important factor for environmental preservation. To explore this, an experiment that clarified how red sea bream's growth differed in relation to feeding frequency was conducted. Red sea bream (130 individuals with mean body weight 190g) were distributed in three cages (volume 22.5m^3). The diet type given to red sea bream was extruded pellets commercially available. Feeding experiments were conducted for 225 days, starting March 14, 2003. The feeding frequencies were four (experimental plot 1), three (experimental plot 2), and two (experimental plot 3) times a week. The results obtained from the experiment were compared with fish growth obtained from three private farms in the prefecture in 2002.

Rearing experiment III

Red sea bream (mean body weight 410 g) were distributed in four cages (volume 22.5m^3) at densities of 2.4 (fish cage 1), 3.6 (fish cage 2), 4.7 (fish cage 3), and 5.7kg/m^3 (fish cage 4). The feeding frequency was the same for all four cages. The diet type given to red sea bream was extruded pellets commercially available. The rearing experiment was conducted over for 140 days from April 9, 2004. At the beginning, the purpose was to demonstrate the relationship between growth and rearing density in red sea bream farming. But the mortality of red sea bream in fish cage 4 increased rapidly due to an outbreak of *Edwardsiella* since day 100. As a result, I changed the purpose to develop a relationship between mortality and rearing density.

Results

Rearing experiment I

Water temperature, salinity, and dissolved oxygen ranged from 22.7-23.6℃, 33.69-33.92, and 6.26-6.87 mg/l, respectively. The total amount of extruded pellets fed was 68.4 g, and the carbon, nitrogen, and phosphorus levels in the diet were 532.9, 102.2, and 16.7 mg/g, respectively.

The amounts of particulate matter and levels of carbon, nitrogen, and phosphorus discharged (per 1 kg of red sea bream) are shown in Figure 2. Particulate matter discharged as waste feed and feces were 367.7 and 1028.5 mg which correspond to 11.7% of the amount of diet fed. Carbon, nitrogen, and phosphorus discharged in waste feed were 167.4, 30.5, and 6.5 mg, respectively, while the levels in the feces were 411.1, 32.9, and 27.1 mg. The particulate matter discharged and levels of carbon and phosphorus in feces were more than 71.1% of the total amounts discharged. Nitrogen discharged as waste feed reached 48.1%, which is greater than the level of particulate carbon and phosphorus discharged as waste feed. With respect to the three elements discharged, the ratio of the phosphorus discharged to the total phosphorus in the diet offered was the largest.

C:N, C:P and N:P ratios as a function of time after feeding are shown in Figure 3. C:N was ≤6.5 in the discharged particulates until three hours after feeding. These values were similar to 6.1 of C:N in the diet. C:P and N:P at 0.5 hours were 104.2 and 16.1, whereas those ratios in the diet were 82.4 and 13.6. The values decreased sharply three hours after feeing. C:P and N:P were ≤47.6 and ≤3.6 since six hours after feeding.

Figure 4 shows the particulate carbon, nitrogen, and phosphorus discharge levels in waste feed and feces in relation to feeding extruded pellets. With respect to the particulate carbon and nitrogen discharged, the data obtained from the similar experiment by Uede (2007) were included. Particulate carbon discharged as waste feed and feces ranged from 1.9-3.2 and 4.7-6.5%. From 2.0-3.5% of the dietary nitrogen was discharged as waste feed and 2.2-2.7% was discharged as feces. In

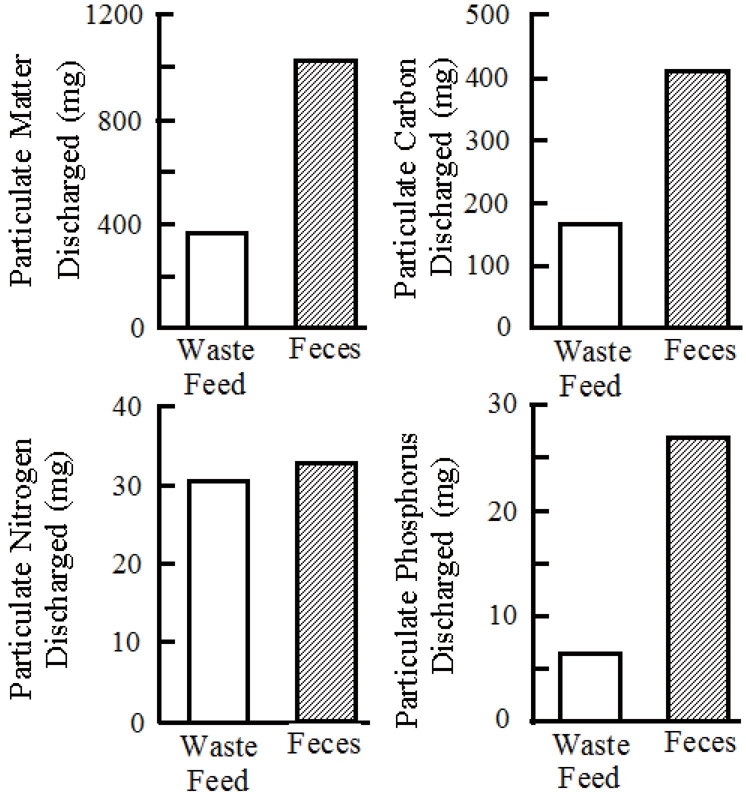

Fig. 2. Amounts of particulate matter, carbon, nitrogen and phosphorus discharged as waste feed and feces (per 1 kg of red sea bream).

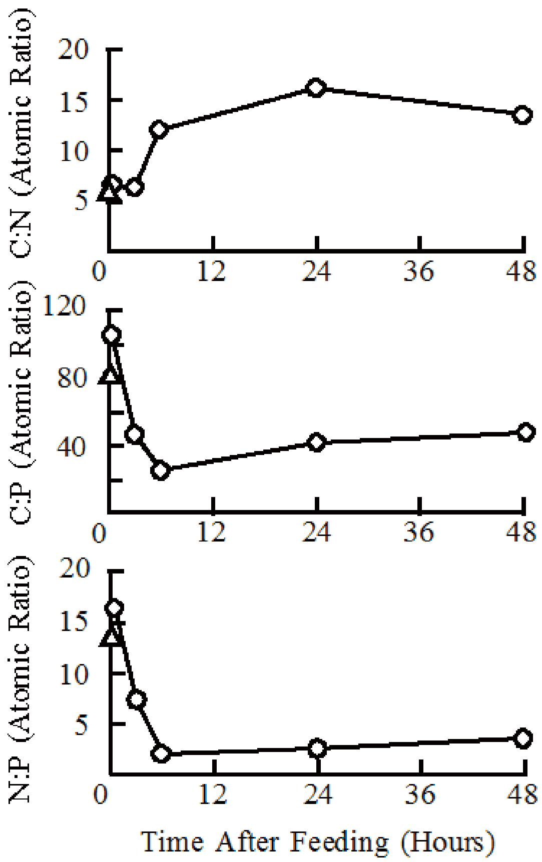

Fig. 3. C:N, C:P and N:P atomic ratio as a function of time after feeding.
△ shows each values in extruded pellets diet.

the case of phosphorus, the proportions discharged in waste feed and feces were 3.3 and 13.6%.

Rearing Experiment II

The summary of the rearing performance of the rearing experiment II is shown in Table 1. Red sea bream growth improved with increasing feeding frequency. Daily feed consumption and growth rate both increased with feeding frequency, while the feed to gain ratio decreased. Best growth was obtained from experimental plot 1 which received the highest feeding frequency.

Figure 5 indicates the growth of red sea bream from rearing experiment II in comparison to those on private farms. Table 2 provides a summary of the variables on three private farms compared to those of rearing experiment II. Both sets of data were compared after the same number of days of growth, though the times when the data were obtained were different. Fish growth in plot 1 was better than the average obtained from the three private farms.

Figure 6 shows red sea bream growth in conjunction with rearing density. In the prefecture, generally, after initial rearing is conducted in a small net pen, red sea bream of about 100 g or more are distributed into net pens for growout. The experiment was initiated at the same time that growout began on the private fish farms. Rearing density was consistently lower in the experimental cages than on the private farms.

Rearing experiment III

Fish performance in conjunction with rearing experiment III is summarized in Table 3. The change in cumulative mortality and number of survivors over time are shown in Figure 7 and 8. The mortality in cage 4 due to the outbreak of *Edwardsiella* increased rapidly from the 100th day. Best fish growth was maintained in cage 2 until day 103 (2nd period). Mortality gradually spread to fish cage 3, and occurred in cages 1 and 2 after day 130. As a result, when the rearing trial was terminated, the number of individuals in cages 2, 3, and 4 ranged from 160-172. Cumulative mortalities in cages 1, 2, 3, and 4 were 16.2, 11.8, 38.5, and 49.4%, respectively.

Change in the mean body weight of red sea bream over time is shown in Figure 9. Growth in fish cage 2 was best until day 103. However, mean body weight decreased as a result of the *Edwardsiella* outbreak except in cage 1 when the rearing trial was terminated.

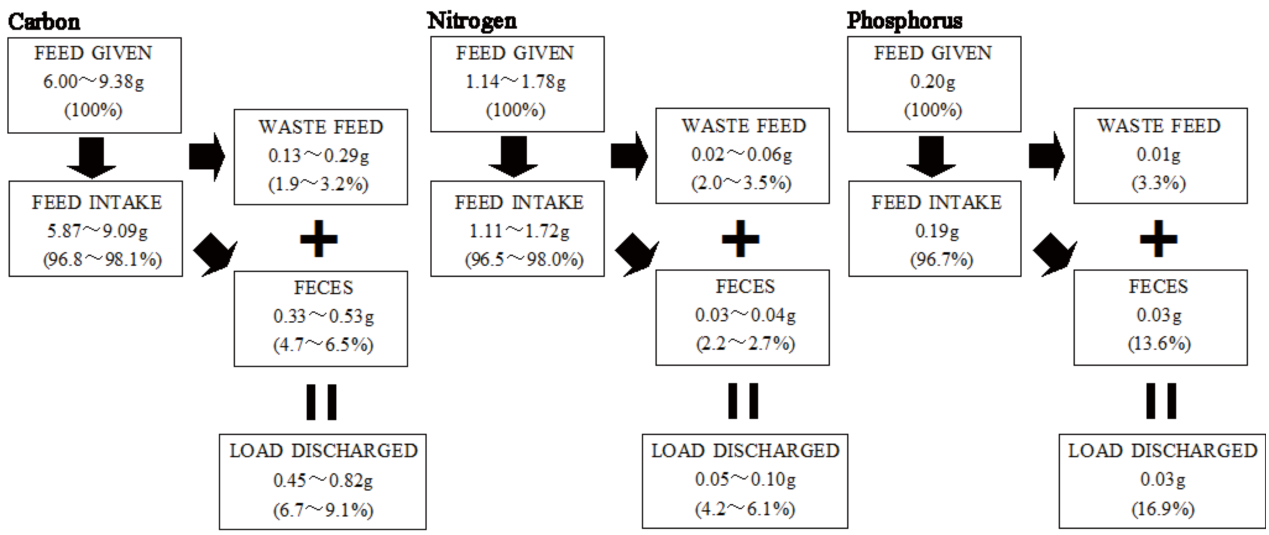

Fig. 4. Diagram showing particulate carbon, nitrogen and phosphorus discharge level in waste feed and feces in relation to feeding extruded pellets to 1 kg wet weight of red sea bream. The amount of extruded pellets to 1 kg wet weight of red sea bream was 11.9 g dry weight. With respect to the particulate carbon and nitrogen discharged, the data obtained from the similar experiment by Uede (2007) were included.

Table 1. The summary of the rearing performance of the rearing experiment Ⅱ

Experimental plot		1	2	3
Feeding frequency (times/week)		4	3	2
No. of fish	Initial	130	130	130
	1st period	124	127	126
	2nd period	124	127	126
	3rd period	120	127	126
Total fish weight (kg)	Initial	24.3	25.0	24.9
	1st period	39.3	37.8	36.6
	2nd period	58.1	55.0	50.7
	3rd period	123.5	112.8	92.6
Average body weight (g)	Initial	186.9	191.9	191.5
	1st period	316.9	297.6	290.5
	2nd period	468.1	433.1	402.0
	3rd period	1029.2	888.2	734.9
Mortality (%)		7.7	2.3	3.1
Feed supplied (kg)	1st period	17.7	15.8	13.0
	2nd period	32.5	27.8	24.6
	3rd period	89.7	81.0	66.1
	Whole period	140.0	124.6	103.7
Daily feed consumption (%)	1st period	0.97	0.88	0.74
	2nd period	1.19	1.07	1.01
	3rd period	0.86	0.85	0.81
	Whole period	0.82	0.80	0.78
Feed to gain ratio	1st period	1.07	1.16	1.02
	2nd period	1.73	1.62	1.75
	3rd period	1.31	1.40	1.58
	Whole period	1.33	1.39	1.49
Growth rate (%)	1st period	169.6	155.1	151.7
	2nd period	147.7	145.5	138.4
	3rd period	219.8	205.1	182.8
	Whole period	550.6	462.8	383.7

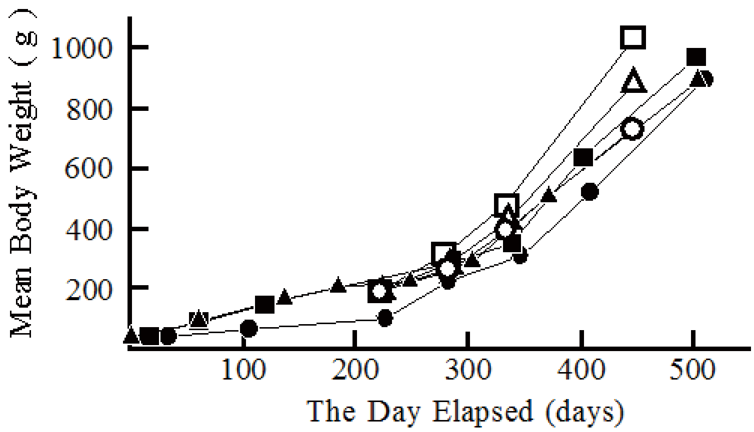

Fig. 5. Red sea bream growth from rearing experiment II in comparison to those in private farms. □ : Experimental plot 1, △ : Experimental plot 2, ○ : Experimental plot 3, ■ : Private farm No.1, ▲ : Private farm No.2, ● : Private farm No.3.

Table 2. The summary of the variable on three private farms compared to those of the rearing experiment Ⅱ

		Private farms			Number of fish cage for the rearing experiment		
		№1	№2	№3	1	2	3
Size of cage	Initial	7×7×7	6×6×4	6×6×4	3×3×2.5	3×3×2.5	3×3×2.5
	growout	15×15×9	12×12×7	13.5×13.5×9			
No. of fish		14,000	9,900	14,000	130	130	130
Date of beginning		Aug. 4, 2002	Aug. 23, 2002	Sep. 7, 2002	Mar. 14, 2003	Mar. 14, 2003	Mar. 14, 2003
Diet type		EP	EP、MP Almost EP	EP、MP	EP	EP	EP

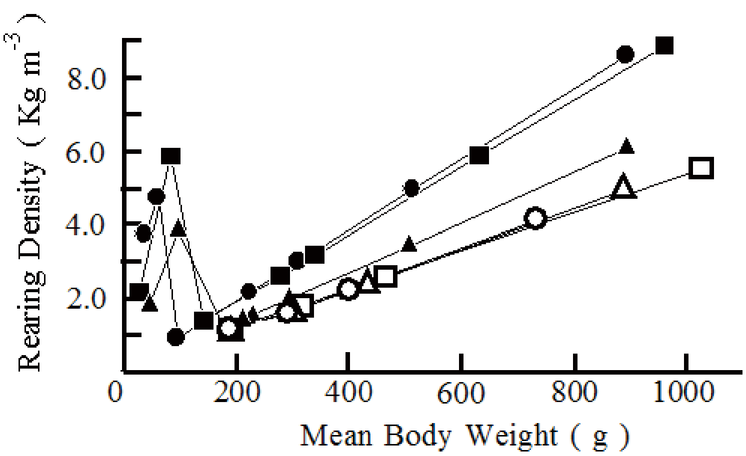

Fig. 6. Red sea bream growth in conjunction with rearing density.
□ : Experimental plot 1, △ : Experimental plot 2, ○ : Experimental plot 3,
■ : Private farm No.1, ▲ : Private farm No.2, ● : Private farm No.3.

Discussion

Particulate carbon and phosphorus in feces accounted for ≧71.1% of the total discharged. The proportion in waste feed reached 48.1% of the total amount in particulate nitrogen discharged. Waste feed is assumed to be the source of the majority of the total particulate nitrogen discharged according to Uede (2007b). That assumption is supported by the research reported here. Hence, it is concluded that the reducing the amount of feed that is not consumed by the fish is an effective way to reduce the particulate nitrogen loading in the sediments.

With respect to the C:N ratio in particulate discharges, Uede (2007b) indicated that particulate discharge for the first three hours after feeding is primarily from waste feed, after which it is from feces. The results presented here support that conclusion. The C:P ratio in the particulate matter discharged at 0.5 hours after feeding was higher than that in the diet. This indicates that phosphate, which forms the chemical union to organic compounds in the diet by an ester bond, is immediately dissociated after feeding (Laws, 1993). Six hours later, the C:P ratio decreased sharply to ≤47.6. The change in N:P was same as that of C:P. It is concluded that low values of C:P and N:P are associated with high rates of carbon and nitrogen absorption in the digestive tract of the fish. On the other hand, calcium bond phosphorus, which composes a large part of phosphorus compounds, is not highly absorbed. Uede (2007a) reported there are high phosphorus concentrations, which are predominantly composed of calcium bound phosphorus, in the sediments in fish farming areas. Compared with the ratios of C:P and N:P (≤25.5 and ≤2.82) in the sediments in fish farming areas, the values in feces found in this investigation (47.6 and 3.55) were higher. Reasons for this include the fact that a large part of the phosphate, which is predominantly calcium bound phosphorus, is discharged as feces. Moreover, calcium bound phosphorus, which is a stable compound, accumulates in the sediments for long periods of time. Hence, I need countermeasures, which are different from those that may work with respect to nitrogen discharges, to reduce the phosphate discharge.

In rearing experiment II, the best growth rates and feed to gain ratios were obtained with increasing feeding frequency. The growth in experimental plot 1 and 2 was better than on the private farms. The feeding frequencies on the three private farms were 0.41, 0.70 and 0.53 times a day, while rate associated with experimental plots 1, 2, and 3 were 0.61, 0.41, and 0.30 times a day, respectively. Feeding frequencies in conjunction with experimental plots 1 and 2, which had the best fish growth rates, were similar to the rates used on the private farms, though the fish densities in the experimental plots were lower than on the private farms. From these results, it is suggested that that rearing at low density promotes good growth in red sea bream.

Mortalities from the *Edwardsiella* outbreak decreased with decreasing fish density in rearing experiment III. Therefore, it is thought that resistance to fish diseases like *Edwardsiella* increases when the fish are present at low density.

When the above-mentioned results are considered together, it can be concluded that the amount of particulate nitrogen, which is discharged primarily from waste feed, is more than that of

Table 3. The summry of the rearing performance of the rearing experiment Ⅲ

Experimental plot		1	2	3	4
Number of fish	Initial	130	195	260	318
	1st period	128	195	259	310
	2nd period	122	194	252	296
	3rd period	109	172	160	161
Total body weight (Kg)	Initial	53.8	80.4	106.3	129.0
	1st period	70.7	113.1	146.0	173.1
	2nd period	89.3	153.6	180.3	205.6
	3rd period	85.2	128.8	110.5	107.7
Mean body weight (g)	Initial	413.8	412.3	408.8	405.7
	1st period	552.3	580.0	563.7	558.4
	2nd period	732.0	791.8	715.5	694.6
	3rd period	781.7	748.8	690.6	668.9
Mortality (%)		16.2	11.8	38.5	49.4
Feed supplied (g)	1st period	37.3	60.3	75.3	96.0
	2nd period	41.6	63.2	82.2	97.6
	3rd period	31.8	43.7	41.3	42.1
	Whole period	110.7	167.2	198.8	235.7
Daily feed consumption (%)	1st period	1.13	1.18	1.13	1.20
	2nd period	1.02	0.93	0.99	1.01
	3rd period	0.96	0.82	0.75	0.71
	Whole period	1.11	1.12	1.23	1.31
Feed to gain ratio	1st period	2.09	1.84	1.87	2.00
	2nd period	1.85	1.53	2.12	2.36
	3rd period	5.54	-5.57	-8.06	-7.18
	Whole period	2.52	2.71	3.36	3.74
Growth rate (%)	1st period	133.5	140.7	137.9	137.6
	2nd period	132.5	136.5	126.9	124.4
	3rd period	106.8	94.6	96.5	96.3
	Whole period	188.9	181.6	168.9	164.9

feces. The primary cause of eutrophication in the fish farming areas is excessive loads of nitrogen and phosphorus. Therefore, reduction in waste feed is an important means of reducing nitrogen discharges. Since the chemical characteristics of phosphorus are different from those of nitrogen, so the different countermeasures are required for phosphorus reduction in discharges. Finally, it is suggested that rearing at low density promotes the growth of red sea bream, though more data are required for verification. Low density also appears to increase resistance to *Edwardsiella*.

These results explain the opinion that reducing the nutrient loads discharged from aquaculture can help to improve environmental conditions. It is thought that rearing in a low density is good for not only the environment in fish farming areas but also may improve the health of cultured fish, though the conclusions are based on limited data. I'm now trying to establish techniques to evaluate the environment in fish farming areas. I want to develop the technologies that can provide harmony between aquaculture and coastal ecosystems. I believe that the only way aquaculture can make strides forward in the future is for it to exist in harmony with the surrounding ecosystem.

Acknowledgements

I thank Dr. K. Ikuta and Dr. H. Yokoyama of the National Research Institute of Aquaculture, Fisheries Research Agency, for continuous support. A very special thanks to A. Sasaki, S. Komi, T. Tanaka and K. Takenaka for help in

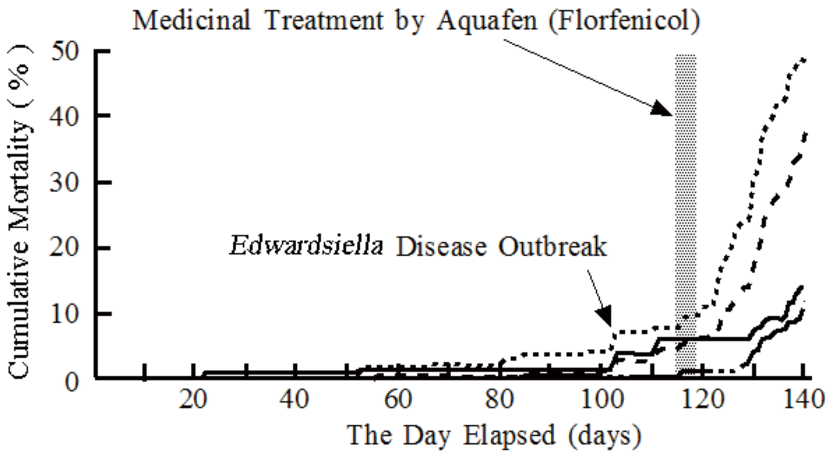

Fig. 7. Change in cumulative mortality of red sea bream as a function of the day elapsed.
——Fish cage 1, —-·—Fish cage 2, ––––Fish cage 3, ------Fish cage 4.

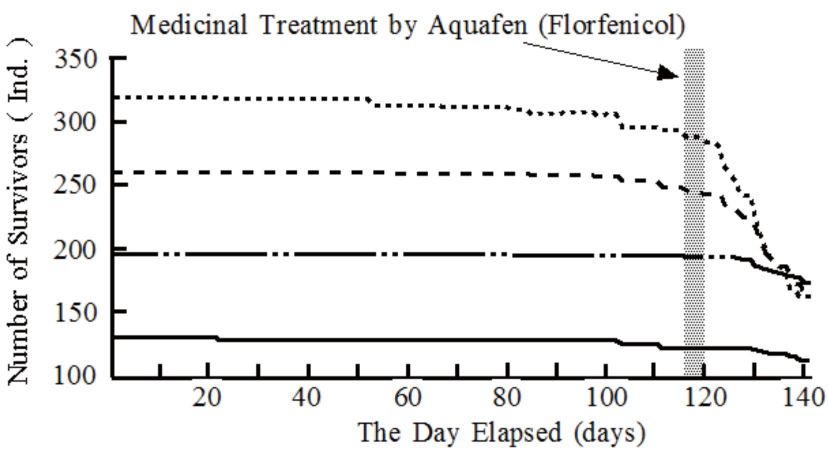

Fig. 8. Change in number of survivors of red sea bream as a function of the day elapsed.
——Fish cage 1, —-·—Fish cage 2, ––––Fish cage 3, -----Fish cage 4.

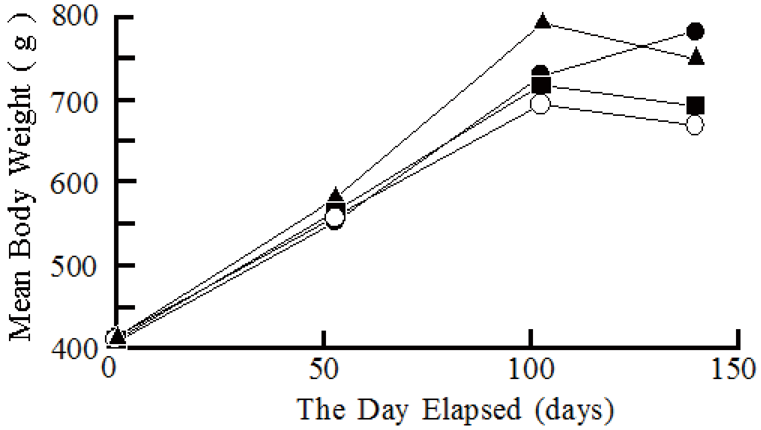

Fig. 9. Change in mean body weight of red sea bream as a function of the day elapsed. ● : Fish cage 1, ▲ : Fish cage 2, ■ : Fish cage 3, ○ : Fish cage 4

conducting the experiments in this study, and to M. Tanaka for help in working as my good assistant. This study was conducted by a grant from the Fisheries Agency of Japan.

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Manila Clam and Pacific Oyster Culture in Isahaya Bay — For the Sustainable Production in Stressful Environment —

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Abstract Isahaya Bay is a branch of Ariake Sound, Kyushu, where the tidal range is the largest in Japan. Culture of Manila clam, *Ruditapes philippinarum,* commenced in the 1970s and is currently the most important industry in the Konagaicho Fisheries Cooperative. The Cooperative introduced a demarcated fishery for Manila clam culture, so that the fishermen are in charge of the management of their own culture grounds, such as sand placement on muddy substrate, installation of facilities for accumulating the juvenile clams and preventing predators, and registering landings under the cooperative sales. The annual landing normally reaches 400-700 metric tons for about 100 individual fishermen. But Manila clam culture has occasionally suffered from mass mortality during summer since 1998 when the barrage in the Isahaya Reclamation Project closed the inner bay area in the previous year. We studied the mass mortality from the aspects of environment and clam physiology and determined that the main cause of mass mortality was anoxia by means of continuous monitoring of water quality factors and analysis of organic acids in the pallial cavity fluid of Manila clams. For sustainable and stable production of Manila clams, prediction and prevention of anoxic water intrusion to the culture grounds are of critical importance. Suspended culture of Pacific oyster, *Crassostrea gigas,* was introduced in late 1990s in Isahaya Bay, which had naturally produced delicious native oysters near the shoreline. The oyster culture industry has grown up to 175 metric tons a year by 42 fishermen in 2005. However, there are several problems constricting the increase in production; namely, summer mortality after spawning, heavy fouling by barnacles, and lower consumer demand in the local market. Increasing market demand and improvement of the culture technique are necessary.

Key words: Manila clams, Pacific oysters, pen shells, Ariake Sound, summer mortality

Introduction

Isahaya Bay, a branch of Ariake Sound where tidal range reaches ca. 5 m, possesses a large tidal flat of 29 km^2 out of 100 km^2 in the total bay area (Figure 1). The sediment of the tidal flat in Isahaya Bay and Inner area of Ariake Sound mostly consists of silt and clay (Kamata 1980). However, the tidal current in inner Ariake Sound is very strong because of tidal movement and the resonance of stationary waves (Inoue 1980). In Japan, the coastline has been artificially changed for many years, especially in sheltered bays where reclaimed lands and artificial structures such as dikes, breakwaters, and jetties have replaced the natural coastal line. Reclaiming tidal flats is the easiest way to extend farmland, industrial zones, and residential areas. Ariake Sound has been gradually reclaimed for a long time since the 6th century in accordance with natural land forming. After the Meiji era (from 1868), a huge

2009 年 8 月 10 日受理（Received. August 10. 2009）

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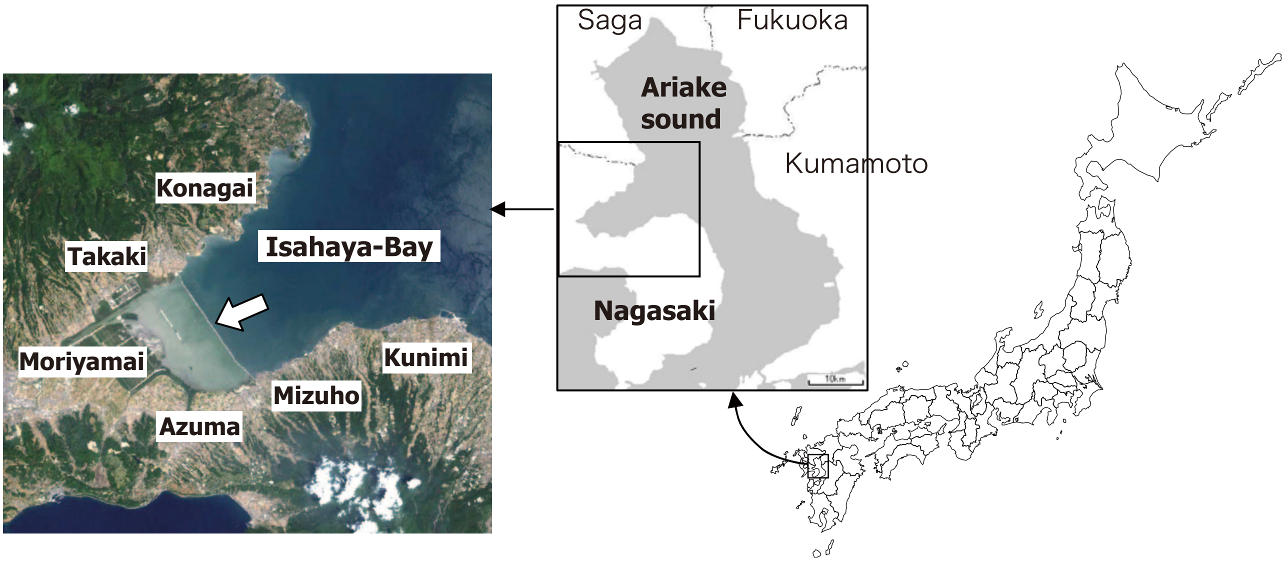

Fig. 1. Location of Ariake Sound and Isahaya Bay. Ariake Sound is surrounded by four prefectures. In Isahaya Bay, six fisheries cooperative had existed but three were abolished due to the construction of barrage in Isahaya reclamation project (arrow).

undertakings of reclamation was started and the shoreline moved forward up to 5 km (Satoh 2000). In Isahaya Bay, construction of the Isahaya Reclamation Project was started in 1989. A dike and water gate were constructed up to 1996 without opening 1.2 km out of 7 km total width. In 1997 the opening was completely closed (Sasaki 2005). In Isahaya Bay as well as other tidal flats of Ariake Sound, there was a good habitat for large amounts of filter feeding bivalves and fishes along with laver, *Porphyra yezoensis*. culture (Coastal Oceanography Research Committee 1985), so that a lot of fishing activity has occurred. However, recent environmental changes including reclamation, barrage construction, port construction, seabed collapse by coal mining and excavation of the seabed, presumably brought about negative ecological impact to indigenous marine organisms (Sasaki, 2005).

In this paper, Manila clam culture in Konagaicho Fisheries cooperative is described as an ideal example of development of a Manila clam aquaculture system in the face of difficult conditions in an altered environment. Moreover, we introduce the fact that hanging culture of Pacific oysters contributes to the production system in the bay.

Pen Shell Fisheries in Isahaya Bay

Pen shell, *Atrina pectinata*, was a dominant fisheries product in Konagai Fisheries Cooperative and caught by means of diving. Figure 2 shows the annual production of *A. pectinata* in each prefecture surrounding Ariake Sound. Production of *A. pectinata* periodically fluctuated presumably due to dominant year classes. Landing and sales of *A. pectinata* in three fisheries cooperatives surrounding Isahaya Bay are shown in Figure 3. In 1989, annual landings of the adductor muscle valuable as edible meat, reached 300 metric tons. It corresponds to three thousands metric tons of total animal weight. As sales reached 800 million yen, pen shell was the most important fisheries product in Isahaya Bay. Nevertheless, only four year after starting the construction of Isahaya Reclamation Project production was diminished in 1993.

Manila Clam Culture in Isahaya Bay

Figure 4 shows the annual production of Manila clam in each fisheries cooperative surrounding Isahaya Bay. Takaki and Azuma occupied half of total production in the 1970s and 1980s, but both were diminished with the progress of reclamation in the mid-1990s. Instead of these, Konagai became dominant after 1990. Manila clam culture commenced in the 1970s and is currently the most important industry in Konagaicho Fisheries Cooperative in accordance with the decrease of pen shell landings. The annual landing in the Cooperative normally reaches 400-700 metric tons by about 100 individual fishermen (Figure 4).

The characteristics of clam culture in the Cooperative are the introduction of a demarcated area for Manila clam culture. Each member owns an average of 1 ha of culture ground in the intertidal zone. Individual fishermen manage their own culture ground by taking actions such as placing sand on muddy substrate, developing facilities for producing juvenile clams and preventing predators.

According to Mori (1982), introduction and development of Manila clam culture in Konagaicho Fisheries Cooperative is as follows. Although the substrate on most of the tidal flat in Konagai consists of silt and clay with high iron content, successful production of Manila clam has been possible by placing sand placement on the muddy substrate. Trial and error of sand placement led to the determination that a sand mound was suitable for seawater circulation and prevention of mud accumulation. Thus sand placement contributes to

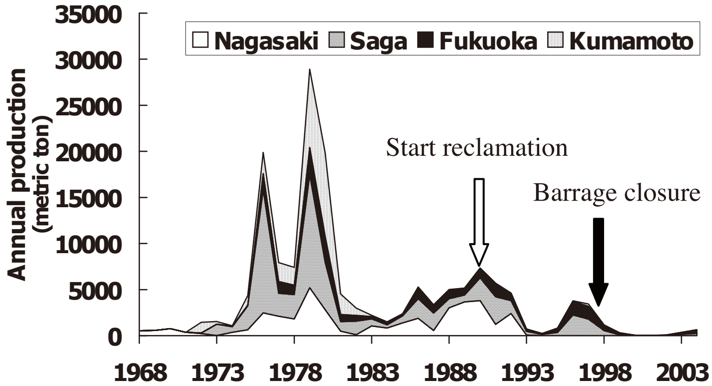

Fig. 2. Annual production (with shell) of pen shell, Atrina pectinata, in Ariake Sound. Each prefecture was shown in Figure 1.

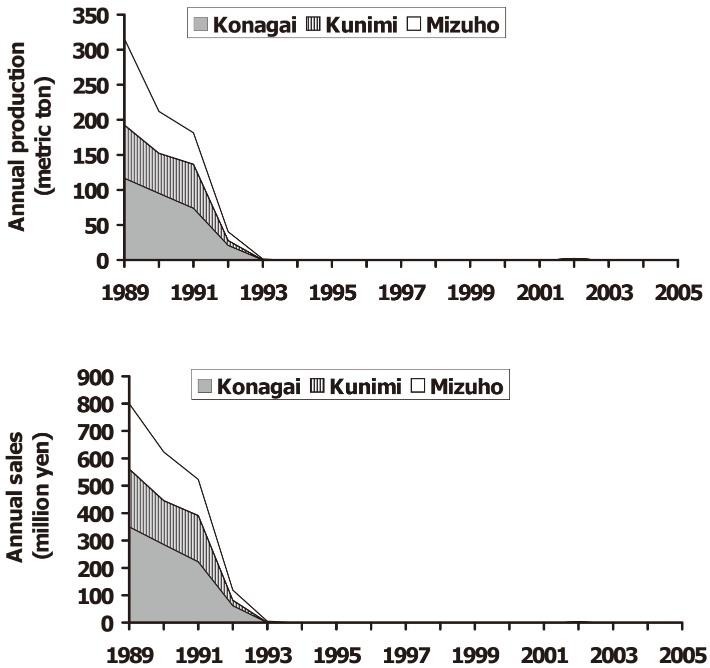

Fig. 3. Annual production (edible meat: adductor muscle) and sales of pen shell, Atrina pectinata, in main fisheries cooperative of Isahaya Bay

increase the area of high productivity, and the production reached up to 4.2 kg/m^2 from 1.2 kg/m^2 before sand placement. In addition, the following devices have been used for maintaining productivity of the culture ground. Fine mesh net was applied to prevent sand from sinking on extremely soft substrate. Setting of sand bags on the created sand flat can control bottom sand movement and create a natural nursery. Rakes and waterjets from submerged pumps are recognized as effective means of removing accumulated mud and dead shells from the bottom substrate. Each culture ground is enclosed by net fence in order to prevent the invasion of longheaded eagle rays, *Aetobatus flagellum,* which are predators of shellfish (Yamaguchi *et al.* 2005).

The cost of purchasing seed and sand against annual total sales of Manila clam in Konagaicho Fisheries Cooperative is shown in Figure 5. Total sales were affected by the total production and unit price, but cost of seed has been constant and cost of sand has been increasing since the mid-1990s. So the benefit is extremely depressed in lean years and recent decrease of total sales is disadvantageous for the business of Manila clam culture in the Cooperative. The proportion of the production to the seed amount in each year is shown in Figure 6. The proportion is higher in 1988, 1999, 1995, 1996, and 1997, but lower in 1991, 1992, 1994, and after 1998. Recovery of released seed should affect the budget of the culture business. In fact the ratio of production/seed is significantly correlated with the benefit (r = 0.609, $p<0.05$). Production is relatively low in comparison with the amount of seed released, so benefit only comes from the increase in unit price after growth

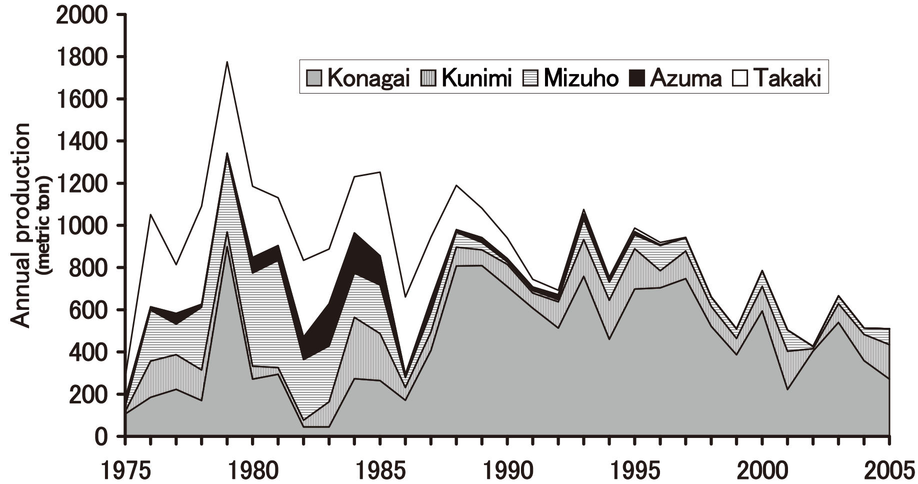

Fig. 4. Annual production of Manila clam, Ruditapes philippinarum, in main fisheries cooperative of Isahaya Bay. Only Konagai, Kunimi and Mizuo were running at present.

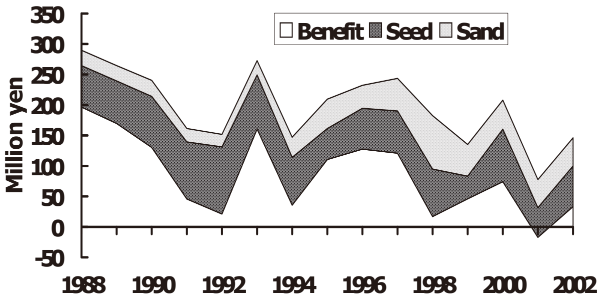

Fig. 5. Annual balance of cost and benefit on Manila clam culture at Konagaicho fisheries cooperative. The upper line shows the annual total sales of Manila clam.

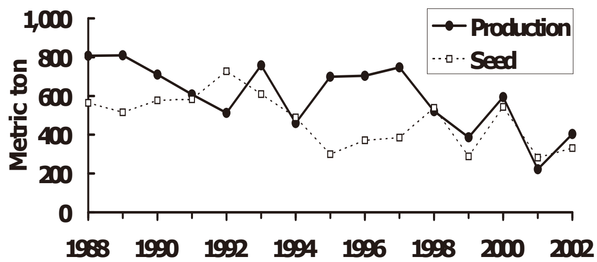

Fig. 6. Annual production and amount of seed for planting to aquaculture ground on Manila clam culture at Konagaicho fisheries cooperative.

of Manila clam seed. But Manila clam culture has occasionally suffered from mass mortality during summer since 1998 when the barrage in Isahaya Reclamation was closed in the preceding year. Actually, mass mortality on the Manila clam culture ground in Konagai was reported in 1994, 1998, 1999, 2000, 2001, 2002, and 2004.

Mass Mortality of Manila Clam on Culture Grounds of Konagai and Search for a Causal Effect of Anoxia

The Manila clam is the most important product in the Konagaicho Fisheries Cooperative, but it occasionally suffered from mass mortality during summer since 1998. It brought severe adverse impact for production of the Manila clam for the following couple of years. The certain fact was recognized that only a pile of dead shells emerged at ebb tide. The cause of the mortality had not been understood, although anoxia and/or red tide had been thought to be main factors associated with mass mortality in Isahaya Bay.

In order to make clear the possible cause of mass mortality and find out the appropriate management strategy for Manila clam culture, we have been studying the relationship between the physiological condition and environmental factors. During the summer season (June - September) from 2003 to 2005, continuous real-time monitoring of water quality and periodic monitoring of survival and physiological condition of Manila clam on the culture ground were performed (Figure 7). Water temperature, salinity, and dissolved oxygen were measured with a Hydrolab Co. DS-4 water quality meter connected with a cellphone transmission module and a solar electric supplier. Data were transferred by cellphone communication to the mail server and recorded on a hard drive. Manila clams were placed in plastic baskets with sand on the culture ground and checked for survival rate and carbohydrate contents fortnightly. In august 2004 we encountered highly anoxic water and mass mortality of Manila clams during normal monitoring and intensive observation. From late July to early August in 2004, it had been hot and dry. Red tide of *Chattonella marina* and *C. antiqua*, Raphidophyceae, had broken out on August 5, and extremely low oxygen was observed from August 11-14 intermittently (Figure 8). All the Manila clams in the area died during that period.

According to the monitoring of Manila clam in baskets, carbohydrate contents of soft tissues were stable from May to July and still showed more than 30 mg/g wet weight of soft tissue and 80% survival on August 2. It is thought that the

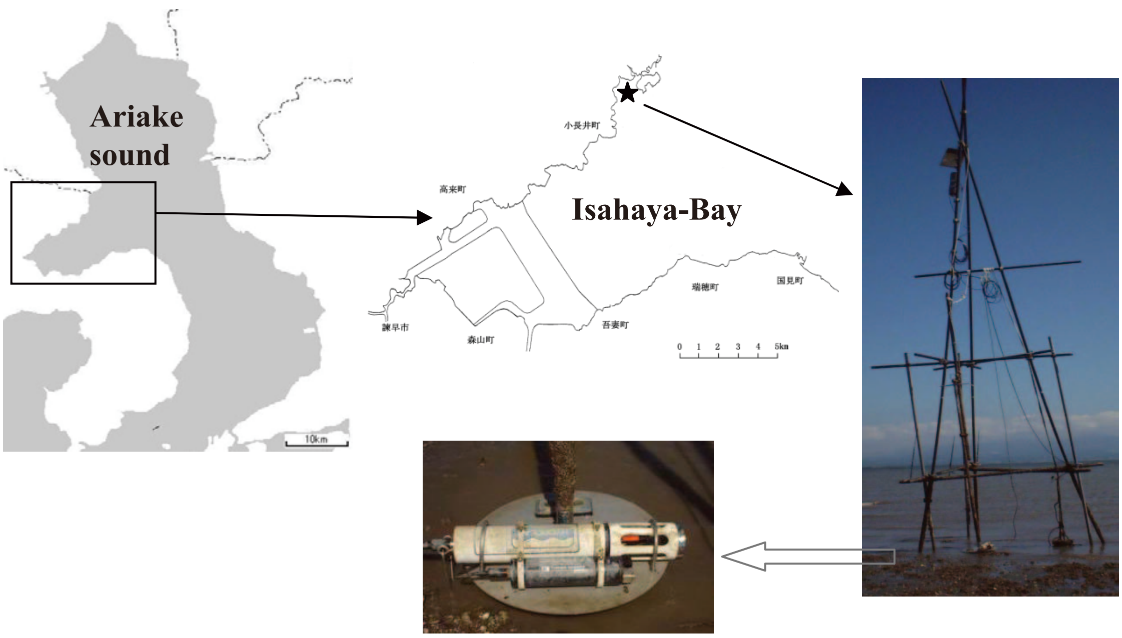

Fig. 7. Research site at Manila clam culture ground in Isahaya-Bay and scaffolding water quality meter is equipped. Solar cell module and cell-phone module are installed on the top.

Manila clams had conserved enough energy until mass mortality occurred.

Figure 9 shows the survival rate and organic acid contents in pallial cavity fluid of Manila clams put in mesh bags placed on the bottom of the culture ground at 1500 August 10 along with the record of dissolved oxygen. Both succinate and propionate, which are known as end products of

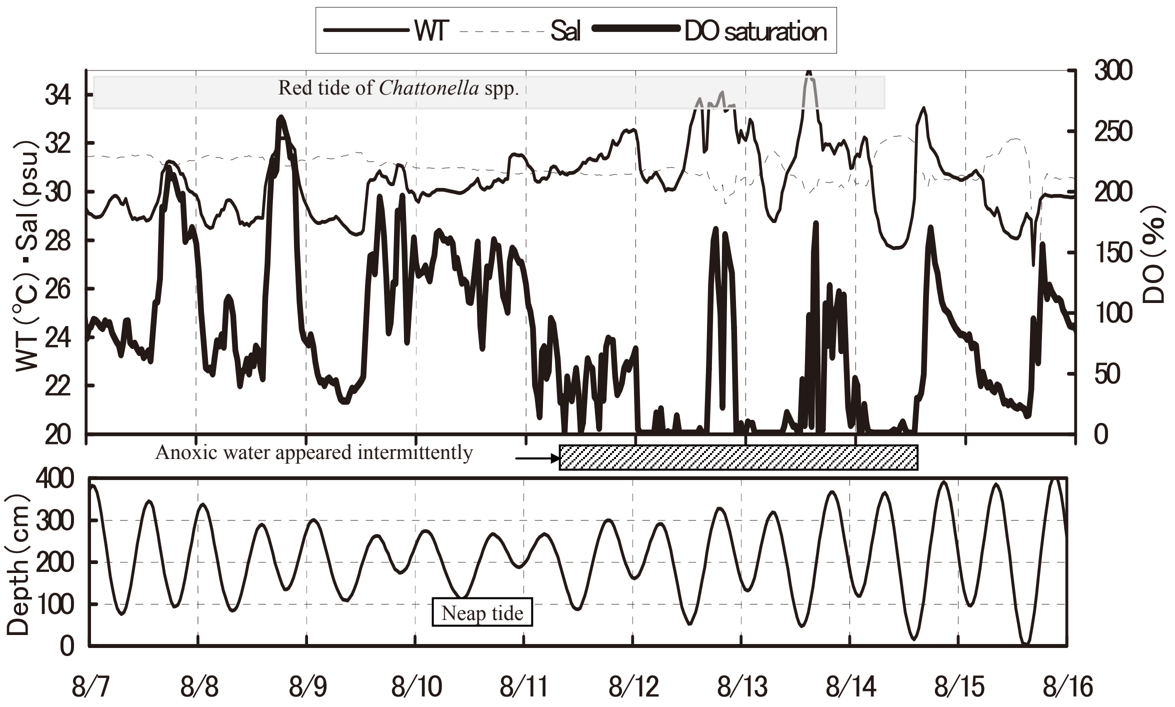

Fig. 8. Water temperature, salinity, dissolved oxygen and depth in second week of August, 2004 on the bottom of Manila clam culture ground recorded by water quality meter.

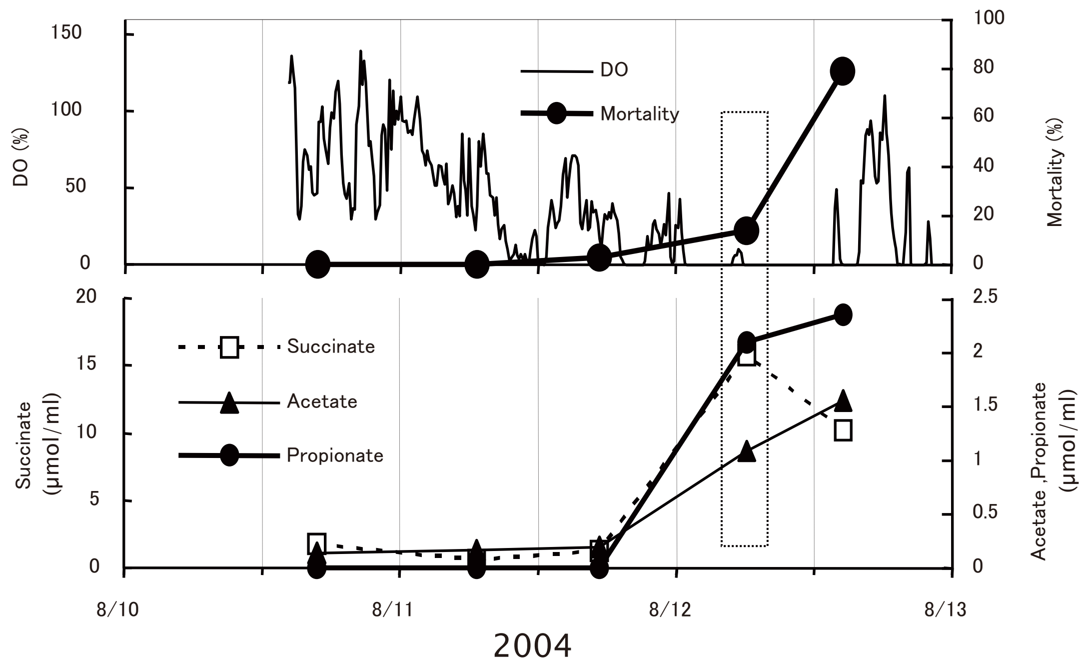

Fig. 9. Dissolved oxygen concentration at the Manila clam culture ground in Isahaya-Bay and the clam mortality (upper), and organic acid contents in pallial cavity fluid of Manila clam placed in mesh bag on the bottom (lower). Organic acids significantly increased before rapid rise of fatality (framed rectangle).

anaerobiosis (Hochachka 1984, Zwaan 1983) significantly increased by 0600 on the 12th before a rapid rise of fatality. The propionate concentration of 2 μmol/ml indicates no recovery state to the aerobic pathway in Manila clams even if they are supplied sufficient oxygen (Shinagawa, personal communication). In fact, most of the clams died until 1400 on the 12th. Average water temperature during the period exceeding 30℃ even including anoxic water flowed into the culture ground. This fact demonstrates that the clams exposed to anoxic water for 13 hours from the evening of the 11th to the morning of the 12th had reached the fatal step of anaerobiosis. The anoxic water had a strong odor of hydrogen sulfide and the sulfide concentration of the bottom water ca. 5 km from this site was 3 mg/l on 13 August. A tank experiment in which Manila clams were exposed to anoxic water and plus hydrogen sulfide at 30℃ demonstrated that hydrogen sulfide increased propionate in the pallial cavity fluid within 13 hours. Anoxia and (normoxia, sometimes hypoxia) alternated with the interval of 15 hr, (6 hr), 14 hr, (13 hr), 12 hr within 60 hours from August 12 at 0030 to the 14th at 1230. It is thought that the combination of hydrogen sulfide generation with anoxic water at high water temperature above 30℃ brought Manila clams to the fatal state of metabolite accumulation.

The cultured Manila clam was lost by only a three days event, namely anoxia. It is foremost important to establish measures to prevent mass mortality by anoxia. Research on the development of simple facilities to prevent the invasion of anoxic bottom water and on a device to efficiently supply oxygen to the bottom layer where Manila clam inhabits is currently progressing.

Pacific Oyster Culture in Isahaya Bay

In Isahaya Bay native oysters have long been utilized at local retail shops and seafood restaurants along the shoreside road before the reclamation construction. The native oysters have been in high repute with good flavor although their size is quite small. But most of the oyster reefs were diminished with the construction. Suspended culture of the Pacific oyster, *Crassostrea gigas*, was introduced to Isahaya Bay in the late 1990s. Figure 10 shows the increasing number of fishermen and facilities for oyster culture in the Konagaicho Fisheries Cooperative and they reached ca. 40% of the members and averaged 1.5 rafts in 2005. The growth of cultured oysters is good and can be harvested after only a half year of growout. Annual production and sales of the oysters in Konagaicho Fisheries Cooperative is shown in Figure 11. Production increased constantly except in 2004 due to damage by a typhoon on the 18th of September, 2004.

Production and the sales in 2005 reached 175 tons and 74 million yen. The spat of cultured oysters were transported from Miyagi Prefecture, northern Japan. The oyster rafts are placed 2-4 m of the depth at low water spring tide in several locations of Isahaya Bay, so suitable area for culture are limited. They grow fast, but summer mortality occurs during the culture period by

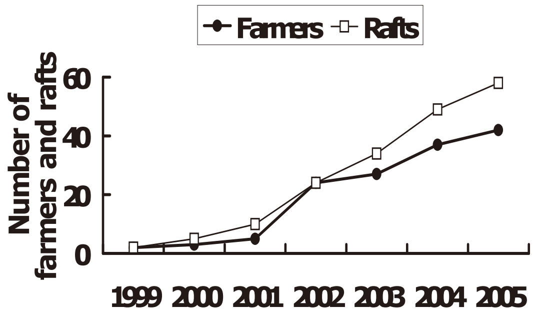

Fig. 10. Increasing number of farmers and rafts on Pacific oyster culture at Konagaicho fisheries cooperative.

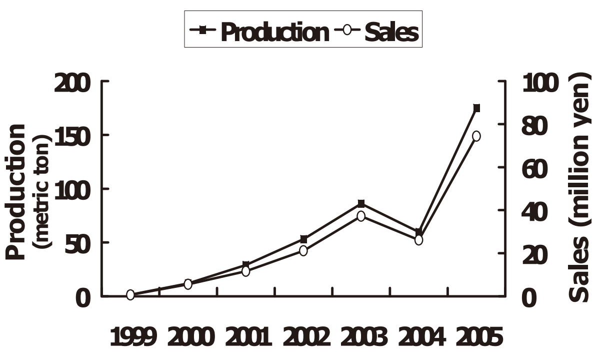

Fig. 11. Annual production and sales of Pacific oyster at Konagaicho fisheries cooperative.

oysters weakened after spawning because of high water temperature and sometimes perhaps hypoxic water. More effort to introduce native oysters to hanging culture is essential not using spat from coldwater areas in order to avoid summer mortality. Heavy fouling by barnacles, ascidians and other animals is a constraining factor for the management of oyster culture. Attachments and/or settlement of larvae are inevitable in shallow water, so development of novel equipment and methods against fouling animals is necessary.

Discussion and Conclusions

After the crash of the pen shell fishery, Manila clam culture has been the most important industry in Isahaya Bay. Oyster culture helps compensate for the reduction of Manila clam production (Figure 12). These transitions could support total income of the fishermen in Konagaicho Fisheries Cooperative so far. Nevertheless both Manila clam and Pacific oyster culture haven't compensated for the entire portion of the lost pen shell industry. In order to increase the production of both species, technical and administrative supports are necessary. For Manila clam culture, establishment of effective measures to prevent anoxic water is indispensable. Development of the reproduction system of natural seed on the culture ground is essential in order to reduce costs. Development of methods and devices for improving substrate on the culture grounds is necessary for reducing the costs of sand. For oyster culture, improvement of the culture technique including using local broodstock is necessary. Exploit of the market demand is inevitable for further increasing total production. Furthermore, the problem is that the culture of both species is faced with the reduction of productivity due to environmental factors.

For sustainable shellfish production in Isahaya

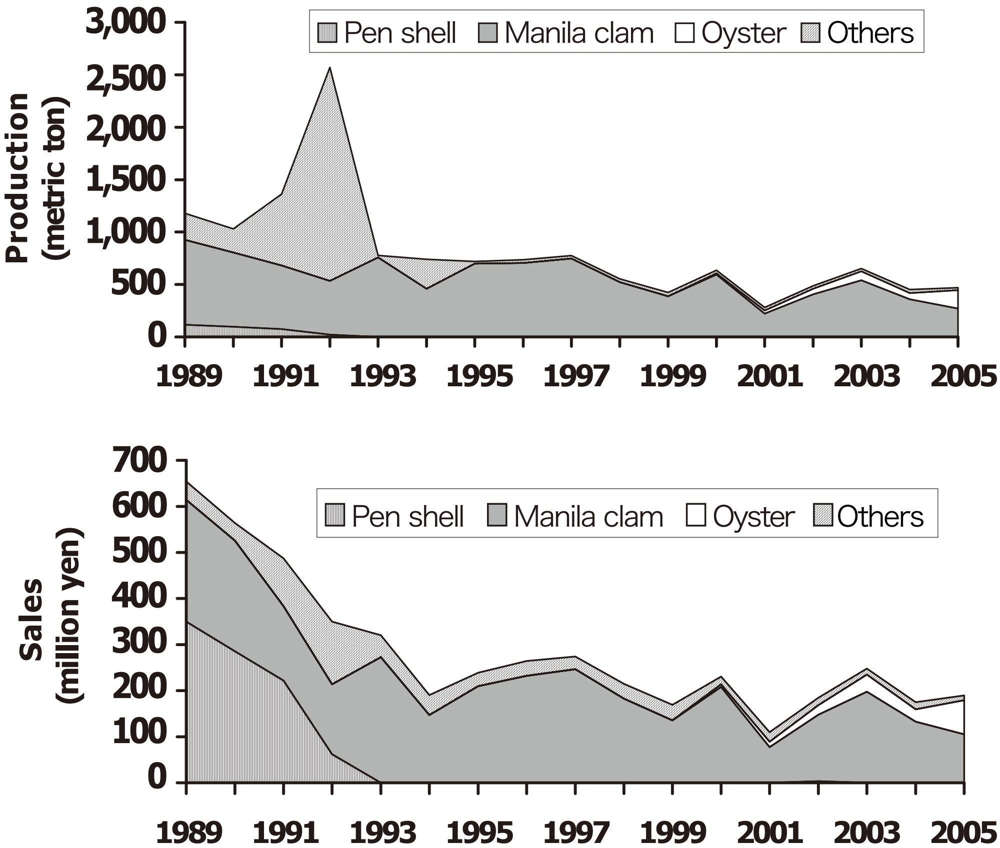

Fig. 12. The breakdown of main fisheries products in terms of production and sales at Konagaicho fisheries cooperative. The production of pen shell is expressed as amount of edible meat.

Bay, a fundamental solution is necessary for generation of hypoxic/anoxic water. Rapid decrease of the nutrient removal from the ecosystem, i.e. fisheries production, may cause increased harmful phytoplankton blooms and anoxic water through collapse of the balance between the inflow and the outflow of nutrients. Extractive culture, such as Manila clam and oyster culture, must contribute to restoration of the environment. So, we should make a great effort to enhance bivalve culture in Isahaya Bay. Both the Manila clam and Pacific oyster are key species for a balanced ecosystem through their filter feeding activities and harvest without feeding in terms of removing organic matter from the ecosystem (McVey *et al.* 2002).

Acknowledgement

We thank Konagaicho Fisheries Cooperative for providing the statistical data of shellfish culture and its cooperation on our research.

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New Technology for Developing Biologically Productive Shallow Area in Ago Bay

Hideki KOKUBU* and Hiroyuki OKUMURA*

Abstract In Ago Bay, sediment eutrophication and frequent occurrence of hypoxia has caused the deterioration of benthic ecosystem and decrease of biological productivity in recent years. Furthermore, harmful algal blooms and infectious diseases make sustainable pearl culture difficult. It is considered that one of the major causes of these phenomena are stagnation of the material circulation by reduction of the shallow coastal areas. The natural shallow coastal areas were decreased everywhere in the inner parts of the bay by land reclamation and the dike construction. Then we made clear that approximately 70% of the tidal flat and shallow areas have already been decreased in Ago Bay. Therefore, for environmental restoration of Ago Bay as a major site of pearl culture, it is necessary to enhance the biological productivity which these shallow areas provide and to enhance the material circulation around the shallow areas. In this study, the suitable range of sediment quality of tidal flat for benthic species was found to be 3-10mg/g dry weight for chemical oxygen demand and 15-35% for mud content ratio. New technology for enhancing the biological productivity in the reclaimed shallow areas by controlling sediment quality was developed.

Key words: Tidal flat, biological productivity, Ago Bay, dredged sediment, macrobenthos

Introduction

Ago Bay is located in Ise-Shima National Park and is famous for the cradle of the pearl culture. However, harmful algal blooms and infectious diseases make sustainable pearl culture difficult. Furthermore, sediment eutrophication and frequent occurrence of oxygen-deficient water has caused the deterioration of the benthic ecosystem and decreased biological productivity in recent years. It is considered that one of the major causes of these phenomena is reduction of the material circulation by reduction of shallow coastal area including a tidal flat, sea grass and seaweed beds. The natural shallow coastal areas have decreased everywhere in inner parts of the bay due to land reclamation and the dike construction. Then we found out by the multi-spectrum aerial photo analysis that approximately 70% of tidal flat and shallow areas have already been lost in Ago Bay. Therefore, for environmental restoration of Ago Bay as the major site of pearl culture, it is necessary to enhance the biological productivity which tidal flats, seagrass and sea weed beds provide, and to recover good material circulation around the shallow areas. New technology for enhancing biological productivity by controlling sediment quality was developed.

Experimental Suitable Sediment Condition for the Benthic Species

To determine the suitable sediment condition for the benthic species, six experimental tidal flats in which the organic content has changed, were set up in Ago bay. The sediment qualities and benthic species of the experimental tidal flats were monitored for three years. The results indicated that the suitable range of sediment qualities of tidal flats for benthic species was 3-10mg/g dry weight for chemical oxygen demand (COD) and 15-35% for mud content ratio. By utilizing the above

2009年8月10日受理（Received. August 10. 2009）
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results, the two types of artificial tidal flats by controlling sediment condition were constructed in Ago Bay.

Enhancing the Biological Productivity in the Relatively Oligotrophic Tidal Flat in Front of a Dike by Using Dredged Sediment

In Ago Bay, natural tidal flats in front of the dike are relatively oligotrophic. Total area of the tidal flats is about 84 ha. The sediment of the tidal flats are gravel and contain low organic matter because the dike shut out the nutrient supply from the land. Thus, in these tidal flats, the abundance and diversity of benthos are very low. To enhance the biological productivity of such ecosystems, new artificial tidal flat using muddy dredged sediment from Ago Bay was constructed. A total area is about 7,200m^2. The artificial tidal flat was constructed by mixing muddy dredged sediment with existing oligotorophic sediment in front of the dike (Figure 1). The construction of the artificial tidal flat was completed in March, 2005.

The sediment samples from the artificial tidal flat and neighboring natural tidal flat were measured for COD, TOC, TN, IL, AVS, ORP, particle size, chlorophyll *a*, benthic abundance and species numbers every season for two years. (Figure 1). In April 2004, before construction, sediment samples were obtained and analyzed for same characteristics. To analyze for chlorophyll *a*, this sediment samples were sliced into the 1 cm sections from the surface. For analyzing other sediment characteristics, samples were sliced up to 12 cm from the surface.

Investigation of the Oxygen Consumption and the Primary Production Rate on the Artificial and Natural Tidal Flats

Two transparent chambers (made from chloroethylene diameter 25cm, height 20cm), one each on the artificial and natural tidal flats in front of the dyke, were set on their sediment surface (Figure 2). The oxygen consumption rate was measured continuously for two hours with dissolved oxygen probes in both chambers. Solar radiation was measured continuously with a light quantum sensor. The sediment samples under their chambers were measured for AVS, TOC, TN, chlorophyll *a*, DIN, and DIP (interstitial water). These measurements were carried every month in 2005. The primary production rate was calculated by subtracting the oxygen consumption rate in the dark chamber from that in light chamber.

Investigating Changes in Water Quality During Ebb and Flow on the Artificial Tidal Flat

The artificial tidal flat was enclosed in two areas with polyethylene sheets. First was all the artificial tidal flat area (DL = +1.5 m to about -1.5 m) which contained a rich macrobenthos area (DL = 0 m to about -1.5 m). Second was a relatively shallow artificial tidal flat area (DL = +1.5 m to about 0 m) that did not contain an area of rich macrobenthos (Figure 3). Water quality was investigated every hour for one day during ebb and flow conditions in the two areas. Those studies were carried on during the summer (21-22 July and 4-5 August 2005), autumn (13-14 October and 2-3 November 2005), and winter (26-27 January and

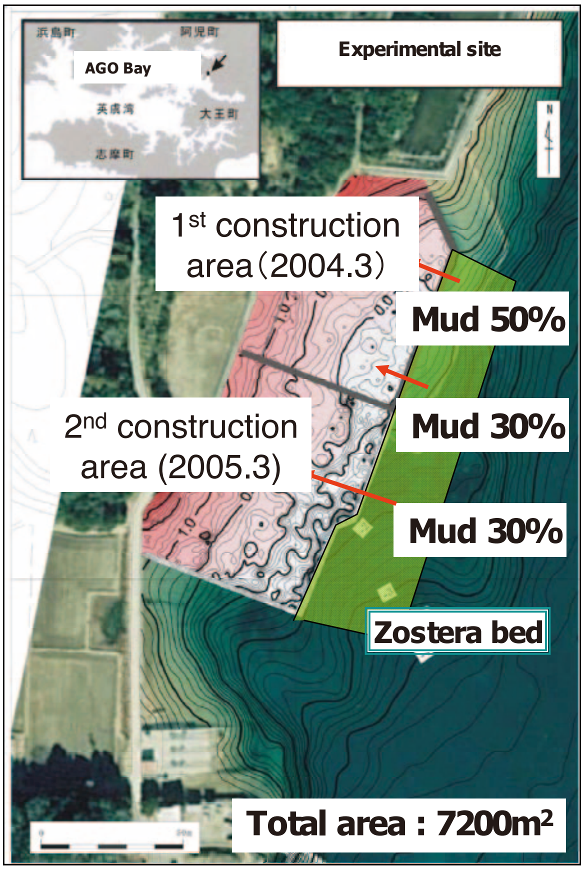

Fig. 1. Outline of the artificial tidal flat.

16-17 February 2006), during flood tides. The study areas are shown in Figure 3. DO, salinity, turbidity and pH were measured by multi-sensor every hour. At the same time, sea water samples were collected. Water temperature, depth, and light were measured on the artificial tidal flat every 10 minutes with recording instruments. The water samples were filtered in the field and analyzed for SS, chlorophyll *a*, TOC, DOC, TN, DTN, TP, DTP, DIN, and DIP.

Enhancing the Biological Productivity on the Hypertrophic Wetland Behind the Dike by Promoting Water Exchange

Behind the dike there were hypertrophic wetlands which in the past were a part of the natural tidal flats prevalent in Ago bay. Such areas add up to some 153 ha. The sediments of the wetland are muddy and contain high levels of organic matter because the dikes accumulate nutrients and organic matter due to runoff from the land. In these wetlands, the abundance and diversity of benthos are very low. Attempts were made to enhance the biological productivity by

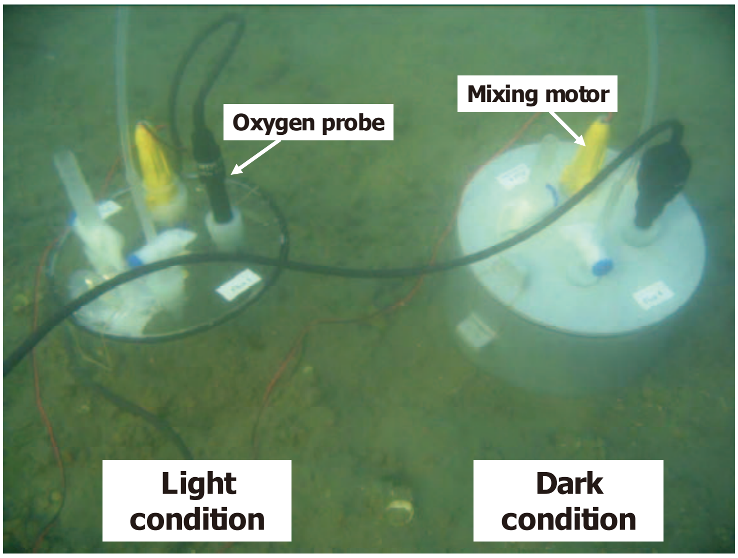

Fig. 2. Light and dark chambers on the tidal flat.

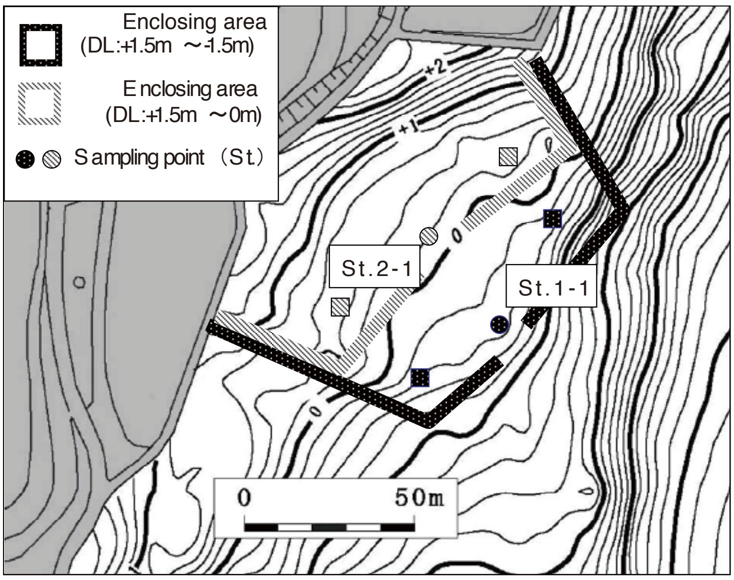

Fig. 3. Outline of the flux investigation area.

promoting water exchange between the wetland and bay using pumps in conjunction with a pipeline system. Improvements were evaluated by monitoring sediment quality, benthic abundance and species diversity seasonally.

Results and Discussion

The Function of Habitat on the Artificial Tidal Flat:

Seasonal Changes in the Abundance and Diversity of Macrobenthos

The seasonal changes in chlorophyll *a* in the sediments (DL = +0.5m) on the natural and artificial tidal flats containing 50% and 30% mud are shown in Figure 4. After two months, chlorophyll *a* on the experimental tidal flat increased significantly compared to that of the natural tidal flat. One year after construction the chlorophyll *a* on the artificial tidal flat was about four times higher than before construction. On the other hand, after one year the abundance of macrobenthos on the artificial tidal flat had increased markedly and subsequently, the chlorophyll a was the same as before construction due to greater grazing pressure. These results indicated that benthic algae increased soon after construction because dredged sediments contained rich in organic matter.

The seasonal changes in abundance of macrobenthos on the artificial tidal flat sediment (DL = +0.5m) comprised of 50% and 30% mud are shown in Figure 5.

The macrobenthos were classified as polychaeta, bivalvia, gastropoda, crastacea, and ichthyoid. Immediately after the construction, the gastropoda and the crastacea were dominant. After six months, the polychaetes and the bivalves had increased, and after 10 months, species numbers also increased remarkably compared to the present before construction, indicating increased diversity. After four months, the abundance of macrobenthos had increased significantly, and after one year they had increased four-fold compared to before construction and had reached steady state.

The recovery time for the macrobenthos in 30% mud on the experimental tidal flat was faster than that of the community in 50% mud. Furthermore, according to the results of the carbon and nitrogen stable isotope analyses, the carnivores were not present on this tidal flat. Thus, the community was in a transition phase toward stability. Therefore, these results indicated that it takes more than one year to develop a stable habitat on an artificial tidal flat.

It is clear from the study that after the construction of tidal flats, benthic algae increase first, followed by the macrobenthos. On the other hand, after the dredged sediment was mixed, deposit and suspension feeders became more abundant. Thus, the constructed tidal flat ecosystem had changed to an ecosystem with high diversity. For about one year the abundance and diversity of benthos had increased more than four-fold compared with the pre-construction situation.

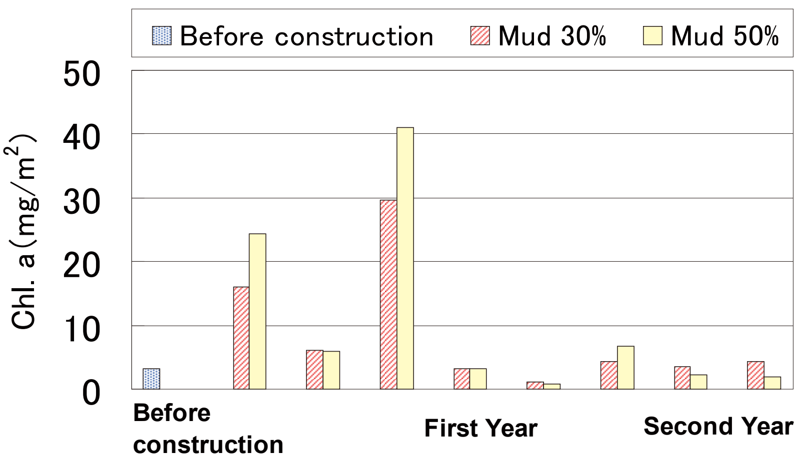

Fig. 4. Seasonal changes of chl. a in artificial tidal flat.

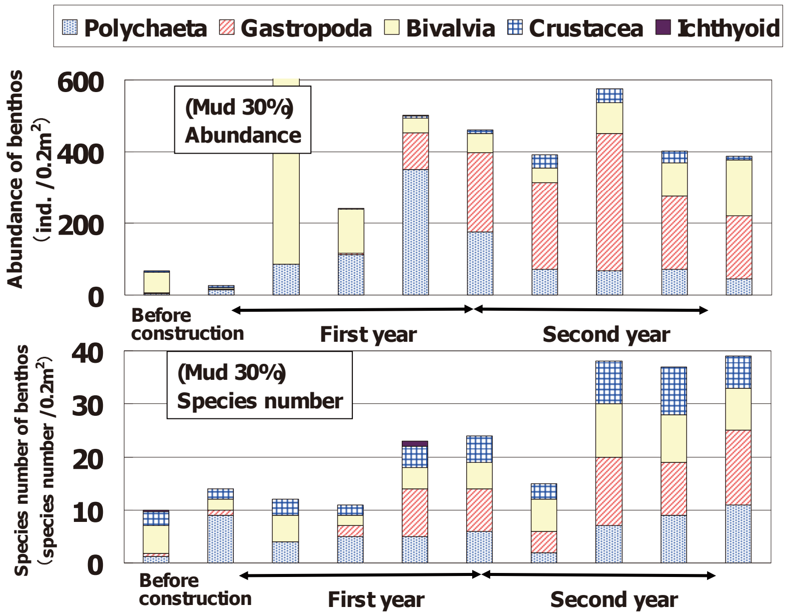

Fig. 5. Seasonal changes in abundance and diversity of the macrobenthos.

Tsopographic Change on the Artificial Tidal Flat

The changes in elevation a year beginning immediately after construction of the artificial tidal flat are shown in Figure 6. The ground elevation increased from 30-40 cm below DL= 0 m, and above DL = 0 m elevation had decreased 10-20 cm. It is thought that tidal flat sediments moved offshore. The inner part of Ago Bay in which artificial tidal flat was constructed is characterized by calm water, but it is possible that large amounts of the tidal flat sediments can be moved by turbulence caused by typhoons. Therefore, to estimate the topographic change in the artificial tidal flat, it is necessary to understand the pattern of change in wave patterns. To protect the loss of silt and clay, it is necessary to provide stability for the tidal flat sediments.

Monthly Changes in the Oxygen Consumption and Primary Production Rates on the Artificial and Natural Tidal Flats

Monthly changes in the oxygen consumption rate on the artificial and natural tidal flats are shown in Figure 7. During winter the oxygen consumption rate on the flats were not very different. However, from May to October when the water was warmer, the oxygen consumption rate on artificial tidal flat increased significantly. In August and September, oxygen consumption was greater on the artificial flat than on the natural one. These results indicated that under aerobic conditions, decomposition of organic matter was enhanced on the artificial tidal flat from spring to autumn.

The monthly changes in the primary production rate and chlorophyll *a* on the artificial and natural tidal flats are shown in Figure 8. The primary production rates were low during summer, then increased and reached its highest level in autumn (from September to November). The chlorophyll *a* level in the tidal flat sediments was also low during summer and highest during autumn. It is concluded that grazing of benthic algae by macrobenthic organisms and the inhibition of primary production by strong solar radiation caused the lower primary productivity in summer. During August and November the primary productivity on the artificial tidal flat was higher than on the natural tidal flat. It is concluded that under aerobic conditions the rich organic matter in artificial tidal flat sediments decomposed and the benthic algae increased by taking up the nutrients that were released. Subsequently, the diversity and abundance of the benthos on the artificial tidal flat were enhanced over those on the oligotrophic natural tidal flat.

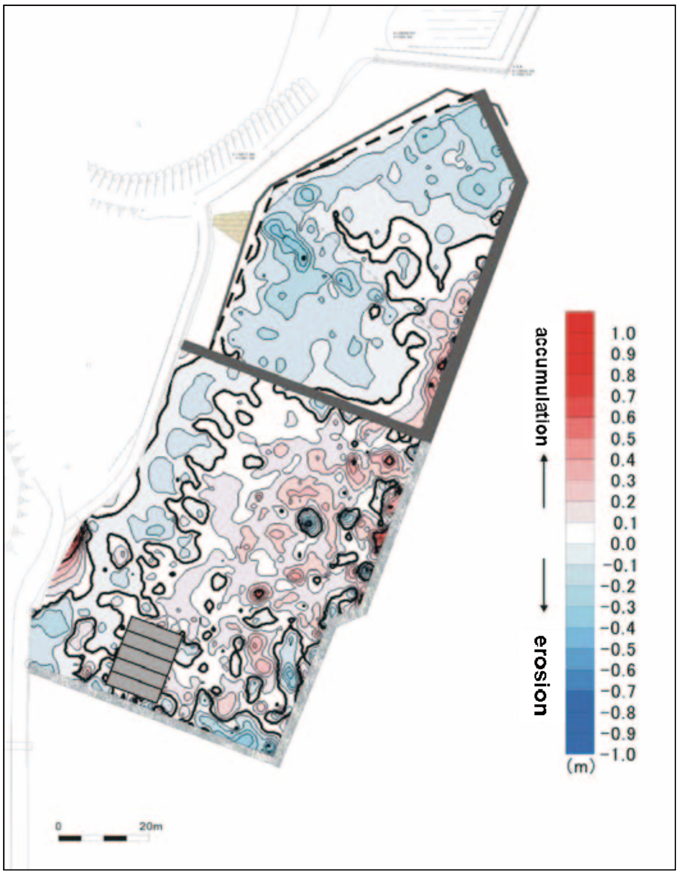

Fig. 6. The topographic change in the artificial tidal flat.

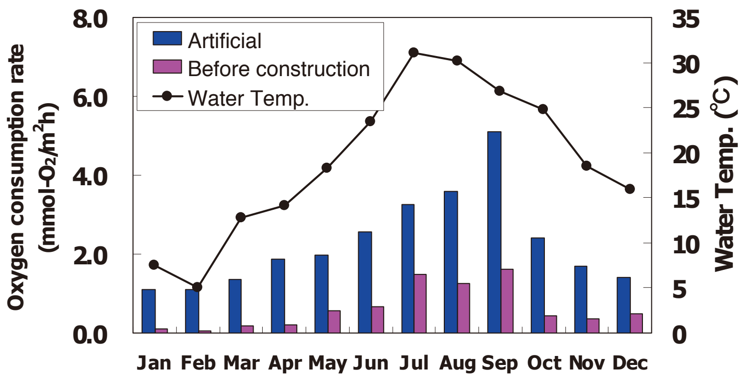

Fig. 7. Oxygen consumption rate on the artificial and natural tidal flats.

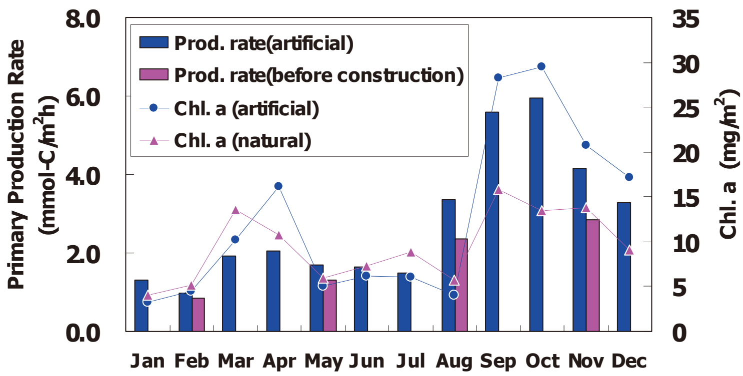

Fig. 8. Primary production rate on the natural and artificial tidal flats.

Nutrient Flux on the Artificial Tidal Flat

To investigate the changes in diurnal water quality around the artificial tidal flat, the clock, light, DIN, DIP, chlorophyll *a*, DO, depth, temperature, and turbidity were measured on 21-22 July 2005 (Figure 9) and 26-27 January 2006 (Figure 10).

Then the flux of water quality (TN, DIN, PON, TP, DIP, POP, and chlorophyll *a*) under ebb and flow conditions were calculated by integrating the data (Table 1). Negative values were indicated that materials were absorbed into the tidal flat, while positive values were indicated that the materials were flowed out of the tidal flat. During every season, particulate organic matter indicators (PON, POP, and chlorophyll *a*) showed absorption into the tidal flat, while dissolved inorganic nutrients (DIN and DIP) always flowed out of the tidal flat. These results indicated that the offshore water which contains rich particulate organic matter (POM), such as phytoplankton, flowed into the tidal flat with the high tide, and they were removed by filter feeders on the artificial tidal flat. This results indicated that the dissolved inorganic nutrients flowed out from the tidal flat by decomposition of the organic matter in tidal flat sediments and by being discharged from the macrobenthos. These phenomena were supported by increasing nutrient levels in the interstitial water and elution rate from tidal flat sediments (Kokubu *et al.* 2006). These

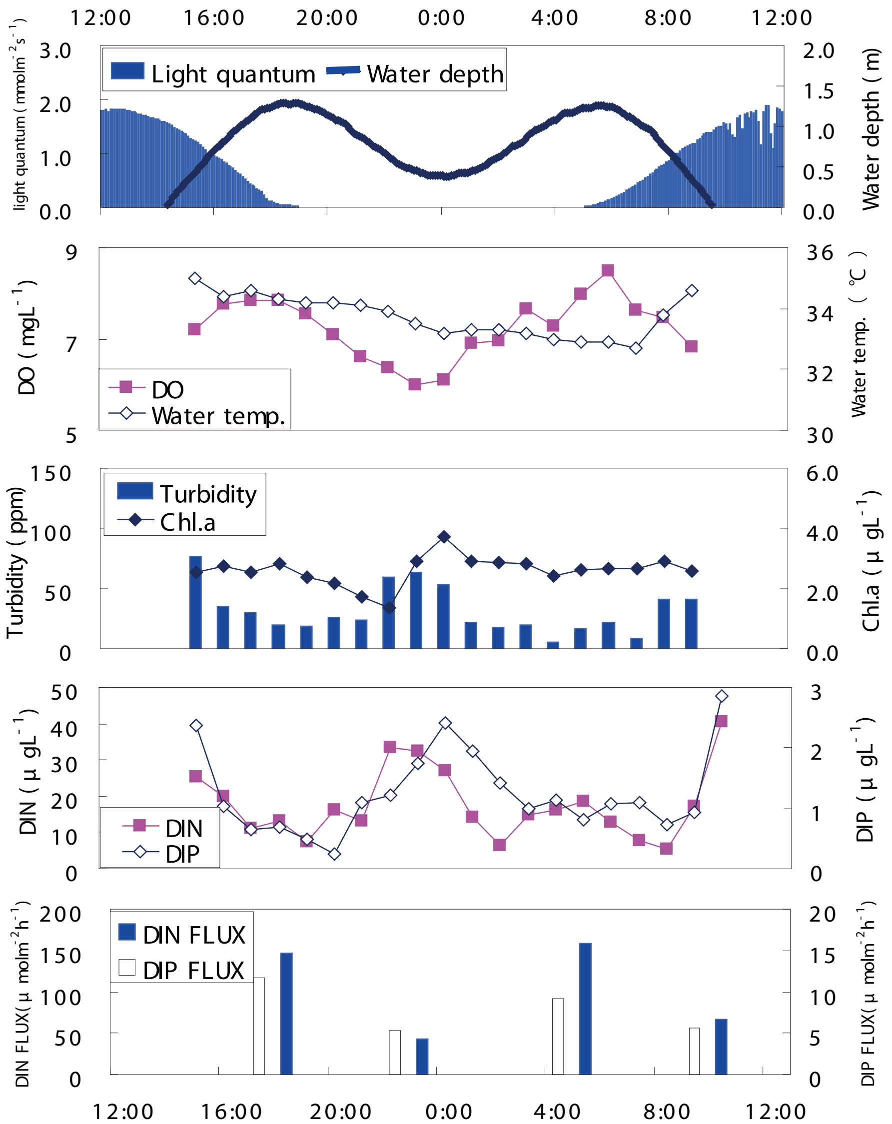

Fig. 9. Time course of the water quality during ebb and flow on the artificial tidal flat (4-5 Aug. 2005).

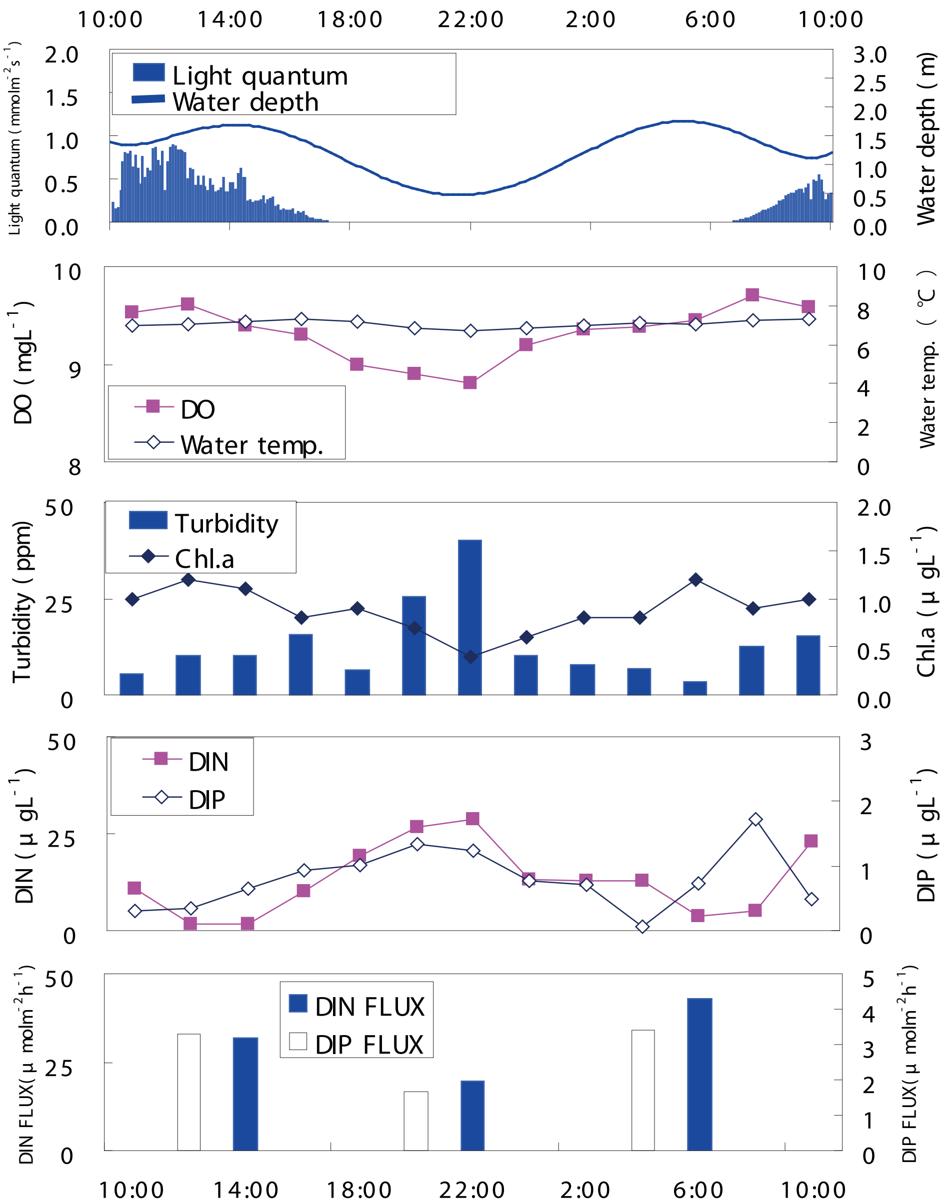

Fig. 10. Time course of the water quality during ebb and flow on the artificial tidal flat (26-27 Jan. 2006).

Table 1. The flux of water quality during ebb and flow on the artificial tidal flat.

	Cal. Time	TN	DIN	PON	TP	PO4-P	POP	Chl.a	
21.JUL	15:00-09:00	44.4	15.4	-52.2	-8.44	0.83	-1.67	-12.4	DL:+1.5m～+0m
04.AUG	13:00-10:00	-97.5	110	-109	4.95	7.62	-7.67	-23.1	DL:+1.5m～-1.5m
13.OCT	15:00-09:00	-55.0	13.8	-39.4	-2.00	1.44	-2.72	-10.3	DL:+1.5m～+0m
02.NOV	13:00-10:00	-60.9	30.9	-107	-4.71	6.14	-4.81	-14.2	DL:+1.5m～-1.5m
26.JAN	11:00-09:00	-38.2	3.41	-27.2	-0.18	0.55	-0.82	-2.36	DL:+1.5m～+0m
16.FEB	11:00-05:00	-69.3	5.83	-41.3	-1.50	1.39	-5.78	-5.67	DL:+1.5m～-1.5m

results corresponded with those from the Banzu tidal flat in Tokyo Bay as reported by Nomura *et al*. (2002). During all seasons the fluxes in water quality when all the artificial tidal flat areas were enclosed were larger than when only the relatively shallow artificial tidal flat area was enclosed.

Conclusion

In the present work, the new technology for enhancing biological productivity by controlling sediment quality was developed, and the function of habitat and material circulation were investigated. It was clear that the abundance and diversity of macrobenthos and biological productivity were enhanced by supplying nutrients to a relatively oligotrophic tidal flat in the form of dredged organic matter-rich sediments. Furthermore, the mechanism of enhancement of the biological productivity was clarified. First of all, the decomposition of the organic matter in added dredged sediment was rapid, resulting in greater regeneration and release of dissolve nutrients. The released nutrients were utilized by benthic algae. Subsequently, the macrobenthos increased more abundant by feeding on the algae. Thus these results were supposed that the benthos are strongly linked with material circulation on tidal flats, and artificial tidal flats work as sinks for particulate organic matter sources of dissolved nutrient. However, in the present artificial tidal flat ecosystem, after up to one year following construction, carnivores were still not existed, so the ecosystem was considered to still be in the transition phase. It was also evident that the organic matter in the artificial tidal flat was slightly decreased, so it is necessary to consider the stability and durability of tidal flat sediments. The present study is a part of the Ago Bay Environmental Restoration Project under the program of Japan Science and Technology Agency.

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Stable Isotope Analyses of the Trophic Structure of Macrobenthos on an Artificial Tidal Flat Developed Using Sediments Dredged from Pearl Oyster Farms in Ago Bay

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Abstract In a study organized by the Mie Prefectural Government, an artificial tidal flat was created on a sandy shore in Ago Bay using enriched sediments that had been dredged from pearl oyster farms. The aim of the artificial tidal flat (ATF) was to remove enriched sediments from pearl oyster farms and to re-mineralize the organic matter in the sediment through the activity by the biota. We investigated the trophic structure of the macrobenthos on the intertidal flat before (November, 2003) and after (November, 2004 and 2005) the ATF was constructed using the stable carbon and nitrogen isotope technique in order to evaluate the effect of the ATF. Before the ATF, the consumers were classified into four groups: group A, which was composed of suspension feeders and characterized by depleted $\delta^{13}C$ values (-19.5 to -18.0‰), group B, in which members had intermediate $\delta^{13}C$ values (-14.8 to -12.1‰), group C, in which members had enriched $\delta^{13}C$ values (-11.5 to -10.7‰) and group D, in which members had enriched $\delta^{15}N$ values (11.9 to 13.7‰). The members of groups A, B, and C are primary consumers and the food sources of each group are considered to have been a mixture of coastal phytoplankton and benthic microalgae, benthic microalgae, and a mixture of benthic microalgae and eelgrass or other unknown primary producers that have enriched $\delta^{13}C$ values, respectively. The members of group D are secondary consumers. Benthic animals collected after ATF construction were also divided into four groups, however the number of species in groups C and D decreased due to the change of sediment composition from sand to sandy mud and to the short duration (8 months) after the completion of the ATF. After the ATF, the suspension feeding bivalves were enriched in ^{13}C by 0.6 to 1.4‰ and were depleted in ^{15}N by 0.5 to 1.3‰, suggesting the increased dependency on benthic microalgae that had increased their biomass by utilizing the nutrients from the pearl-oyster farm sediments.

Key words: intertidal flat, stable isotopes, benthic microalgae, phytoplankton, suspension feeders

Introduction

Continuous culture of pearl oysters over extended periods within a confined farm area generates a large amount of biodeposition, oxygen deficient bottom water, and free hydrogen sulfide from the enriched sediments. Those conditions often result in a decline in pearl oyster productivity (Sawada and Taniguchi 1965). Some measures taken to improve farm environments have been based on engineering approaches, such as digging trenches to create water routes along the seabed, widening the mouths of bays, aeration or vertical stirring of the water, and dredging enriched sediments from the seabed (Yokoyama *et al.* 2006). Among those measures, dredging enriched sediments leads to an immediate effect, however finding disposal sites for the enriched sediments has been a major problem.

In a study organized by the Mie Prefectural Government, an artificial tidal flat was created on

2009年8月10日受理（Received. August 10. 2009）
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a sandy shore in Ago Bay using enriched sediments that were dredged from pearl oyster farms. The aim of the artificial tidal flat (ATF) was to remove enriched sediments from the pearl oyster farms and to re-mineralize sediment organic matter through the activities of the biota at the oxygen-rich sediment-water and sediment-air interfaces.

The stable isotope technique has been used successfully to follow the flows of organic matter and to point out linkages from primary producers to higher trophic levels. Stable carbon isotope ratios (δ^{13}C) have been extensively used to elucidate the sources of nutrition of consumers based on the close relationship between the δ^{13}C of the food items and that of the consumer (DeNiro and Epstein 1978). On the other hand, stable nitrogen ratios (δ^{15}N) have been applied to investigations of the trophic levels because of the large and consistent ^{15}N enrichment with increasing trophic level (DeNiro and Epstein 1981, Minagawa and Wada 1984). The coupling of δ^{13}C and δ^{15}N values therefore results in a clear bi-dimensional separation of the different potential food sources for estuarine consumers. In this paper, we report on the application of the stable carbon and nitrogen technique to determine the food sources and trophic levels of intertidal animals before and after ATF construction in Ago Bay.

Materials and Methods

Study Area

Ago Bay has a ria style coastline with an area of 27 km^2 and a mean depth of 10 m (Figure 1). Pearl oyster farming began in the bay in the 1900s. In 2004, 6,600 rafts for pearl oyster farming covered 620,000 m^2 of the bay, and 2,000 kg of pearls were produced (Tokai Regional Agricultural Administration Office 2006).

The ATF was conducted at 34°18.0'N, 136°50.7'E in Ago Bay during the period from December 2003 to March 2005 using enriched sediments (COD$_{sed}$, 12mg/g dry, mud content, 91.9%) that had been deposited on the seabed beneath rafts of pearl-oyster culture in Ago Bay (Katakura *et al.* 2005, Kokubu *et al.* 2005). The enriched sediments were spread over the shore and were mixed with the existing sandy sediment to a depth of 1.0 m under the sediment surface, resulting in the emergence of a tidal flat with an area of 5,000 m^2. After the ATF was constructed, the mud content of the sediments changed from 12.1 to 29.8%, COD$_{sed}$ changed from 0.46 to 4.8 mg/g-dry, and the chlorophyll a concentration on the sediment surface increased from 0.9 to 1.9 mg/kg (Kokubu 2005).

Sampling and Isotope Analysis

Surveys were conducted before and after the ATF was constructed. Before the ATF, we sampled the reeds (*Phragmites australis*) in August 2003; particulate organic matter in surface

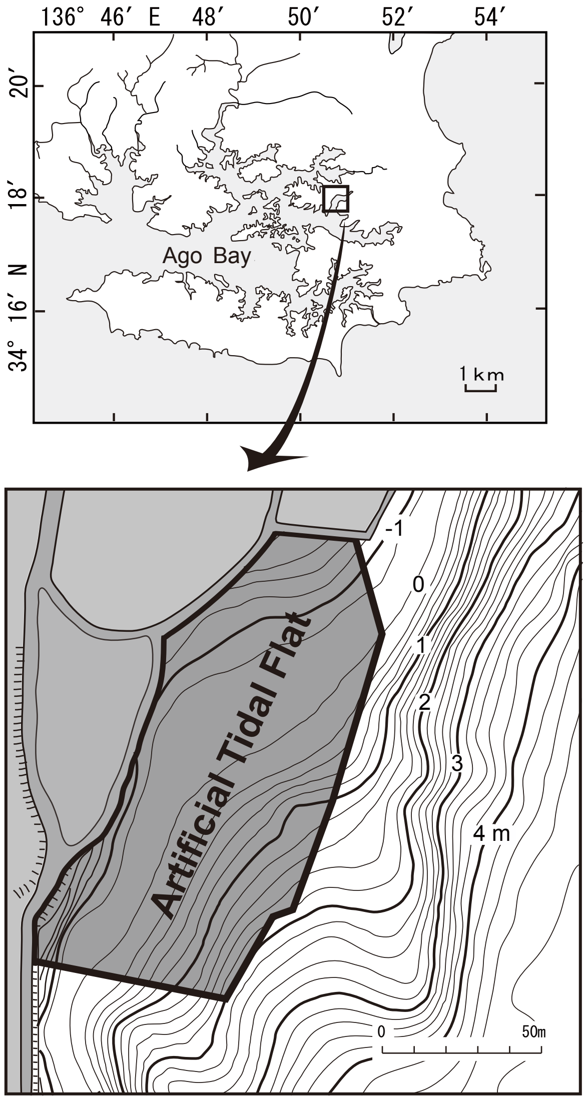

Fig. 1. Map of Ago Bay showing the artificial tidal flat with depth contours.

seawater (coastal POM) and benthic microalgae in May, July, and November 2003; seaweed in July, August, and November 2003; eelgrass (*Zostera marina*) in July and November 2003; and intertidal macrobenthos in November 2003 on and around the sandy shore in Ago Bay (Table 1). After the ATF, we also sampled coastal POM in February and May 2004; July and November 2005, and February 2006; seaweed in November 2005; benthic microalgae in January, July, and November 2005; eelgrass in February and May 2004; and intertidal macrobenthos in November 2004 and 2005 at the ATF. Benthic microalgae were extracted from the surface sediments following the procedure of Couch (1989) as modified by Riera and Richard (1996). The seawater for coastal POM was filtered on pre-combusted Whatman GF/F glass fiber filters, washed with 1.2N HCl, rinsed with distilled water, and dried at 60℃.

Collected animals were kept frozen until analysis. For the molluscs, the shell was removed and the soft tissues were used as the sample. The other animals were analyzed whole. The animal tissues were soaked in 1.2N HCl for a few minutes to remove traces of carbonates. The animal and plant samples were freeze-dried and ground to a fine powder.

The ^{15}N and ^{13}C compositions of the samples were determined using a mass spectrometer (MAT 252, Finnigan MAT) coupled online via a Finnigan ConFlo II interface with an elemental analyzer (EA 1110, ThermoQuest). Results are expressed in the standard δ unit notation as $\delta X = [(R_{samples} / R_{reference}) - 1] \times 10^3$, where X is ^{13}C or ^{15}N and $R = {}^{13}C / {}^{12}C$ for carbon and $^{15}N / {}^{14}N$ for nitrogen. The values are reported relative to the Vienna Pee Dee Belemnite standard (PDB) for carbon and to air N_2 for nitrogen.

Results and Discussion

Primary Producers

In the study area, there are various potential food sources for benthic animals, which include coastal phytoplankton (coastal POM), benthic microalgae, eelgrass, and reeds. Figure 2 is a dual isotope plot of the potential food sources. As the

Table 1. Isotopic compositions of primary producers. Mean values are indicated. Numbers in parentheses indicate sample size.

	2003				2004		2005			2006	Total
	May	Jul	Aug	Nov	Feb	May	Jan	Jul	Nov	Feb	mean ± SD
δ^{13}C (‰)											
reed			−26.7 (5)								−26.7 ± 0.5 (5)
phytoplankton	−20.4 (4)	−21.1 (4)		−21.9 (4)	−23.1 (4)	−21.5 (16)		−22.7 (3)	−21.4 (3)	−23.1 (2)	−21.7 ± 1.2 (40)
seaweed		−16.3 (5)	−10.6 (2)	−17.1 (3)					−16.9 (5)		−16.7 ± 3.4 (15)
benthic microalgae	−15.7 (4)	−15.6 (3)		−18.0 (3)			−14.3 (5)	−14.6 (1)	−15.6 (3)		−15.8 ± 1.8 (19)
eelgrass		−11.6 (5)		−10.4 (4)	−7.2 (5)	−8.9 (24)					−9.2 ± 1.6 (38)
δ^{15}N (‰)											
reed			3.4 (5)								3.4 ± 0.7 (5)
phytoplankton	8.5 (4)	7.4 (4)		7.2 (4)	7.1 (4)	5.0 (16)		5.5 (3)	4.9 (3)	6.0 (2)	6.1 ± 1.6 (40)
seaweed		8.3 (5)	8.7 (2)	8.0 (3)					8.1 (5)		8.1 ± 0.5 (16)
benthic microalgae	6.5 (4)	6.5 (3)		5.9 (3)			3.9 (6)	5.8 (1)	5.5 (3)		5.6 ± 1.4 (20)
eelgrass		5.6 (5)		4.2 (4)	4.2 (5)	4.6 (24)					4.6 ± 0.7 (38)

isotopic compositions of the primary producers showed large temporal variations and we could not find any seasonal pattern (Table 1), a mean (±SD) value for each producer was used for the identification of food sources. Among the primary producers, reeds had the most depleted δ^{13}C and δ^{15}N values, -26.7±0.5‰ and 3.4±0.7‰. The eelgrass had enriched δ^{13}C (-9.2±1.6‰) and comparatively low δ^{15}N (4.6±0.7‰) values. The δ^{13}C and δ^{15}N values for phytoplankton were -21.7 ±1.2‰ and 6.1±1.6‰. The values are within the range of those previously reported for marine organic matter in temperate regions (e.g. Fry and Sherr 1984, Owens 1987). The δ^{13}C and δ^{15}N values of benthic microalgae were -15.8±1.8‰ and 5.6±1.4‰. The δ^{13}C value was significantly different from that of phytoplankton (Mann-Whitney *U*-test, $p<0.05$). The δ^{13}C of seaweeds (-16.7±3.4‰) was close to the δ^{13}C of benthic microalgae, whereas the δ^{15}N of seaweeds (8.1± 0.5‰) was significantly more enriched than the δ^{15}N of benthic microalgae (Mann-Whitney *U*-test, $p< 0.01$). Dual isotope plots of δ^{13}C vs. δ^{15}N for consumers and their potential food sources at the sandy shore before the artificial tidal flat are shown in Figure 3.

Food Sources of Animals Before the ATF

Intertidal animals collected from the sandy shore before the ATF were composed of 41 species, including two actinians (sea anemone), two chitons (Polyplacophora), nine gastropods, 10 bivalves, five polychaetes, 12 decapods, and one holothurian (sea cucumber, Table 2). The δ^{13}C of the animals ranged from -19.5 to -6.5‰, while the δ^{15}N ranged from 6.1 to 13.7‰. The animals were roughly divided into four groups: A, B, C, and D, based on the δ^{13}C and δ^{15}N values.

Group A was constituted of 10 bivalves and one polychaete. Animals in this group were all suspension feeders. The δ^{13}C values for that group (range -19.5 to -18.0‰), was the most depleted among the four animal groups, and were intermediate between those of phytoplankton and benthic microalgae. The δ^{15}N values (8.7 to 9.9‰) for the group A were approximately 3-4‰ enriched relative to the phytoplankton and benthic microalgae, suggesting that the members of Group A incorporated a mixture of these two primary producers.

Group B was comprised of a variety of taxa, including eight gastropods (Nos. 5-7 and 9-13), two polychaetes (Nos. 30 and 33), six decapods (Nos. 39, 41 and 46-49) and one holothurian (No. 51). The δ^{13}C values of that group ranged from -14.8 to -12.1‰, while the δ^{15}N showed a large range (6.7 to 10.7‰). Taking into account the small difference in the δ^{13}C between group B and benthic microalgae which are considered to be a major food source of the members of group B. In group B, four gastropods (Nos. 7, 9, 10 and 12) had relatively depleted δ^{15}N values (6.7 to 8.4‰), indicating that those animals are primary consumers. Animals showing the δ^{15}N values of >10‰ (> 4.3‰ enriched relative to benthic microalgae) are considered to include omnivores and/or carnivores. The mean δ^{15}N for seaweeds (8.3‰) was the same level as, or more enriched than those of the

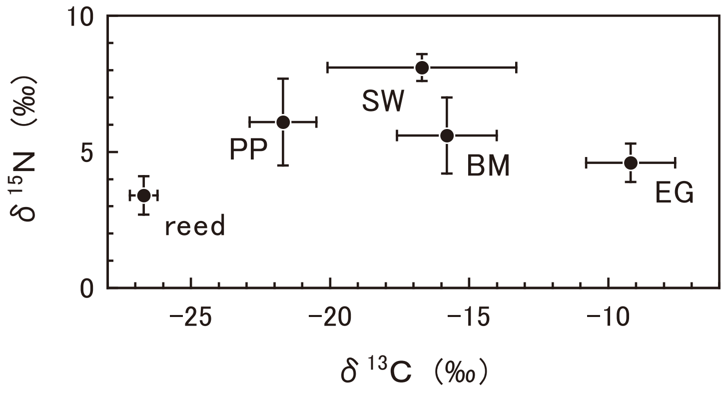

Fig. 2. Dual isotope plot of δ^{13}C vs. δ^{15}N for potential food sources for consumers. Error bars are SD. PP: coastal phytoplankton. BM: benthic microalgae. SW: seaweeds. EG: eelgrass.

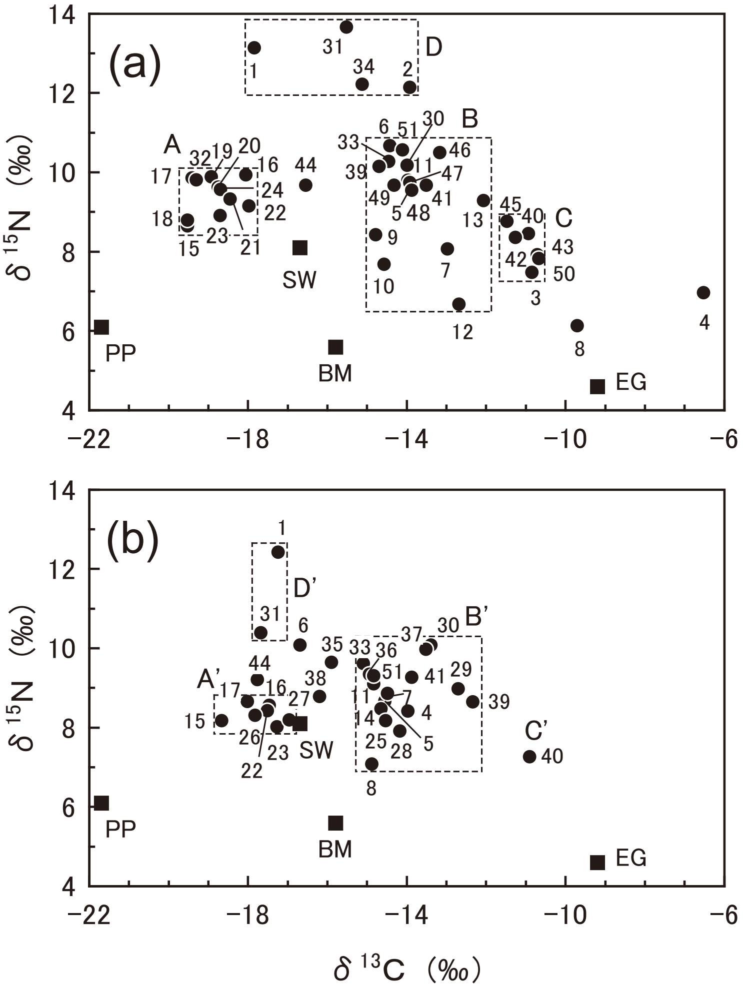

Fig. 3. Dual isotope plots of δ^{13}C vs. δ^{15}N for consumers (●) and their potential food sources (■) at the sandy shore before the artificial tidal flat making (a) and at the artificial tidal flat (b). See Table 1 for species identification numbers (1-51). Error bars are SD for the primary producers. PP: coastal phytoplankton. BM: benthic microalgae. SW: seaweeds. EG: eelgrass.

primary consumers. Assuming a 3-4‰ shift in N assimilation per trophic level, seaweeds were probably not important in the diet of the consumers.

The depleted δ^{15}N values (7.5 to 8.8‰) for animals in group C, which was composed of a chiton (No. 3) and five crabs (Nos. 40, 42, 43, 45 and 50), indicate that those animals are primary consumers. Among the primary consumers, the members of the group showed the most enriched δ^{13}C, ranging from -11.5 to -10.7‰. A possible explanation for the observed δ^{13}C is that group C feed on a mixture of benthic microalgae and eelgrass. However, the chiton in group C, *Liolophura japonica*, and the other chiton species, *Acanthochitona* sp. (No. 4), showed a more enriched δ^{13}C value (7.0‰) than those of group C overall, can feed on crustose algae growing on stones and rocks (Steneck and Watling 1982). Thus, we conclude that their enriched δ^{13}C values were not due to the assimilation of eelgrass. It may be that crustose algae had more enriched δ^{13}C values than benthic microalgae, however we did not measure the isotopic compositions of crustose algae at that time.

Group D was comprised of four species: two actinians (Nos. 1 and 2) and two polychaetes (Nos. 31 and 34). The range of the δ^{15}N for the animals in the group was from 11.9 to 13.7‰, which was 4.2 to 8.0‰ enriched relative to phytoplankton or microalgae, indicating that the animals in group D were secondary consumers. The actinian *Haliplanella luciae* showed a more depleted δ^{13}C value (-17.8‰) than the other animals (-15.5 to

Table 2. Isotopic compositions of consumers before and after the artificial tidal flat making. . The mean ± SD (n≧3) or the range (n=2) of the $\delta^{13}C$ $\delta^{15}N$ values. Numbers in parentheses refer to the species identification number.

Species	Before $\delta^{13}C$ (‰)	Before $\delta^{15}N$ (‰)	n	After $\delta^{13}C$ (‰)	After $\delta^{15}N$ (‰)	n
Actinia						
(1) *Haliplanella luciae*	−17.8 ±0.5	13.1 ±0.3	4	−17.2 ±0.4	12.4 ±0.3	4
(2) *Edwardsia* sp.	−14.4 to −13.5	11.9 to 12.4	2			
Polyplacophora						
(3) *Liolophura japonica*	−10.8 ±0.1	7.5 ±0.1	3			
(4) *Acanthochitona* sp.	−6.5	7.0	1	−15.0 to −13.0	7.9 to 8.9	2
Gastropoda						
(5) *Batillaria cumingii*	−13.9 ±0.3	9.6 ±0.1	5	−14.6 ±0.9	8.7 ±0.6	9
(6) *Reticunassa festiva*	−14.4 ±0.8	10.7 ±0.4	5	−16.7 ±0.8	10.1 ±0.4	9
(7) *Lunella coronata coreensis*	−13.0 ±0.5	8.1 ±0.2	5	−14.5 ±0.5	8.9 ±0.3	10
(8) *Patelloida pygmaea*	−9.7 ±1.5	6.1 ±1.1	5	−14.9 ±2.9	7.1 ±1.6	10
(9) *Monodonta labio confusa*	−14.8 ±0.5	8.4 ±0.2	5			
(10) *Notoacmea radula*	−14.6 ±0.8	7.7 ±0.3	5			
(11) *Batillaria multiformis*	−14.0 ±0.4	9.8 ±0.3	3	−14.8	9.1	1
(12) *Littorina brevicula*	−12.7 ±0.5	6.7 ±0.3	3			
(13) *Cerithideopsilla cingulata*	−12.2 to −12.0	9.2 to 9.4	2			
(14) *Clypeomorus coralia*				−14.7 ±0.7	8.5 ±0.4	5
Bivalvia						
(15) *Vignadula atrata*	−19.5 ±0.2	8.7 ±0.2	5	−18.7 ±0.5	8.2 ±0.3	4
(16) *Anomalocardia squamosa*	−18.1 ±0.1	9.9 ±0.2	5	−17.5 ±0.3	8.6 ±0.6	4
(17) *Crassostrea gigas*	−19.4 ±0.4	9.9 ±0.4	5	−18.0 ±0.3	8.7 ±0.1	10
(18) *Hormomya mutabilis*	−19.5 ±0.3	8.8 ±0.1	5			
(19) *Claudiconcha japonica*	−18.9 ±0.4	9.9 ±0.6	5			
(20) *Barbatia virescens*	−18.8 ±0.3	9.6 ±0.2	5			
(21) *Cyclina sinensis*	−18.7 ±0.2	9.6 ±0.4	4			
(22) *Ruditapes philippinarum*	−18.1 to −17.8	8.9 to 9.4	2	−17.5 ±0.2	8.4 ±0.2	5
(23) *Laternula limicola*	−18.7	8.9	1	−17.3 ±0.2	8.0 ±0.2	3
(24) *Gafrarium divaricatum*	−18.5	9.3	1			
(25) *Macoma incongrua*				−14.5	8.2	1
(26) *Pitar sulfreum*				−18.0 to −17.7	8.3 to 8.3	2
(27) *Musculus senhousia*				−17.0 ±0.3	8.2 ±0.1	5
(28) *Moerella rutila*				−14.2 ±0.6	7.9 ±0.4	8
Sipunculida						
(29) *Siphonosoma cumanense*				−12.7	9.0	1
Polychaeta						
(30) *Notomastus* sp.	−14.0 ±0.6	10.2 ±0.9	6	−13.4	10.1	1
(31) *Lumbrineris nipponica*	−15.5 ±1.1	13.7 ±0.4	4	−17.7	10.4	1
(32) *Chaetopterus cautus*	−19.4 to −19.3	9.6 to 10.1	2			
(33) *Cirriformia tentaculata*	−14.5	10.3	1	−15.1 ±0.5	9.6 ±0.5	10
(34) *Marphysa sanguinea*	−15.1	12.2	1			
(35) *Perinereis nuntia* var. *brevicirris*				−15.9 ±0.4	9.6 ±0.9	3
(36) *Perinereis nuntia* var. *vallata*				−14.9 ±1.8	9.4 ±1.2	5
(37) *Ceratonereis erythraeensis*				−13.5 ±0.3	10.0 ±0.8	10
Crustacea						
(38) *Sphaeroma sieboldii*				−16.2 ±2.3	8.8 ±1.0	5
(39) *Hemigrapsus penicillatus*	−14.7 ±0.2	10.1 ±0.7	5	−13.5 to −11.2	7.3 to 10.0	2
(40) *Ilyoplax pusillus*	−10.9 ±0.3	8.5 ±0.1	5	−10.9 ±0.9	7.3 ±0.5	5
(41) *Pagurus dubius*	−13.5 ±0.6	9.7 ±0.3	5	−13.9 ±1.2	9.3 ±0.6	9
(42) *Macrophthalmus japonicus*	−11.3 ±0.5	8.4 ±0.3	5			
(43) *Scopimera globosa*	−10.7 ±0.4	7.9 ±0.7	5			
(44) *Diogenes spinifrons*	−16.6 ±0.9	9.7 ±0.5	4	−17.8 ±0.9	9.2 ±0.2	3
(45) *Macrophthalmus dilatatus*	−11.5 ±0.4	8.8 ±0.3	3			
(46) *Charybdis japonica*	−13.3 to −13.1	10.5 to 10.5	2			
(47) *Nihonotrypaea* sp.	−14.4 to −13.5	9.7 to 9.8	2			
(48) *Alpheus brevicristatus*	−13.9	9.5	1			
(49) *Laomedia astacina*	−14.3	9.7	1			
(50) *Macrophthalmus banzai*	−10.7	7.8	1			
Holothuroidea						
(51) *Patinapta ooplax*	−14.4 to −13.8	10.5 to 10.7	2	−14.8	9.3	1

-14.0‰), suggesting that *H. luciae* depended on phytoplankton and that the other animals incorporated benthic microalgae through primary consumers.

Food Sources of Animals After the ATF

Eight months after the completion of the ATF, we sampled animals from the artificial tidal flat. The 30 species collected were composed of one actinian, one chiton, six gastropods, nine bivalves, one sipunculid, six polychaetes, five decapods and one holothurian. Benthic animals collected after the ATF were also classified into 4 groups: group A', group B', group C', and group D', which corresponded to groups A, B, C and D before the ATF.

Group A' included seven bivalves representing five species (Nos. 15-17, 22 and 23) that had occurred before the ATF and two species (Nos. 26 and 27) that did not occur before the ATF. Five bivalves (Nos. 18-21 and 24) and one polychaete (No. 32) disappeared after the ATF. The δ^{13}C and δ^{15}N values of group A' ranged from -18.7 to -17.0‰ and from 8.0 to 8.7‰, of which the range shifted considerably after the ATF. That is, the δ^{13}C enriched, while the δ^{15}N values decreased. Figure 4 shows the shift of the isotopic compositions of five bivalves after the ATF. For all five species that occurred before and after the ATF, the δ^{13}C values increased by 0.6‰ (*Ruditapes philippinarum*) to 1.4‰ (*Crassostrea gigas* and *Laternula limicola*), while δ^{15}N values decreased by 0.5‰ (*Vignadula atrata*) to 1.3‰ (*Anomalocardia squamosa*) after the ATF. There were significant differences (Mann-Whitney U-test, all $p < 0.05$) in the δ^{13}C and δ^{15}N for *Vignadula atrata*, *Crassostrea gigas*, and *Anomalocardia squamosa* before and after the ATF.

Group B' consisted of 16 species, including one chiton (No. 4), six gastropods (Nos. 5-8, 11 and 14), two bivalves (Nos. 25 and 28), four polychaetes (Nos. 30, 33, 36 and 37), two decapods (Nos. 39 and 41), and one holothurian (No. 51). Among the members of group B', nine species, including four gastropods (Nos. 5-7 and 11), two polychaetes (Nos. 30 and 33), two decapods (Nos. 39 and 41), and one holothurian (No. 51) were collected at both before and after the ATF. After the ATF, one gastropod (No. 14), two bivalves (Nos. 25 and 28), two polychaetes (Nos. 36 and 37) and one isopod (No. 38) were new to the area, while five gastropods (Nos. 9-13) and four decapods (Nos. 46-49) disappeared. The change of species composition may have been due to the change in the sediment composition from sand to sandy mud. We excluded the gastropod *Reticunassa festiva* (No. 6), which

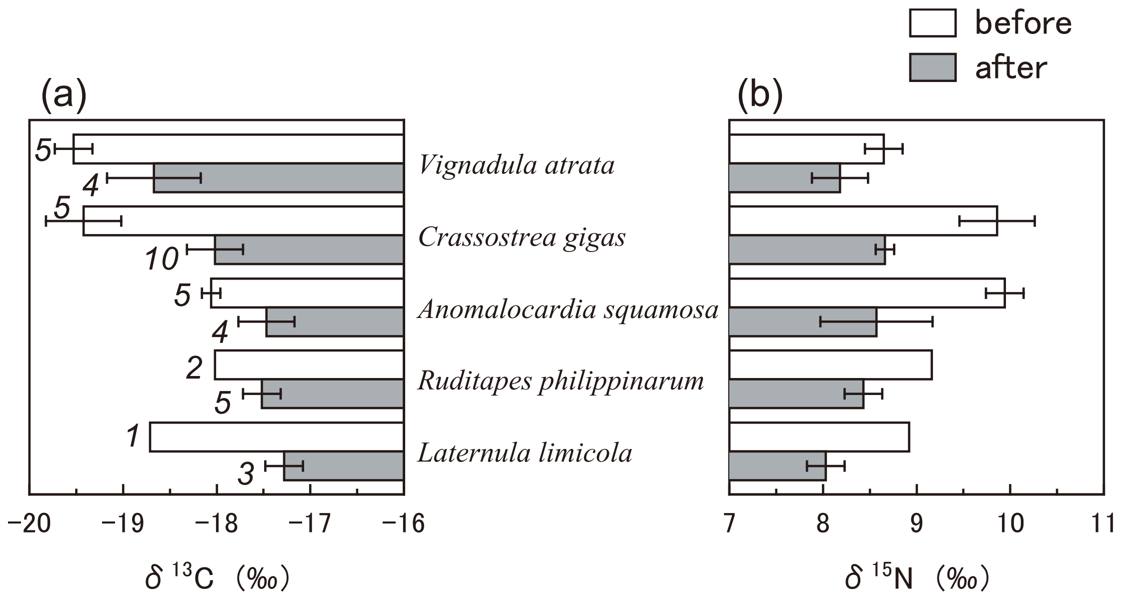

Fig. 4. (a) δ^{13}C and (b) δ^{15}N values for 5 bivalve species of suspension feeders collected from the sandy shore before the artificial tidal flat making (□) and at the artificial tidal flat (■). Error bars are SD. Numerals denoted in italics indicate sample size (n).

was a member of group B before the ATF, from group B', because the species showed a markedly depleted $\delta^{13}C$ after the ATF. On the other hand, the $\delta^{13}C$ values of the chiton *Acanthochitona sp.* (No. 4) and the gastropod *Patelloida pygmaea* (No. 8) shifted in the range of group B'. The range of the $\delta^{13}C$ and $\delta^{15}N$ of group B' was from -15.1 to -12.4‰ and from 7.1 to10.1‰, which was close to the range of group B before the ATF, suggesting a close similarity in the food item benthic microalgae between the members of groups B and B'.

Group C' consisted of a single species, the decapod *Ilyoplax pusillus* (No. 40) that showed a $\delta^{13}C$ of -10.9‰ and a $\delta^{15}N$ of 7.3‰. The other five species in group C disappeared after the ATF, probably due to the change of the sediment composition.

Group D' contained two species, the actinian Haliplanella luciae and the polychaete *Lumbrineris nipponica* and had $\delta^{13}C$ and $\delta^{15}N$ values of -17.2‰ and 12.4‰ for the actinian and -17.7‰ and 10.4‰ for the polychaete. Two members in group C, the actinian *Edwardsia* sp. and the polychaete *Marphysa sanguinea* were not collected after the ATF.

The most characteristic findings in the present study are that the dependency of suspension feeders on benthic microalgae increased after the ATF. It has been suggested that ATF resulted in the enrichment of the sediments and increased the biomasses of benthic microalgae and macrobenthos (Kokubu *et al.* 2005). The present study suggests that macrobenthic animals assimilated benthic microalgae that increased their biomass using nutrients that were contained in the pearl oyster farm sediments. Thus, the ATF may be effective from the viewpoint of giving the disposal site of enriched sediments that are produced from mariculture and of mineralizing the accumulated organic matter in the sediment. On the other hand, we must note that the ATF may exert an influence on the local biota as shown by the fact that the macrofauna changed from that characteristic of a sandy shore to one characteristic of a mudflat after the ATF.

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Introduced Species and Aquaculture

Cheng-Sheng Lee*

Abstract The yield from global capture fisheries is the current main sources of seafood for human consumption but has reached a plateau since 1990, and is not expected to have any further significant growth. Aquaculture contributions have increased significantly since 1970 and now account for more than 32.3% of all fish consumed worldwide in 2004 (FAO, 2006). From 1950 to 2004, a total of 442 aquatic species have been cultured at least one time in the world (FAO 2006). In 2003, of these species, 314 had production of one tonne or more.

Problems associated with the culture of local species led culturists in many regions of the world to seek related non-indigenous species as alternatives (Stickney, 2001). Aquaculture, then, has become the main cause of the introduction of non-indigenous species, accounting for 38.7% of introduced species recorded in the Food and Agriculture Organization (FAO) database (Garibaldi and Bartley 1998). The practice of culturing non-indigenous species has existed for many years to take advantage of existing markets, as well as available technology and resources. Almost 10% of global aquaculture production came from introduced species (Garibaldi and Bartley 1998). The pressure to culture non-indigenous species has increased, given expanding aquaculture production and increasing demand for diversified seafood from consumers.

Aquaculture farms in the United States currently produce more than 100 different species of aquatic plants and animals; most major aquatic species cultured in the U.S. are not native to their farm sites (Naylor et al., 2001). Non-indigenous species have been introduced for farming in particular regions because of the immediate social and economic benefits. Some non-indigenous species, however, have quickly adapted to their new environment, have become established, and now compete with indigenous species for limited habitats.

Biological invasions are recognized as serious threats to marine biodiversity and ecosystem structure and function (Frisch and Murray, 2002). In addition, introduction of non-indigenous species for aquaculture has resulted in numerous unintentional introductions of pathogens, parasites, and pest species (Galil, 2000).

This presentation will review and provide several cases for the significance of introduced species to total aquaculture production. The culture of marine shrimp will be used as an example to explain the impacts on surrounding environments in both physical and biological aspects. To keep the contribution of introduced species in aquaculture a positive one, certain measures must be developed to avoid any negative impacts. Thus, mitigation strategies and monitoring capabilities for introduced species are very important.

Introduction

According to statistical data released by the Food and Agriculture Organization (FAO) in 2006, aquaculture contributed to 32.3% of the total global seafood supply (excluding aquatic plants) in 2004 (Fig. 1). Total seafood supply in 2004 was 150 million mt, of which 45 million mt came from aquaculture and 95 million mt from capture fishery. Even though the main source of the world's seafood is still from capture fisheries, the total yield from this source has been in a plateau since 1990, and no further significant growth is

2009 年 8 月 10 日受理（Received. August 10. 2009）
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expected in capture fisheries.

Thus, it has been predicated that the world increasingly will have to rely on aquaculture in the future to match rising seafood consumption. Lester Brown at Worldwatch Organization stated (2001) that fish farming might soon overtake cattle ranching as the world's largest food source (http://www.naia.ca/faq.asp). Jacques Cousteau (1973) stated "we must plant the sea and herd its animals, using the sea as farmers instead of hunters" and encouraged farming of the sea because of the earth's burgeoning human population. Aquaculture, in fact, is the fastest growing sector of worldwide agriculture with an annual growth rate of 8.9% during the period of 1970 to 2002, compared to 2.8% for livestock and 1.2 % for capture fisheries production (FAO, 2004).

Issues, such as preservation of environmental conditions, however, have challenged the expansion of aquaculture. The quality of seafood has also been closely watched by the public. A report by Hites et al. (2004), for example, pointed out that organic contaminants in farmed salmon would create poor public perception toward aquaculture.

From 1950 to 2004, a total of 442 aquatic species have been cultured at least once in the world (FAO 2006). Problems associated with the culture of local species led culturists in many regions of the globe to seek related non-indigenous species as alternatives (Stickney, 2001). With the expansion of aquaculture production and the increasing demand for diversified seafood from consumers, the pressure to culture non-indigenous species has only increased. There were many reasons identified as the cause of introduction which included aquaculture, aquarium trade, biological control, boats and ships, channels, canals and locks, live bait, nursery industry, scientific research institutions, schools and public aquariums, recreational fisheries enhancement, and restaurants, seafood retail and processing (Copping and Smith 2005). Aquaculture is the main cause of non-indigenous species introduction, accounting for 38.7% of introduced species recorded in the database of the FAO (Garibaldi and Bartley 1998).

The practice of culturing non-indigenous species has existed for many years to take advantage of existing markets, as well as available technology and resources. Bartley and Casal (1998) reported that introduced species contributed about 17%

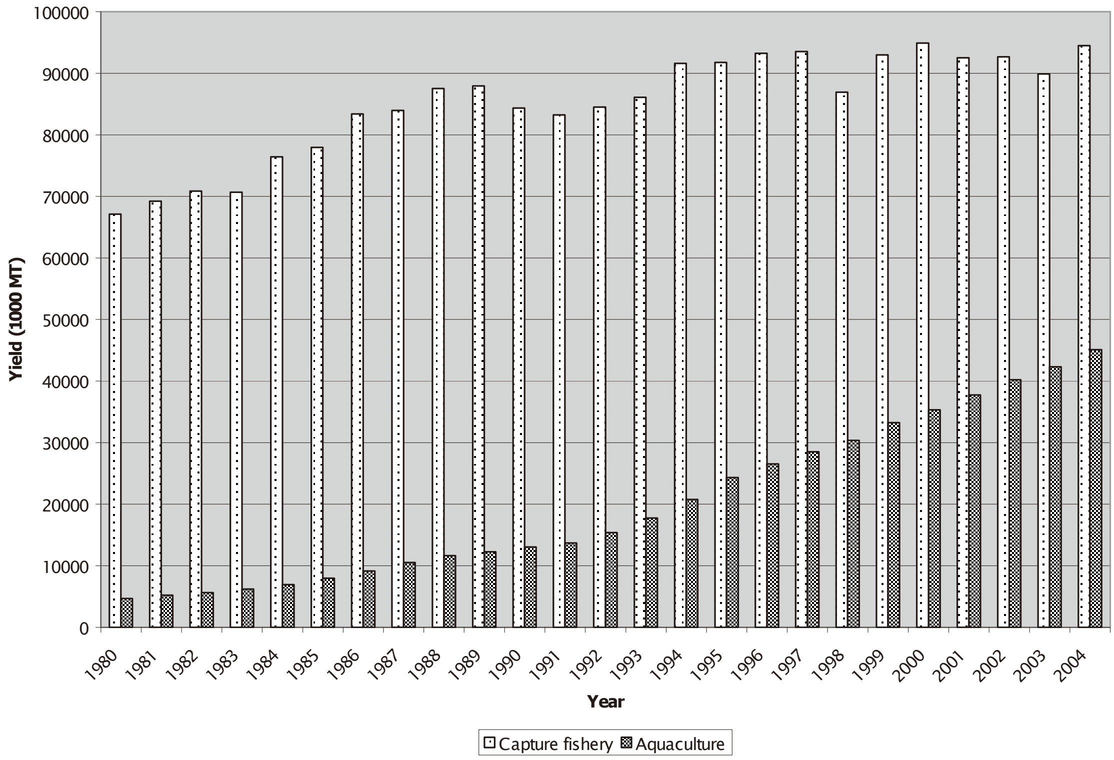

Fig. 1. Production from capture fishery and aquaculture between 1980 and 2004.

of total global fish production in 1996. While the use of introduced species has increased aquaculture production, it also might threaten aquatic biodiversity, transfer disease, alter habitat, and compete with native species on food and space. The estimated loss from introductions was about $137 billion annually in the U.S. in 2003 (Goldsborough 2003).. According to a U.S. congressional report (1993), introduction of the zebra mussel resulted in a $3 billion loss. This paper presents the significance of the contribution made by introduced species to the total global production of several major cultured species. Given current production trends, it is anticipated that the world will have to continually rely on introduced species to increase aquaculture production. At the same time, however, we have to devote part of our effort to conserving biodiversity and otherwise reducing the potential adverse effects of introducing alien species.

R.L. Welcomme in the early 1980s initiated a database on introductions of aquatic species (DIAS) at FAO. This initial database, focused on freshwater species, became the basis for the 1988 FAO Fisheries Technical Paper No. 294 (Welcomme 1988). Currently, DIAS includes additional taxa, such as mollusks, crustaceans, and marine species. Building on this knowledge, Froese and Pauley (1997) developed a FishBase program, which included more information about species introduction. This report compares the production data from the native and new locations for a few cultured and introduced species, such as tilapia, rainbow trout, Atlantic salmon, common carp, and marine shrimp. Marine shrimp farming is used as an example to demonstrate adverse effects that can result from species introduction.

Species introduced as a new species

The rationale behind the introduction of a species to a new location as a target farming species usually includes existing culture technology, existing market demand, and anticipated high profit. Fish farmers expect a quick profit, since a species that can be mass produced with exising technology and already has proven market demand should require no additional investments in technology and market development. On the other hand, species can also be introduced with the intention to supplement food supplies, after researchers determine that environmental conditions are suitable for an introduced species and that production costs are lower than those for other species. This type of introduction is usually carried out by government or nonprofit organizations. The following species are familiar to many consumers, but they are an alien species to many locations where they have been introduced for aquaculture purposes.

1. **Tilapia** (*Oreochromis mossambicus, and O. niloticus*) are native to Africa but were brought to many countries after the first introduction to Java in 1939 (Atz, 1954; Riedel, 1965). The major producers for both tilapia species today are located in Asia. In 2004, total production was 1,495,744 mt for Nile tilapia and 46,665 mt for Mozambique tilapia. Production sharply increased after 1980 (Fig. 2). The farmers in Asia produced 1.29 million mt of tilapia, but farmers in Africa produced only 210,000 mt or 16 % of total worldwide production (Fig. 2). Many domesticated strains were developed at many farming locations. Demand for tilapia has grown continually during the past few years.
2. **Atlantic salmon** (*Salmo salar*) is found in the North Atlantic from New England to Ungava Bay on the west, Iceland, Greenland, and from northern Portugal to the Kara Sea on the east (Laird and Needham, 1990). Farming of this species is done mainly in Norway and Scotland, and in Chile where no native species were found. The first introduction of Atlantic salmon eggs to Chile was in 1916, but the first privately owned salmon farm was not started until between 1975 and 1980 (Wurmann 2007). Production really started to bloom was the 1990s. In 2004, Chile produced 349,329 mt or about 72% of total production in Norway or 28% of total worldwide production (Fig. 3). If its current growth rate of salmon production continues, Chile in a few years may overtake Norway as the nation with the highest

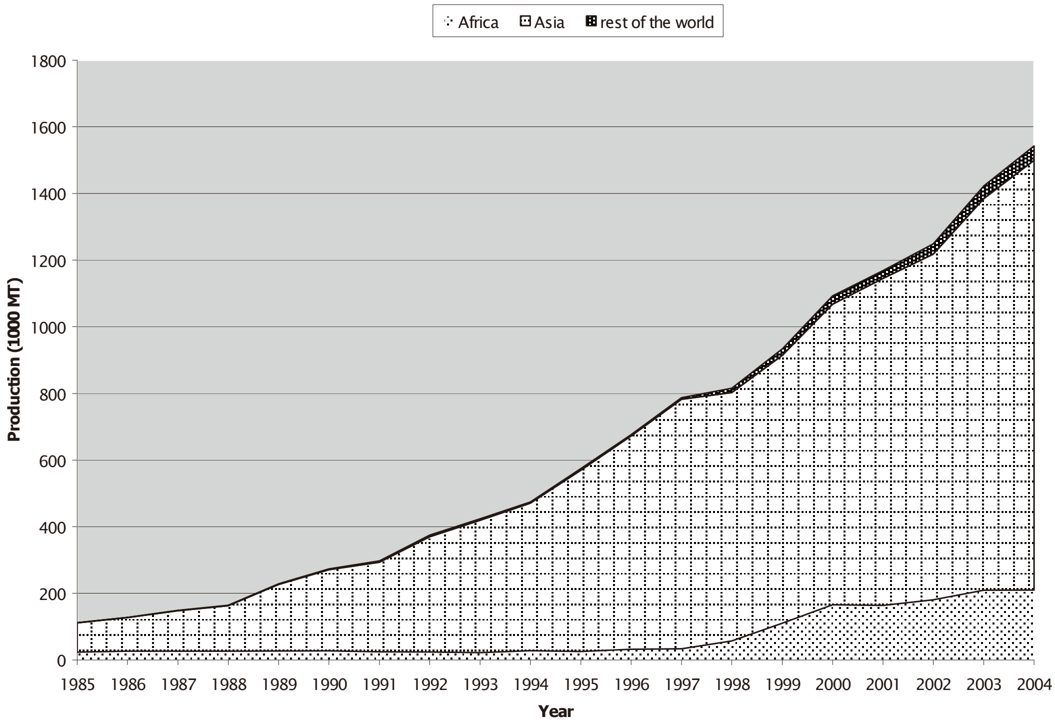

Fig. 2. Production of tilapia from Africa, Asia, and the rest of the world.

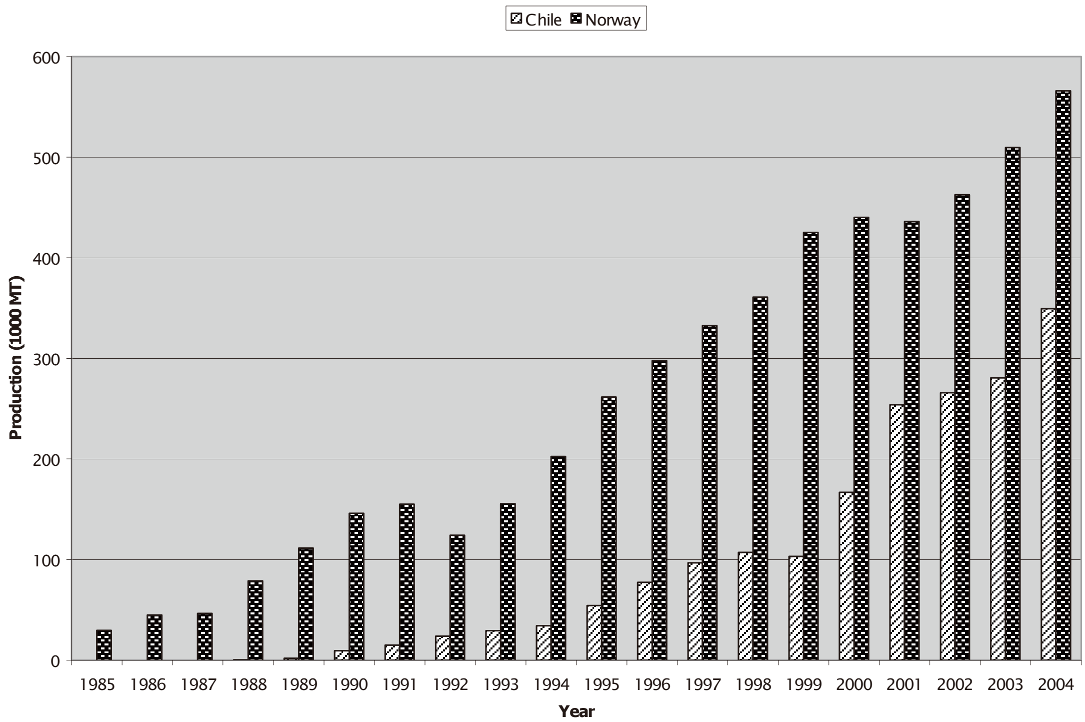

Fig. 3. Atlantic salmon production in Chile and Norway

production of Atlantic salmon worldwide.

3. Rainbow trout (*Oncorhynchus mykiss*) was native to western North America from Mexico to the Bering Sea, Siberia (Laird and Needham, 1990). Since 1874, it has been introduced to all continents except Antarctica for aquaculture and recreation purposes (FAO 2007). By 2002, 64 countries were reporting rainbow trout farming production. The primary trout-farming countries were in Europe, North

America, Chile, Japan, and Australia. According to statistics from FAO, total production in Europe accounted for 57.31% of the total global production of 504,876 mt in 2004 (Fig. 4). In contrast, production in the U.S. was less than 30 thousands MT in 2004. .

4. Common carp (*Cyprinus carpio*) has been reared in China for more than 200 years and currently is cultured throughout the world, with a yield of about 5.8 million mt in 2004. More than 58% of that total production came from countries other than China and Japan, where the carp is

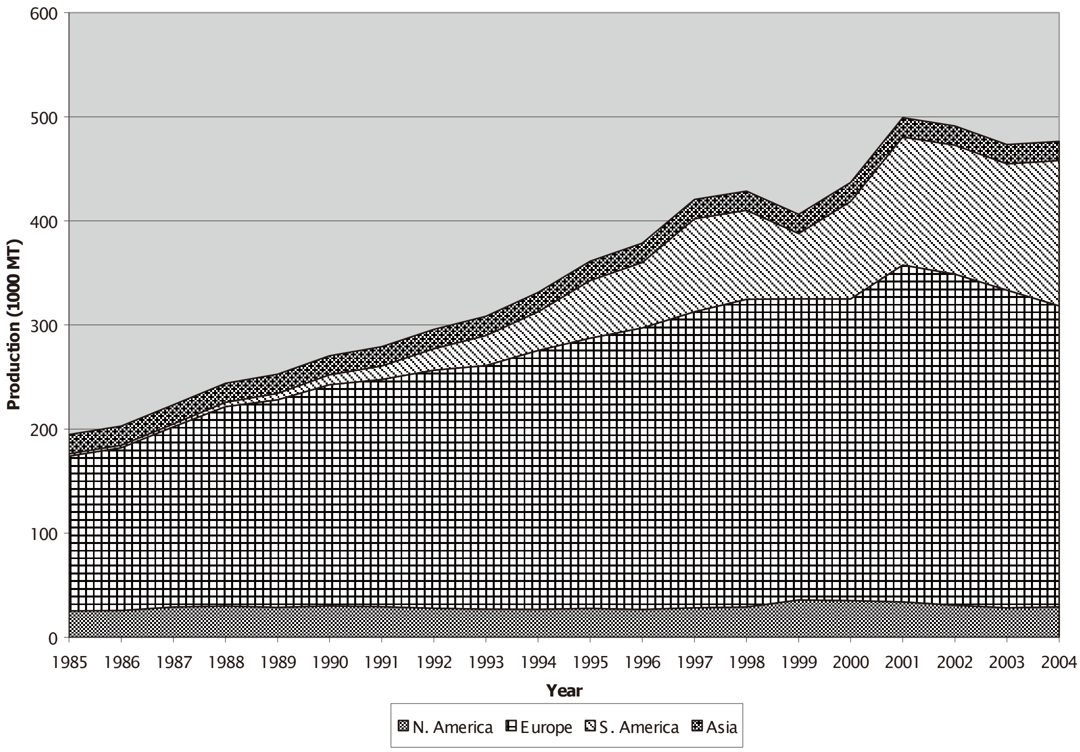

Fig. 4. Rainbow trout production in different continents.

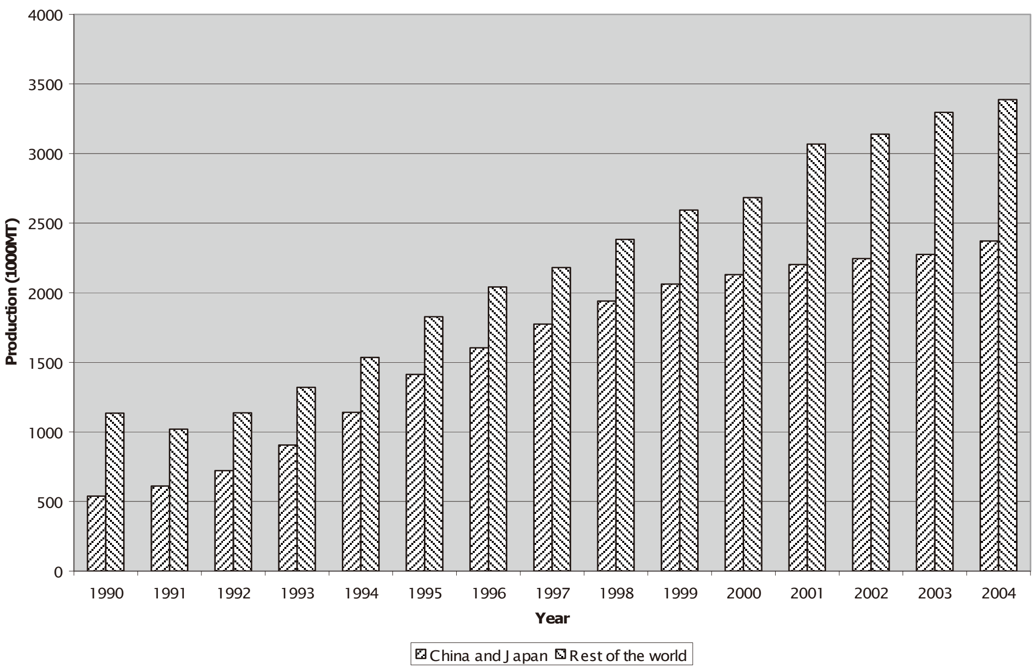

Fig. 5. Comparing common carp production in China and Japan to production in the rest of the world.

native. (Fig. 5). Domesticated carps have been produced in most of the carp producer nations. Strains can be very different from each other in performance. Although it was considered a luxury food in the middle and late Roman period (FAO 2007), it has became a traditional food fish and provided a very important animal protein source in many farming countries.

The above information clearly indicates the significance of the contribution made by the aquaculture production of introduced species, such as tilapia, Atlantic salmon, rainbow trout and common carp. Total aquaculture production from the above species would be reduced by more than half, if they were prohibited from "introduction". It is not difficult to imagine the impact on market prices from the elimination of the production contribution from introduced species. No doubt, we would all have to pay higher prices for the above species.

Species introduced to locations where they already exist

Not all introductions involve bringing species to locations where they are alien. Unlike the previously discussed species, the following species are examples of introductions to a location where the same species already exists. The rationale for this type of transfer can be either to meet a shortage of fingerling supply for farming purposes or to introduce desired traits to a local strain in order to improve its performance. The genetic structure of native strains will be altered eventually.

Milkfish (*Chanos chanos*) have a broad geographic distribution, existing virtually throughout the entire tropical Indo-Pacific Ocean and is a popular farming species in Southeast Asian countries, especially in Taiwan, the Philippines, and Indonesia (Lee, 1995). Before the establishment of hatchery technology, milkfish farmers had to rely on wild collection of fingerlings to stock fishponds. Because of shortages and fluctuations in the number of fingerlings available annually in the region, the milkfish industry had to conduct inter-country transfers of milkfish fingerlings every year to meet demand. Genetic differences among different strains have been diluted or may no longer exist.

This situation has not improved. Even after hatchery technology was established in those three countries (Lee 1995), fingerlings were still moved around the region to meet the needs of farming practice in terms of availability and cost. For example, Taiwanese milkfish farmers would stock their ponds with fingerlings from Indonesia to extend their growing season after winter.

The danger in such transfers is that microorganisms, along with the fish, can be transported from one region to another. Undesired pathogens can be unintentionally introduced to a new location and create other issues. Although no major outbreaks of diseases were reported, additional measures to prevent any negative impacts should always be taken. After all, the intra- and inter-regional transfers of shrimp stocks were one of the causes for the collapse of shrimp farming industries in several countries in Asia and other regions (Lin 1989).

Marine shrimp aquaculture expanded significantly throughout Latin America and Asia during the 1980s (Moss, 2002). Black tiger shrimp (*Penaeus mondon*) and Chinese shrimp (*Fenneropenaeus chinensis*) were the two major marine crustacean species commercially cultured in Asia and China, respectively. Pacific white shrimp (*Litopenaeus vannamei*) was the major species cultured in Central and South America.

During the peak of black tiger shrimp farming in Taiwan, wild shrimp broodstocks were not abundant to meet the demand and were imported from different locations in Southeast Asia to make up for local broodstock supply shortages. Most of the transfers were carried out without any examination of stock health conditions or gone through quarantine procedure. Pathogens could be transferred to new locations if the transported stock carried any infectious disease. Furthermore, intensification of stocking densities and deterioration of culture conditions provided favorable conditions for the outbreak of shrimp diseases.

Shrimp diseases caused by viral infection are not easily treated under current technology and have caused significant economic losses that have affected industry survival in many countries (Lightner, 2003). Shrimp viral disease outbreaks have caused billions of dollars in lost revenue for the global shrimp industry. Disease outbreaks were one of the major reasons for the collapse of the shrimp industry in Taiwan and China in the late 1980s and early 1990s (Fig. 6). Ecuador and Thailand have longer coastlines, so the effect of disease outbreaks on total production in those nations were not seen right away.

Because of the uncontrolled transfer of stock, a disease outbreak in one area could also cause unintended consequences in other parts of the world though trade. The outbreaks of Taura syndrome virus (TSV), white spot syndrome virus (WSSV), and infectious hypodermal and hematopoietic necrosis virus (IHHNV) were found in one location but were identified later in other countries (Lightner, 2003). Nunan et al.(1998) reported that frozen shrimp from an infected area could serve as a vector for exotic shrimp viruses during seafood trade. This report sent out an alarm for international trade.

The most effective way to deal with viral infection is through prevention. The concept of biosecurity has been introduced to aquaculture production systems through a variety of management strategies and by following internationally agreed upon policies and guidelines (Lightner, 2003). The key elements of biosecurity can be summarized into this short list: reliable sources of specific-pathogen-free domesticated stock, adequate diagnostic and detection methods for excludable diseases, disinfection and pathogen eradication methods, best management practices to exclude diseases, and practical and acceptable legislation. In addition to biosecurity, stock improvement can also combat the viral infection issue. Disease-free stocks are not always possible and are not the only tactic. Disease-resistant stocks should be used in any area where the exclusion of disease is difficult.

Under these disease management guidelines and with the availability of specific pathogen free (SPF) shrimp stock from Hawaii, Pacific white shrimp (*L. vannamei*) was introduced to Asia and impressive production data-particularly in China-were reached in less than four years and more than four times

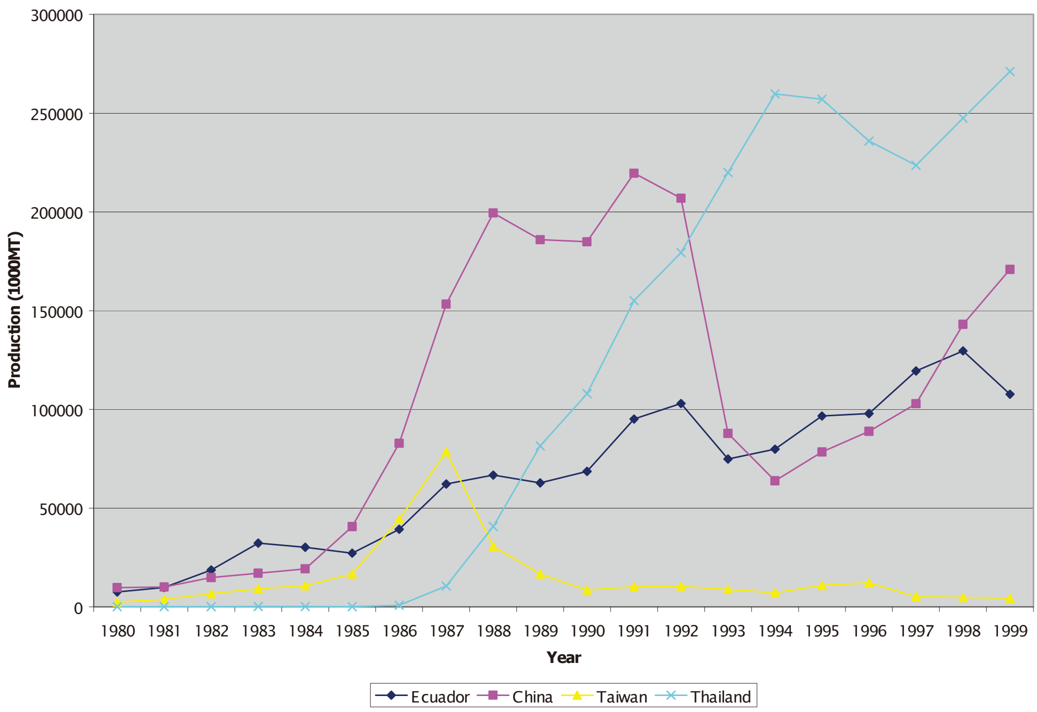

Fig. 6. Shrimp production in selected countries from 1980 to 1990.

production levels in Central and South America (Fig. 7).

Implications and conclusion

The above examples clearly indicate that the culture of introduced species was a common practice throughout the world. Exotic species will be introduced whenever and wherever an aquaculture industry sees potential for making a profit. To stop the importation of non-native species for aquaculture purpose will not only reduce total production but also affect the stability of seafood spplies and prices. Still, environmental and socio-economic damage from farming introduced species will expand if left without any controls. Introductions, for example, will alter the aquatic community structure and genetic composition of native populations, as well as reduce biodiversity (Beveridge et al., 1994; Goldburg and Triplett, 1997; Naylor et al. 2000). The current use of SPF shrimp stock and biosecurity practices in shrimp farming are positive steps toward reducing potential negative impacts of culturing foreign species. Urgently needed, however, are other means of containing introduced species from escaping farm areas and breeding with native species. Meanwhile, all introduction and transfer should follow the code developed by ICES (ICES 1995).

Acknowledgements

Preparation of this manuscript was supported by a grant from the National Oceanic and Atmospheric Administration (NOAA) #NA05OAR4171169, the United States Department of Commerce. The author would like to thank Kathryn Dennis for her assistance in editing.

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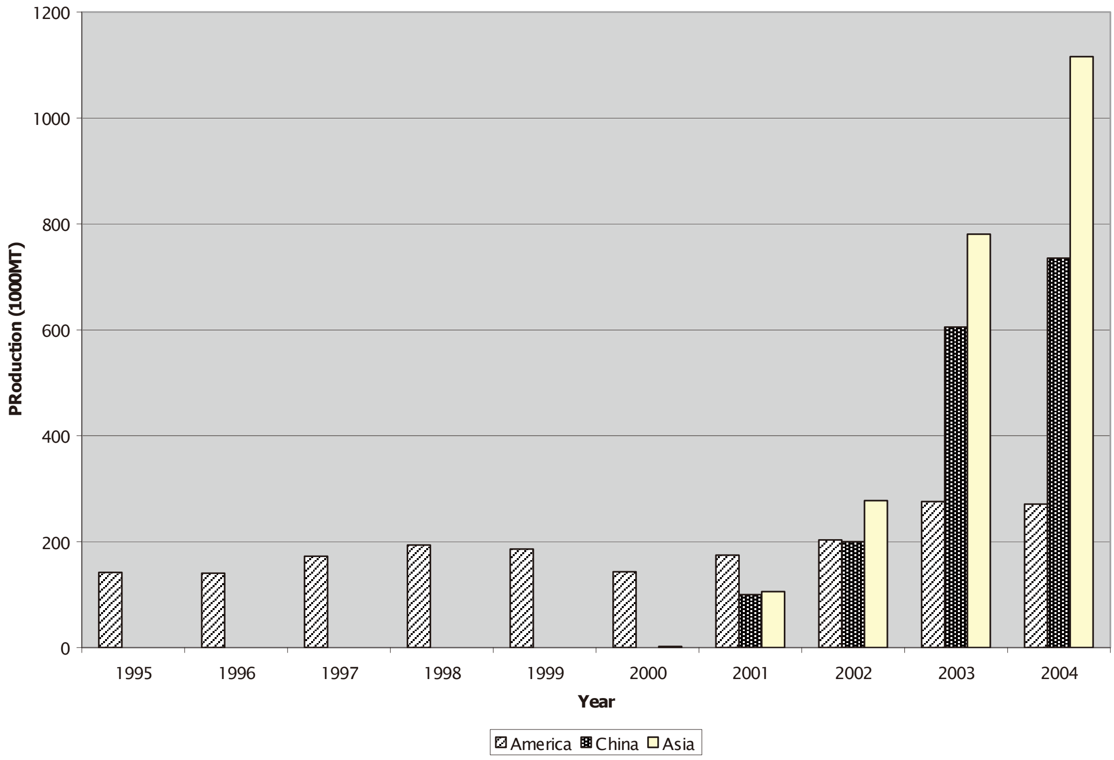

Fig. 7. Production of Pacific white shrimp in Central and South America, Asia, and China.

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Countermeasures against Alien Fishes (Largemouth Bass and Bluegill) in Lake Biwa

Atsuhiko IDE* and Shinsuke SEKI*

Abstract Lake Biwa is one of the world's most ancient lakes, with an origin going back four million years. Many aquatic organisms, including more than 30 endemic species or subspecies of fish and molluscs inhabit the lake, and various kinds of fisheries have targeted those animals for centuries. Bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*) were first found in Lake Biwa in 1965 and 1974. While bluegill spread gradually through the shallow water zones and into small lagoons surrounding the lake, largemouth bass increased explosively in the 1980s. Simultaneously, native fishes such as crucian carp and bitterlings disappeared from the coastal shallows. After that, the population of bluegill began to increase.

In recent years, bluegill has comprised over 90% of the fish fauna in Lake Biwa's south basin. Since 1985, fishermen have been trying continuously to reduce these alien species by several means. Fishing gear such as Eri (a set-net), gill nets, and pulling nets have been used. Recently, over 400 metric tons per year of these alien fishes have been eliminated. At the same time, the Shiga Prefectural Fisheries Experimental Station has tried to develop more effective gear to catch them. We have devised a pot trap, with its top covered by a sheet to provide shade, for efficient capture of the alien fishes, and a small beam trawl for use in beds of submerged aquatic vegetation. Other methods for the eradication of the alien fishes are currently under study.

Key words: Lake Biwa, Alien fish, Largemouth bass, Bluegill

Introduction

Lake Biwa, located on the main island of Honshu, is the largest lake in Japan. It is 63.5 km long and has a maximum width is 22.8 km. Its maximum depth is 104 m. The lake has a north basin and a south basin, with mean depths of 43 m and 4 m (Figure 1).

Lake Biwa is one of the world's most ancient lakes with an origin going back four million years. Many aquatic organisms, including more than 30 endemic species or subspecies of fish and molluscs, inhabit the lake. About 50 fish species or subspecies are distributed in the lake, and more than 10 of them are endemic. The richness of the fauna in the lake may be related to the variety of habitats, including littoral areas with emergent plants, littoral gravelly areas, littoral rocky areas, offshore shallow and offshore deep water.

Various kinds of fisheries have existed over the hundreds of years the lake has been fished. A gill net fishery, Okisukuiami (a scoop net in offshore) fishery, Chubikiami (a pulling net) fishery, a shell dredge net fishery, and Eri (a labyrinth-like set-net) fishery are included among them. The total annual commercial catch of fish and crustaceans was about 4,000 metric tons during the 1970s and 1980s.

The populations of most native littoral fish species, including nigorobuna (*Carassius carassius grandoculis*) and honmoroko (*Gnathopogon caerulescens*), which are the most important commercial fishes in the lake, have decreased greatly in the past twenty years. The decrease was probably caused by increases in the populations

2009年8月10日受理（Received. August 10. 2009）
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of the alien fishes largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*, Figure 2). This report describes countermeasures against alien fishes in Lake Biwa.

Invasion of Alien Fishes

In Lake Biwa, largemouth bass were first found in the north basin in 1974. Their distribution spread throughout the littoral areas by 1980, and the population increased explosively in the 1980s. Bluegill were found in Nishinoko, one of lagoons surrounding Lake Biwa, in about 1965, and the fish spread gradually through the shallow water zones in the 1970s (Terashima 1977). The population began to increase in about 1990, and increased explosively in about 1993.

Stomach contents of the alien fishes in Lake Biwa are shown in Figure 3.Bluegill feed on aquatic plants, zooplankton and insects, in addition to fish eggs and shrimp, while largemouth bass prey mainly on fish and shrimp. The results indicate that bluegill influences other littoral fish species by the competing for food and consuming fish eggs, and largemouth bass affect fish and shrimp through predation.

After the population of largemouth bass increased explosively, the catch of crucian carp decreased rapidly (Figure 4). At the same time, most bitterling species (small native cyprinid fishes) disappeared from the littoral areas of the lake. In addition, the population of bluegill increased explosively after the catch of crucian

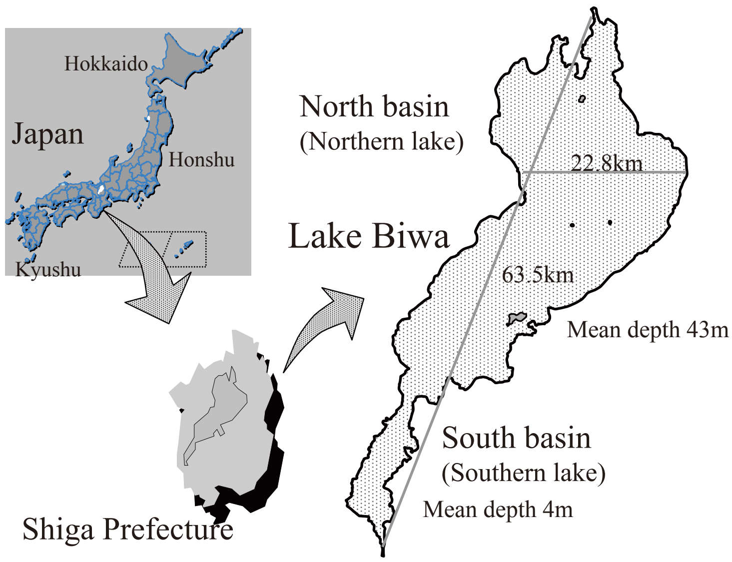

Fig. 1. The outline of Lake Biwa.

Largemouth bass
Micropterus salmoides

Bluegill
Lepomis macrochirus

Fig. 2. Alien fishes affecting native fish fauna in Lake Biwa.

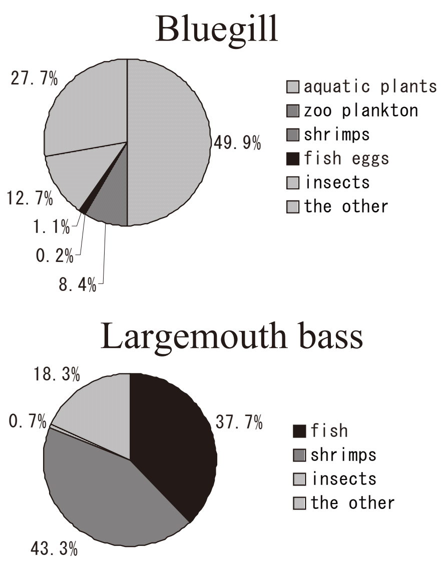

Fig. 3. Weight frequencies of stomach contents of the alien fishes inhabiting Lake Biwa studied in 2003.

carp became stable a reduced level. After that, the annual catch of honmoroko began to decrease as well. The annual catch of littoral commercial species in the lake has decreased to half of that recorded in the 1970s and 1980s.

Fish Fauna in the Littoral Zones of Lake Biwa

The percentages of largemouth bass, bluegill and other species captured by small set-nets at four littoral sites in Lake Biwa in 2002 or 2003 are shown in Figure 5. The percentages of largemouth bass were greatest at the two sites in the northern part of the lake, while the of bluegill portion of the catches exceeded 90% at the two southern sites. At present, the alien fishes are the dominant species in the littoral zones of the lake.

Elimination of Alien Fishes

The project to eliminate the alien fishes from Lake Biwa was initiated by fishermen who have received administrative financial support since 1985. The project was developed in order to protect the native fishes. Usual fishing gear such as Eri, gill nets, and Chubikiami are being used for the project. Eri has a structure that guides fish into the main nets. Gill nets are used to capture the alien fishes mainly in the south basin of Lake Biwa, and most of the fish species captured are bluegill. Many alien fishes can be captured by Chubikiami in water 10 m deep in the north basin of Lake Biwa.

The administrative support for the project was increased beginning in 2002. As the result, the amount of alien fishes captured, which was less than 300 metric tons annually before 2001, increased to more than 400 metric tons annually year since 2002 (Figure 6).

The alien fishes captured by fishermen are transferred in carts to a factory where they are processed into fish powder, which is used as an ingredient for animal feed.

The usual fishing gear types used for capturing alien fishes have some problems. Those gears

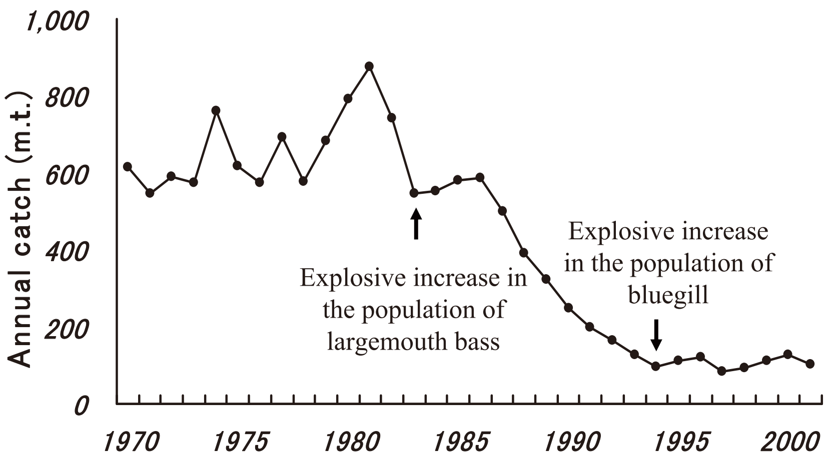

Fig. 4. Change of the annual catch of crucian carp in Lake Biwa, and relationships between the change and the increase in alien fishes.

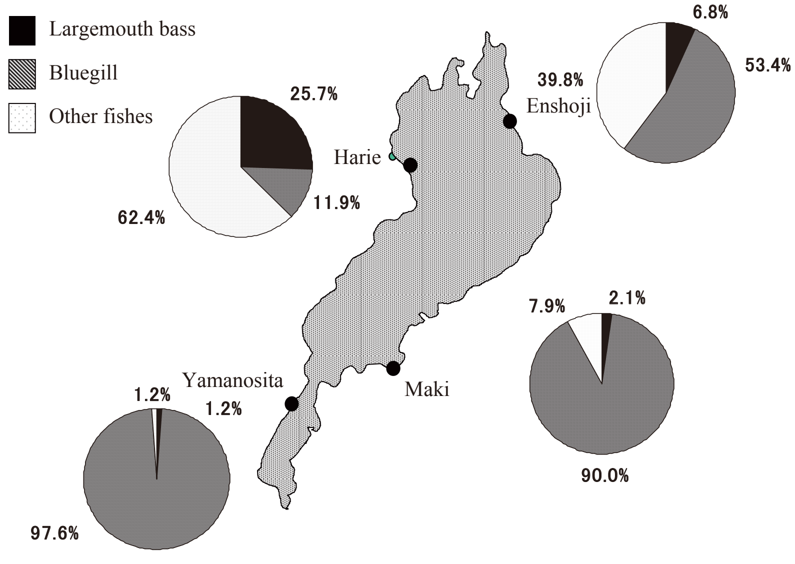

Fig . 5 .

Fig 5. Percentages of largemouth bass, bluegill and other fishes captured by small set-nets at four littoral sites in Lake Biwa in 2002 or 2003.

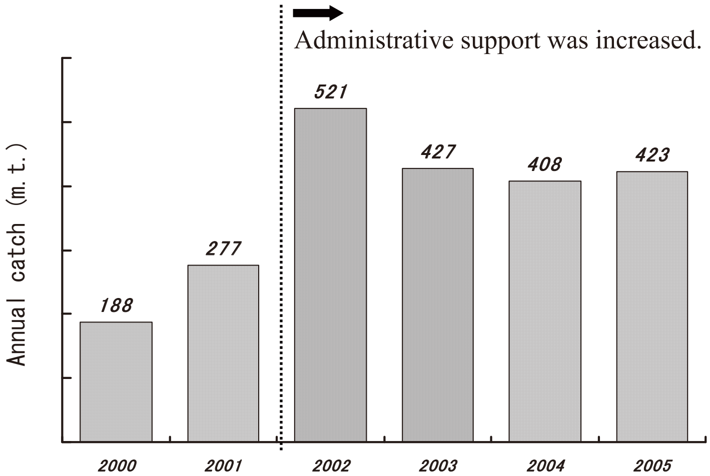

Fig. 6. Annual catches of the alien fishes in Lake Biwa.

cannot be used in the shallow water zones that many alien fishes inhabit because they are too big to set up in those zones. The gears are also not easily used in areas where aquatic plants grow thickly because the plants obstruct setting of the gears. Small (young) alien fishes are not efficiently captured by the traditional gear types, in particular, gill nets. The solution of these problems is necessary to eliminate the alien fishes efficiently.

In order to solve the problems, we devised two new types of fishing gear. Test results showed that a covering sheet put on the top of a pot trap increased its effectiveness in capturing the alien fishes when they gather in shaded areas. The new gear devised for use in shallow water zones is shown in Figure 7. We call this trap "Shading" Type Pot Trap. In the studies, we could capture the alien fishes, in particular bluegill, more efficiently with the gear during its spawning season. The maximum number of the alien fishes captured with one shading type pot trap set for 24 hours in shallow water zones of Lake Biwa or in the lagoons surrounding the lake was 65.

The second new type of gear we developed is a small beam trawl which is effective in beds of submerged aquatic vegetation (Figure 8). The gear was designed after gear used in the Japanese coastal seas to capture shrimp (Tsudani 1978).

The trawl net has two beams. The length of the first beam is 3 m and that of the second beam is 2 m. These two beams stabilize the net for towing in beds of submerged aquatic plants. This net is towed with mowing down the aquatic plants. The maximum catch of alien fishes in test tows of three minutes duration in Lake Biwa's south basin was 1.7kg.

Figure 9 shows the length frequency distributions of bluegill and largemouth bass captured by the small beam trawl in the south basin in 2003. As shown in the graphs, the small beam trawl could capture young alien fishes of less than 60 mm standard length, which are hard to capture with other types of fishing gear.

The new fishing gears have been introduced for the project to eliminate the alien fishes in 2005. The removal of those fishes from Lake Biwa will probably proceed more efficiently by using the older and the new fishing gears in parallel. Verification of the effect of the new gears to the project will be reported on in the future.

The Shiga Prefecture Government established a new local ordinance "Biwa-ko Jorei" in 2003. This ordinance asks recreational fishermen not to release the alien fishes captured in Lake Biwa, in order to get their collaboration in helping to eliminate the alien fishes.

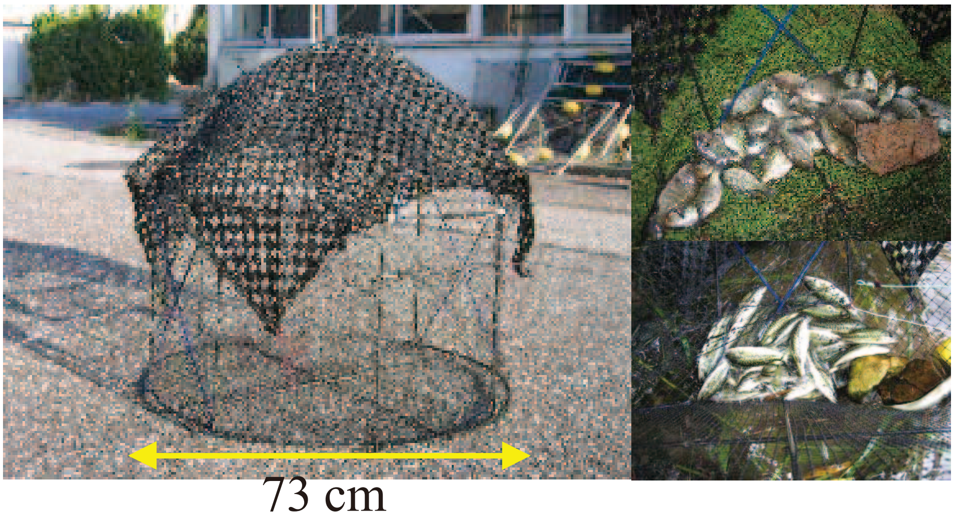

Fig. 7. “Shading” Type Pot Trap for the alien fishes.

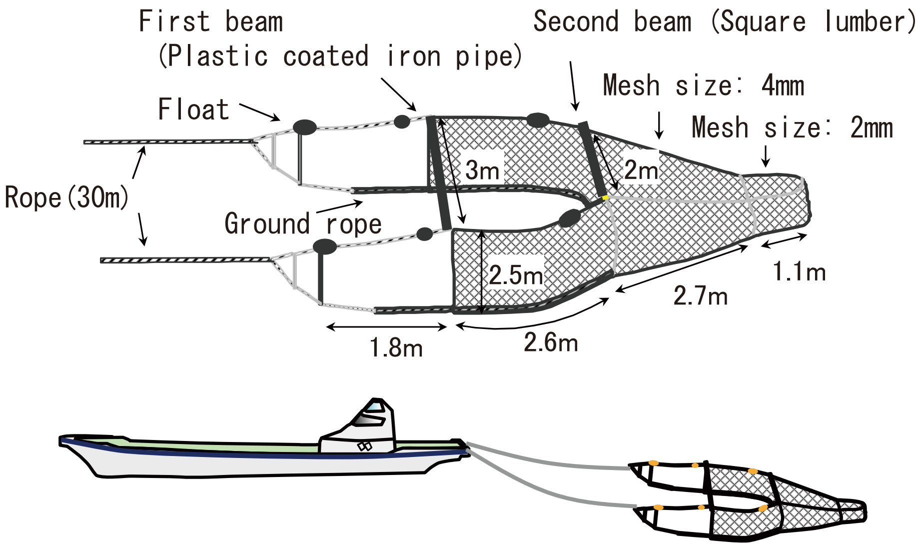

Fig. 8. Appearance of a small beam trawl.

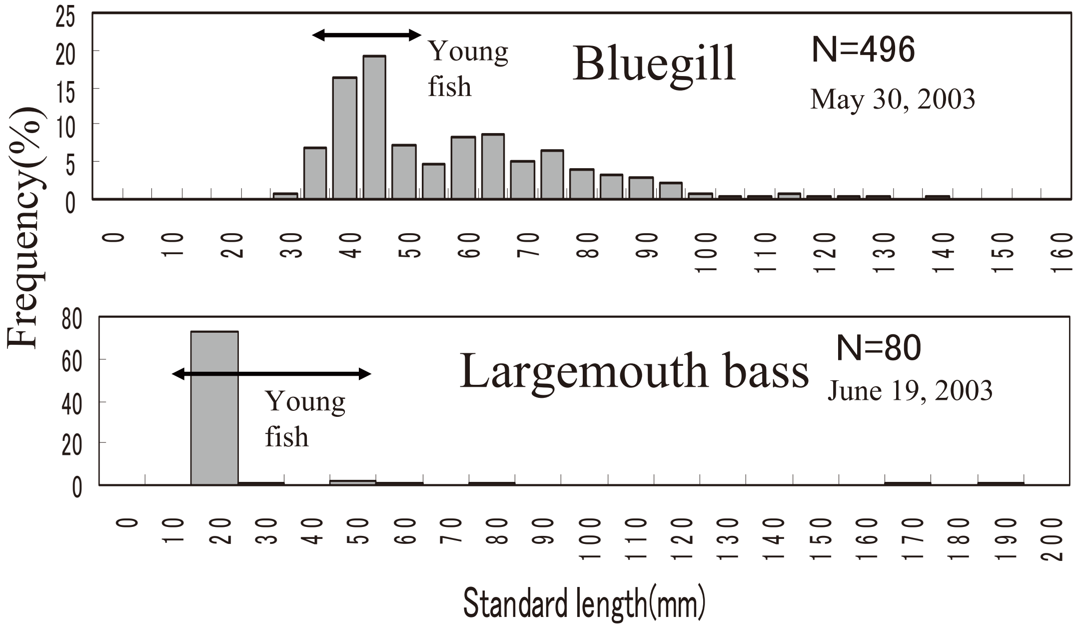

Fig. 9. Length frequency distributions of the alien fishes captured by the small beam trawl net in Lake Biwa`s south basin.

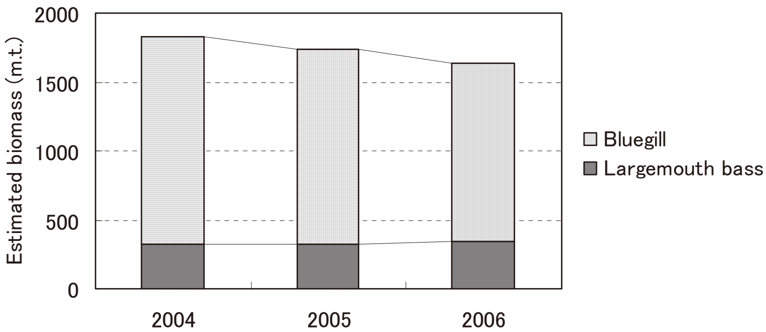

Fig. 10. Biomass of the alien fishes estimated from the data on the fishes captured by the project to eliminate.

Future Plans

As the result of the project to eliminate the alien fishes, the estimated biomass of bluegill in Lake Biwa, tended to decrease recently, but that of largemouth bass continues to be stable (Figure 10). It is, therefore, necessary to increase the countermeasures against largemouth bass. As the next step, we will study methods that might be used to prevent breeding by largemouth bass. The ultimate goal is to restore the Lake Biwa ecosystem to one that has a fauna comprised only of native fishes.

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Conservation Aquaculture Approaches for Hatchery Reform

Thomas A. Flagg[*1] and Lars E. Mobrand[*2]

Development of the North Pacific salmonid hatchery system began in the late 19th century and has played a prominent role in enhancement of the salmonid fisheries in the Pacific Northwest (states of Washington, Idaho, and Oregon, USA) since the 1950s. Most public hatcheries in the Pacific Northwest were originally built to mitigate for loss of natural spawning habitat. Hatchery production goals focused on enhancing harvest of adults in commercial fisheries. The hatcheries were established at a time when many wild salmon stocks were healthy and genetic diversity of stocks was not a concern. Hatcheries have played a major role in supplying salmon and trout to the common property fishery, benefiting commercial, sport, tribal, and nontribal fishers. In fact, hatcheries are so instrumental in supplying fish that it is nearly impossible to separate the management of the salmonid fisheries from the management of the hatcheries. Today in the Pacific Northwest, nearly 400 artificial production programs for anadromous salmon and steelhead (*Onchorynchus spp.*) are producing over 200 million hatchery fish annually. These hatcheries now provide up to 80% of the fish in several of the key fisheries.

Despite the great success of hatcheries in supplying fish for fisheries, the philosophy of salmonid resource management has changed to include a focus on resource management for wild stocks. A number of stocks of anadromous salmonids in the Pacific Northwest are currently listed by the National Marine Fisheries Service (NOAA Fisheries) as threatened or endangered under the U.S. Endangered Species Act (ESA). The need to preserve biodiversity has brought about a new era of conservation of wild stocks that cannot help but impact the operation and management of production hatcheries and the traditional users of hatchery fish.

Since 1999, NOAA has been a partner in a formal process of hatchery reform that has been ongoing in the Pacific Northwest (Mobrand et al. 2005). The Hatchery Scientific Review Group (HSRG) is funded by the U.S. Congress and is a systematic, science-driven redesign of how hatcheries will be used to achieve the goals of: 1) helping to recover and conserve naturally spawning populations, and 2) supporting sustainable fisheries. Initial work by the HSRG included developing a Scientific Framework for Artificial Propagation of Salmon and Steelhead, a Benefit/Risk Assessment Tool, Hatchery Operational Guidelines, and Monitoring and Evaluation Criteria (see **www.hatcheryreform.org**; **http://hatcheryreform.us**; and **www.managingforsuccess.us** for information on the Hatchery Reform process). These tools are being used by the HSRG in a comprehensive Pacific Northwest region-by-region review that evaluates hatchery programs for consistency with established scientific principles and the objectives of hatchery reform.

Where hatchery operations conflict with recovery of ESA-listed stocks, the options appear to be either 1) isolation of hatchery production (e.g., near-tidewater rearing/release and aggressive terminal harvest of hatchery fish) or 2) altering hatchery operation to include a conservation mandate (see Flagg and Nash 1999, Flagg et al. 2004, and Mobrand et al. 2005 for details of conservation hatchery approaches). What follows is a brief discussion of major emerging issues relating to the operation of hatcheries in the Pacific Northwest and examples of what we feel are critical needs for hatchery reform. These discussions provide an example for Pacific salmon

2009年8月10日受理（Received. August 10. 2009）
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of the general shift in aquaculture philosophy from a production-based focus to one that also considers effects of the actions on health and sustainability of the natural ecosystem.

Potential Impacts of Hatchery Rearing--The overall impact of hatchery fish on wild populations can be divided into three broad categories. 1) Over-harvest of wild stocks in mixed stock fisheries can have a profound impact on survival of wild stocks. When productive hatchery stocks are targeted for high harvest, less productive wild stocks cannot withstand the high exploitation rates, resulting in under-escapement of wild fish. 2) A number of ecological interactions can occur between hatchery and wild fish. These can take the form of: competition for food and territory, predation with larger hatchery fish preying on smaller wild cohorts, and other negative social interactions when large numbers of hatchery fish are released on top of small numbers of wild fish. 3) Genetic risks associated with hatchery rearing, including intentional and unintentional events such as domestication selection, inbreeding, and outbreeding depression.

Traditional hatchery rearing for Pacific salmon is most commonly conducted in outdoor raceways and tanks over uniform concrete substrate. Fish in rearing vessels are conditioned to minimal raceway flow regimes; provided no structure in which to seek refuge from predators, or dominant cohorts; held at high, stress-producing densities; surface fed; and conditioned to approach large, moving objects at the surface. The protective nature of hatchery rearing increases egg-to-smolt survival. However, the postrelease survival and reproductive success of cultured salmonids is often considerably lower than that of wild-reared fish. The hatchery practices mentioned above are often considered prime factors that may induce genetic change (e.g., domestication) and reduce fitness of hatchery fish for natural ecosystems. However, it is likely that the most immediate impact of traditional rearing practices is to disrupt innate behavioral repertoires.

Conservation Hatchery approach-Three foundational principles (Table 1) have been described for operation of hatcheries under a conservation aquaculture approach (Mobrand et al. 2005)

Principle 1: *Every hatchery stock must have well-defined goals in terms of desired benefits and purpose*. Well-defined goals provide both targets and measures for success. The goals for each hatchery stock must reflect the purpose and desired benefits of the program (e.g., harvest, conservation, research, education). Wherever possible, goals should be quantified.

Hatcheries should operate as part of an integrated strategy that includes short-term and long-term goals for habitat and harvest. Goals should be related to measures of success, including: (a) the desired number of fish to be harvested each year, (b) the number of fish returning to a hatchery or spawning naturally in a watershed (i.e., escapement), (c) the expected results of scientific research, and (d) the educational benefits to be derived from outreach.

Principle 2: *Hatchery programs must be scientifically defensible*. Hatchery programs and operations must be consistent with stated goals, and they must be defensible scientifically. Once the goals for a program are established, the scientific rationale for the design and operation of the program must be explicitly stated and understood by all personnel. These requirements may necessitate a written, comprehensive management plan for every hatchery program. Scientific oversight and peer review should be integral components of every hatchery program.

Every hatchery program needs to have *operational guidelines and standard operating procedures* (e.g., selection of adults for broodstock, spawning protocols, feeding protocols, etc.) that are scientifically defensible. These guidelines should include decision-making pathways for dealing with potential contingencies.

Principle 3: *Hatchery programs must respond adaptively to new information*. Scientific *monitoring and evaluation* (M&E) of hatchery programs need to be increased. M&E should assess smolt-to-adult survivals, return rates of adults, contributions of adults to harvest and natural spawning, the proportion of naturally

Table 1. Principles for hatchery management and system-wide recommendations developed by the Hatchery Scientific Review Group (HSRG), modified from Mobrand et al. 2005.

1) Well-Defined Goals:
   - Set Goals for all Stocks and Manage Hatchery Programs on a Regional Scale
   - Measure Success in Terms of Contribution to Harvest, Conservation and Other Goals
   - Have Clear Goals for Educational Programs
2) Scientific Defensibility:
   - Operate Hatchery Programs within the Context of Their Ecosystems
   - Operate Hatchery Programs as either Genetically Integrated or Segregated Relative to Naturally-Spawning Populations
   - Size Hatchery Programs Consistent with Stock Goals
   - Consider both Freshwater and Marine Carrying Capacity in Sizing Hatchery Programs
   - Ensure Productive Habitat for Hatchery Programs
   - Emphasize Quality, Not Quantity, in Fish Releases
   - Use In-Basin Rearing and Locally-Adapted Broodstocks
   - Spawn Adults Randomly throughout the Natural Period of Adult Return
   - Use Genetically-Benign Spawning Protocols that Maximize Effective Population Size
   - Reduce Risks Associated with Outplanting and Net Pen Releases
   - Develop a System of Wild Fish Management Zones
   - Use Hatchery Salmon Carcasses for Nutrification of Freshwater Ecosystems, while Reducing Associated Fish Health Risks
3) Informed Decision Making:
   - Adaptively Manage Hatchery Programs
   - Incorporate Flexibility into Hatchery Design and Operation
   - Evaluate Hatchery Programs Regularly to Ensure Accountability for Success

spawning fish composed of hatchery-origin adults, and stray rates of adults to non-target watersheds. Where possible, M&E should include assessments of genetic and ecological interactions (e.g., interbreeding, competition, predation) between hatchery- and natural-origin fish. Centralized databases need to be developed for collating, storing, and retrieving data. Results need to be evaluated annually to allow programmatic adjustments.

Hatcheries need to be flexible and managed adaptively. Many scientific uncertainties are associated with salmon hatcheries. Hatchery programs and facilities must respond to new goals, new scientific information, and changes in the status of natural stocks and habitat. A structured adaptive management program is necessary for the success of hatcheries. Institutional resistance to programmatic flexibility and change needs to be overcome.

Conservation Hatchery Operation--Flagg et al. 2004 described an operational approach for Conservation Hatchery rearing for Pacific salmon (Table 2). The process requires application and integration of a number of rearing protocols, all of which are known individually to affect the inherent fitness of the creature to survive and breed in its natural ecosystem. A Conservation Hatchery approach for salmonids will require a specialized rearing facility to breed and propagate a stock of fish genetically equivalent to the native stock, and with the full ability to return to reproduce

Table 2. Operational comparisons between production and Conservation Hatchery strategies for rearing of Pacific salmon (modified from Flagg et al. 2004).

		Production Hatchery		Conservation Hatchery	
Parameter	**Factor**	**Action**	**Objective**	**Action**	**Objective**
Egg collection	spawn timing	directed (e.g., early or late component, etc.)	synchronize adult return/harvest opportunities	synchronized to wild, representative numbers collected over range of run	maintain wild timing
	number	directed (probably large number of eggs taken)	maximize output	directed (relatively small number of eggs needed)	stage production to habitat carrying capacity
Egg fertilization	mating strategy	directed (for characteristics)	select desired attributes (e.g., return size and age)	directed (to maintain genetic diversity)	maintain diversity
Egg incubation	incubator type	use accepted guidelines for species	maximize output	include substrate	approximate wild conditions/maximize hatch size
	temperature	surface or well	time hatch to production needs	controlled to ambient for stock	synchronize hatch with wild timing
Fish rearing	vessel type	standard (typically smooth with no internal structure)	maximize output	altered to include enriched (seminatural) habitats with cover, structure, substrate, etc.	reduce domestic conditioning
	temperature	surface or well	time rearing to production needs	controlled to ambient for stock	synchronize rearing with wild stock
	culture	standard (designed to maximize fish output)	maximize output	innovative (designed to maximize fish quality)	reduce domestic conditioning and improve fitness
	pond timing	variable	maximize culture opportunity	synchronized to wild	approximate wild rearing scenario
	photoperiod	natural	provide ambient conditions	natural	provide ambient conditions
	density	up to maximum safe levels	maximize space use	use low rearing density	minimize behavioral and health aspects of fish quality
	growth	use accepted guidelines for species that maximize adult return.	maximize output	use growth modulation targeted to approximate wild rearing scenario at all cultured life stages	target fish growth to wild size
	survival	maximum possible	maximize output	maximum possible	maximize output
	Prerelease conditioning	none	maximize output	provide antipredator conditioning	reduce predator vulnerability/ increase postrelease survival
				use substrates that enhance crypsis	reduce predator vulnerability/increase postrelease survival

						provide exercise conditioning	increase postrelease survival
						provide forage training	increase postrelease growth and survival
Health	diseases		fish often released with subclinical health problems	maximize output		release only healthy fish	maximize survival and minimize impacts to wild fish
Fish release	fry release		not used under most circumstances			secondary strategy	seed critical habitats at or below carrying capacity
	presmolt release		not used under most circumstances			primary/secondary strategy	seed critical habitats at or below carrying capacity
	smolt release		primary strategy	maximize adult return opportunity		primary/secondary strategy	maximize adult return opportunity

naturally in the habitat. The fish quality goals and operational approaches for a Conservation Hatchery may be considerably different then for a standard production hatchery. Therefore, a Conservation Hatchery must be equipped with a full complement of culture strategies to produce very specific stocks of fish with specific attributes. Where and when implemented, fish rearing in a Conservation Hatchery must be conducted in a manner that 1) mimics the natural life history patterns, 2) improves the quality and survival of hatchery-reared juveniles, and 3) lessens the genetic and ecological impacts of hatchery releases on wild stocks.

Operational guidelines for conservation hatcheries to help mitigate the unnatural conditioning provided by hatchery rearing described in Flagg et al. 2004 include: 1) Mating and rearing designs that produce minimal genetic divergence of hatchery fish from their wild counterparts to maintain long-term adaptive traits; 2) Simulation of natural rearing conditions through incubation and rearing techniques that approximate natural profiles and through increasing habitat complexity (e.g., cover, structure, and substrate in rearing vessels) to produce fish more wild-like in appearance, and with natural behaviors and higher survival; 3) Conditioning techniques such as anti-predator conditioning to increase behavioral fitness; 4) Release of fish at a size, stage, and condition which approximates the wild population to reduce potential negative ecological interactions and to promote migratory homing; and 5) Aggressive monitoring and evaluation to determine success of conservation hatchery approaches.

Genetic Integration vs. Segregation of Hatchery Broodstocks Relative to Natural Populations--A first step towards "hatchery reform" is to develop a detailed genetic management plan or strategy for every hatchery broodstock. Morbrand et al. 2005 described two genetic management options: (1) manage a hatchery broodstock as a reproductively distinct population that is genetically segregated from naturally spawning populations, or (2) manage a hatchery broodstock as a genetically integrated component of an existing natural population. Each of these broodstock strategies leads to a different set of operational guidelines (detailed information on integrated vs segregated approaches can be found on the HSRG websites described above).

Genetically segregated broodstocks are generally derived strictly from hatchery-origin adults returning back to the hatchery each year. Segregated hatchery programs create a genetically distinct, hatchery-adapted population. Segregated hatchery populations will diverge genetically from naturally spawning populations over time because of founder effects, genetic drift, and domestication selection in the hatchery environment. Such changes may be intentional (e.g., via selective breeding) to maximize benefits or the operational efficiency of a hatchery program. However, natural spawning by hatchery-origin fish from a segregated program may pose unacceptable genetic and ecological risks to natural populations, and the HSRG recommends for segregated programs the percent of hatchery origin spawners (HOS) on the spawning grounds should be less than five percent of the naturally-spawning population (pHOS < 5%). Often, to achieve these goals will require a combination of directed selective fisheries and control structures such as weirs to remove segregated populations prior to arrival on spawning grounds.

Conversely, genetically integrated broodstocks systematically include a prescribed proportion of natural-origin fish in the broodstock each year to maintain genetic integration with a natural population. One goal of integrated hatchery programs is to minimize the genetic effects of domestication by allowing selection pressures in the natural environment to drive the genetic constitution and mean fitness of the population as a whole. For an integrated program, the percent of natural origin fish taken into the broodstock each year (NOB) must be greater than the percent of hatchery origin fish allowed to spawn in the wild (pNOB > pHOS). An integrated program will require methods (such as those described for segregated populations) to remove hatchery origin fish prior to spawning grounds to adequately control hatchery/wild fish ratios.

Integrated hatchery programs require, as a long-term goal, a self-sustaining naturally spawning population capable of providing adult fish for broodstock each year. Integration thus requires suitable natural habitat capable of sustaining a natural population. Under this concept, an integrated hatchery does not replace habitat but adds to existing habitat. An implicit goal of an integrated program is to demographically increase the abundance of a natural population while minimizing the genetic effects of artificial propagation. The size of an integrated hatchery program will necessarily be limited by the habitat available to the natural populations with which it is integrated and by the ability of the hatchery program to restrain natural spawning by hatchery-origin adults.

Risks and Benefits--Salmon hatcheries are a major source of controversy in the Pacific Northwest. The HSRG was mandated by Congress to identify potential solutions to widely-recognized problems to ensure that hatcheries contribute to supporting sustainable fisheries while supporting conservation, restoration, and recovery of natural populations. The review focused on identifying scientific uncertainties and proposing solutions based on the best available science. The need to develop broodstock genetic management plans for every hatchery program with the goal of managing each broodstock as either a genetically *segregated* "hatchery population" or as a genetically *integrated* component of an existing "natural population" became a fundamental foundation for the recommendations. Both strategies require the ability to distinguish hatchery and natural-origin adults, both in the hatchery when adults are spawned for broodstock and on the natural spawning grounds to assess the genetic risks and gene flow rates of hatchery-origin fish to natural populations. Commensurate with these reforms is the need for increased monitoring and evaluation, scientific oversight, and accountability of hatchery operations.

In this context, hatcheries cannot be regarded as surrogates or substitutes for lost habitat. Hatcheries need to operate in scientifically-defensible modes with well-defined goals and substantially increased data collection and evaluation. Hatcheries also need to be flexible and adaptable; that is, they need to operate and be evaluated in the context of both the ecosystem (watersheds) in which the hatcheries occur and other ecosystems and ecological processes on which hatchery-origin fish depend.

Scientific uncertainties associated with hatchery operations are numerous. The science to manage these risks is still inadequate, and some of the risks are still poorly understood. However, one point is clear. Maintaining healthy habitat is critical not only for viable, self-sustaining natural populations, but also to adequately control risks of hatchery programs and realize the benefits of hatcheries to recover populations and sustain healthy harvests in increasingly populated environments.

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Accounting for Economic Risk and Uncertainty in Offshore Aquaculture: A Case Study of Korean Rock Bream Production

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Abstract Interest is growing in offshore aquaculture as a means of overcoming environmental concerns that plague nearshore and coastal aquaculture production. The challenge of dealing in the offshore environment adds expenses that are not present in other aquaculture production systems. We collected financial and production performance data from a commercial scale offshore aquaculture production system for rock bream off the coast of Korea. Financial performance of the system was evaluated using Aquasim, a stochastic financial simulator. To compare performance, we focused on the ten year internal rate of return and net present value based on different assumptions regarding fish survival rates and market prices. The baseline model which used the observed survival and market prices had a high probability of financial success and an internal rate of return of 18%. Financial performance became a lot riskier when we assumed that survival rates followed a triangular distribution with a 25% minimum survival that increased 5% per year, even when the mean survival rate was as high as 97%. Rock bream aquaculture could be successful under that survival scenario if prices are high for the first five years and then start declining due to the industry expanding. In that case, the internal rate of return is around 14%, but with greater variability than the baseline. If prices fall from the initial baseline level in the early years of production, then the operation has little chance of surviving.

Introduction

The continued development of aquaculture as a means of increasing the world's fish supply is a balance between cost efficiency in production and environmental costs that are external to the operation. At one extreme are recirculating systems that are greatly isolated from the environment, but have high investment and operating costs that, at present, are mostly economically viable for high-valued species. These systems have a relatively low impact on the environment since there is little, if any, water exchange, and the effluent can be easily managed. More open systems such as shrimp ponds or coastal net-pen systems have lower costs, but are experiencing growing concerns about environmental impacts (Naylor 2006; Whitmarsh *et al*. 2006; Goldburg *et al*. 2001). Offshore ocean aquaculture systems, within the high energy marine environment and deeper waters, may ameliorate some of the environmental problems of the current systems which tend to be more nearshore and in shallower water (Kalantzi and Karakassis 2006). However, these environmental gains may be offset by higher investment costs, higher operating expenses and greater risk.

As with any new production process, there is little data available about the economic performance until a sufficient size industry develops from which to gather data. Potential investors and government agencies that seek to support the development of aquaculture must rely, at best, on data from experimental or pilot-scale systems, or expert opinion on which to base their decisions. Economic analysis of the performance of two offshore aquaculture systems in the United

2009 年 8 月 10 日受理（Received. August 10. 2009）
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States, one off of Puerto Rico (Brown et al. 2002) and one placed off of Hawaii (Kam et al. 2003), have been conducted based on just such speculative data. In this paper, we base an economic analysis of rock bream, Oplegnathus fasciatus, culture in the offshore waters of Jeju Island, Korea, on the actual performance of a privately owned and operated aquaculture enterprise. Since the data is limited to one year of operation, we use stochastic simulation to project the necessary conditions for long term success for similar offshore operations.

Methodology

Financial Analysis

A basic accounting approach is standard for examining farm enterprises in general and has been applied widely in aquaculture. Greater attention has been paid to accounting for uncertainty and risk, particularly when dealing with relatively new aquaculture operations. Examples of incorporating risk in aquaculture include studies on salmon (Kumbhakar 2000), catfish (Kazmierczak and Soto 2001; Nelson et al. 2001), crawfish (McCullogh et al. 2001) and shrimp (Valderrama and Engle 2001). Sottorio collected data from 16 companies in Spain involved in aquaculture production of eight finfish species. Lipton and Gempesaw (1997) used a software program they specifically developed for evaluating risk in aquaculture enterpises, Aquasim, to compare production technologies for hybrid striped bass.

Aquasim was used in this analysis of offshore aquaculture of rock bream. Aquasim is derived from Chicksim, a stochastic financial simulation program originally designed for analyzing chicken production (Gempesaw et al 1988). Aquasim is capable of simulating four discrete stages of fish production for a single species. The model is also capable of simulating multiple production cycles simultaneously, allowing for continuous stocking on up to a monthly basis. Fish are grown in the simulation based on user specified ending and starting weights and stage length in months. User specified stage-specific mortalities and feed conversion rates are applied to determine production levels and feed costs. Aquasim requires the user to specify ranges or standard deviations for a variety of variables related to the production process and for input and output prices. (Table 1)

In addition to incorporating risk and uncertainty via Monte Carlo simulations, Aquasim provides for a more realistic investment scenario than developed in typical enterprise budgets. The user can specify initial loans and terms, as well as terms for new loans that may be initiated within the time horizon should the cash flow situation require or when capital equipment needs to be replaced as indicated by the depreciation schedule. New loans are allowed during the simulation as long as the operation meets standard equity ratio tests. If the operation runs out of money and borrowing is not allowed due to insufficient equity, the simulation is declared insolvent. The number of insolvencies is tracked during the simulations to generate a probability of survival for the operation. Standard measures of performance such as internal rate of return and ending net worth are tracked for all the solvent iterations, and the mean values, ranges and coefficients of variation are provided for the scenario being tested.

Another feature of Aquasim is that it is a dynamic model with up to a ten year time horizon. Thus, the user can specify different parameter values for all ten years. For example, survival rates may increase or feed efficiency increase due to an assumption about the firm moving up the learning curve of production (Sotorrio 2002). The variance or ranges of the specified parameters can

Table 1. Financial information used in Aquasim.

Market Price	US$12.94/kg
Tax	10%
Discount rate	8%
Loan	US$150,000
Interest rate of loan	2.8%
Life of loan	2years

also increase or decrease over the time horizon. For example, experience may not lead to a higher mean survival rate, but it could lead to less variability in the survival rate.

A baseline scenario using Aquasim is developed using the actual data obtained from a commercial scale operation discussed below. Once the baseline performance is established in terms of net present value (NPV) and internal rate of return (IRR), several other scenarios are run for comparison. In particular we look in detail at a more realistic price scenario over the ten year time horizon, as well as a more realistic fish survival scenario. We then run the price scenario and survival scenario in a combined scenario that we feel most closely approximates the expected performance of the offshore rock bream system. We also conduct sensitivity analysis for key production parameters such as feed and seed costs.

Aquaculture Operation Description

The offshore rock bream cage production system was initially introduced in the Pyo-Sun area of Jeju Island in Korea on April 2005 as part of a commercial farming pilot project (Figure 1). The Pyo-Sun area is close to port facilities and fingerling production facilities. A consortium for the commercial project was formed by the Jeju Fisheries Research Institute (JFRI), a regional institute of the National Fisheries Research & Development Institute (NFRDI) of Korea and a private aquaculture enterprise, Noah Offshore Farm Company Limited.

The city of Jeju issued a permit to conduct the offshore farming in an area covering 10 ha of surface water, 4.5 km off Pyo-Sun for three years (May 2005 to May 2008). The offshore cage system is the Seastation 3000™, a 3000 m^3 biconical sea cage. This is the same cage system as is being used in Hawaii, Puerto Rico, and New Hampshire. The cage system was imported from the United States and currently, three cages are being employed.

Rock bream was selected as the species to be farmed due to its high market price compared to other major species such as the flatfish, Paralichthys olivaceus, and the rockfish ,Sebastes schlegelii.[1] Rock bream fingerlings are readily available, and it has performed well in other aquaculture systems. A total 677,467 fingerlings, weighing 5-10g per fingerling were stocked at the end of June 2005.

Production costs for the first 12 month production cycle were obtained from the Noah Offshore Farm. JFRI provided data on the performance of the fish within the system in terms of growth and survival. Financial parameters for the production of rock bream offshore farming are summarized in Table 2. Parameters include market sale price, tax rate, discount rate, and loan terms. The price of rock bream during the period was estimated to be relatively high (US$12.94/kg) compared to other farmed species. A discount rate of 8% is used to calculate the Net Present Value (NPV). The Noah Offshore Farm Co. Ltd. borrowed US$150,000 from the National Federation of Fisheries Cooperatives (NFFC) at a 2.8% interest rate during a 2-year period.[2]

The overall survival rate was 97%, and we initially assumed it ranged from 90-100%). The feed conversion rate (FCR) was 1.3 with an assumed standard deviation of 0.2. Thee fish had an average weight of 175g with an assumed standard deviation of 0.14g after the 12-month production period. The survival rate is relatively high compared to other species farmed in Korea in land-based raceways or in coastal cage systems. For example, the average survival rate of flatfish in the land-based farms is 80%. The difference might be because there were no serious natural disasters such as a typhoon or red tide during the last 12-month farming period and no problems with diseases that may occur in cage farming. This high rate of survival might be a significant advantage of an open ocean cage system in comparison to coastal cage systems or land-based cage systems.

[1] The production of flatfish and rockfish accounted for 75.4% of Korea's total farmed finfish production in 2005. The annual average price per kilogram of a flatfish and a rockfish in 2005 was US$8.76 and US$9.26, respectively.
[2] This is a government subsidized rate, and other firms would expect to pay higher interest rates. However, the results that follow were not greatly sensitive to the interest rate used.

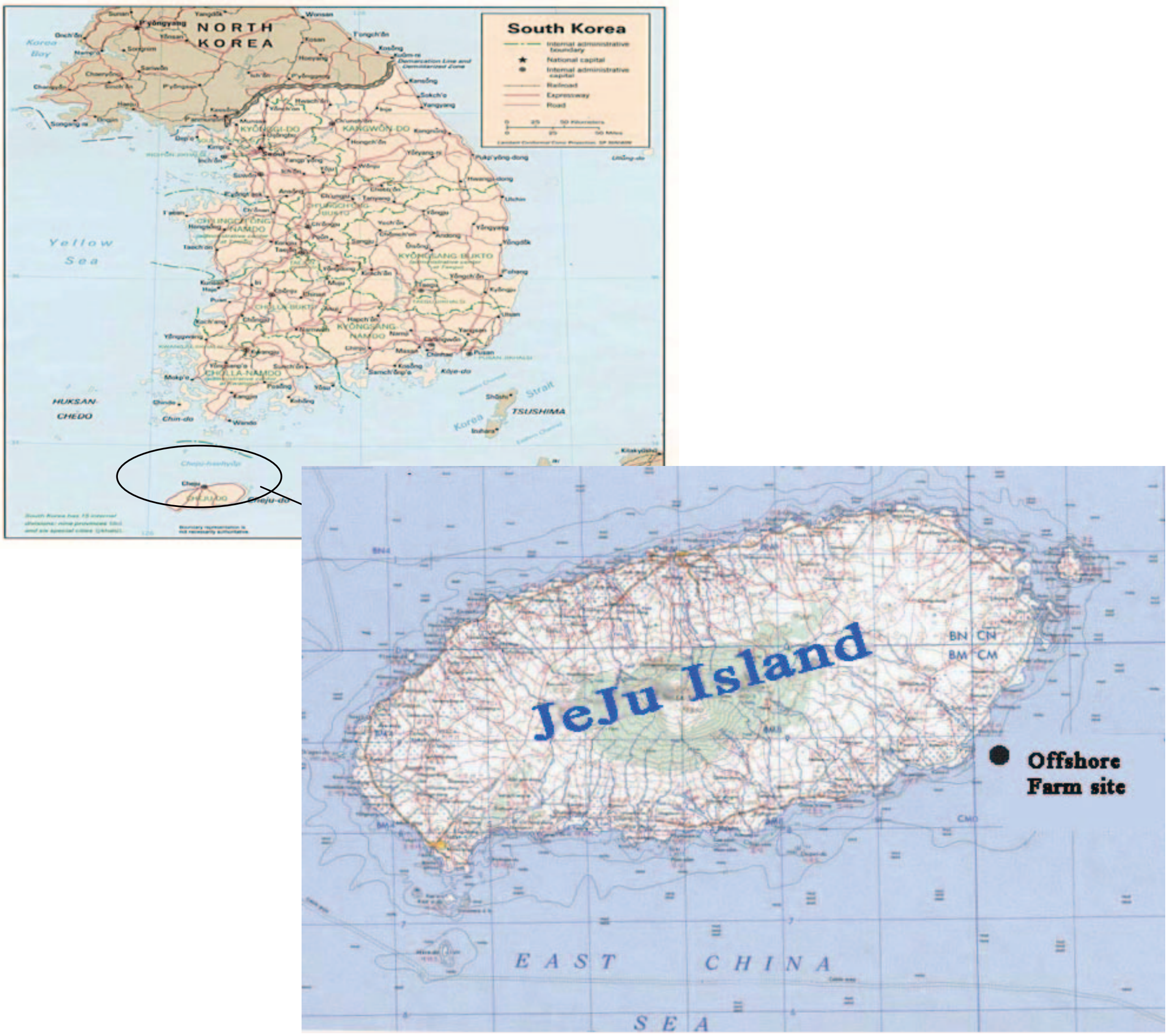

Fig. 1. Map of Jeju Island in South Korea and sight of offshore aquaculture facilities.

Table 2. Production parameters for offshore rock bream culture.

PARAMETER	MEAN VALUE	DISTRIBUTION
Time to market	12 months	Not Applicable
Initial stocking	677,467 fingerlings	Not Applicable
Survival Rate	97%	Triangular (min=90%; max=100%)
Feed Conversion Ratio	1.3	Normal (s.d.=0.2)[3]
Average Market Size	175 g	Normal (s.d.=0.14)

[3] s.d. = standard deviation

However, since these potential natural disasters and disease outbreaks may eventually occur in future offshore farming production, we will focus some attention to a sensitivity analysis on the rate of survival. The FCR is also significantly lower than in other types of cage systems (for example, the FCR averaged at 3.5 in the land-based cage system for flatfish), giving the offshore cage system a decided advantage in this important cost category.

A total of nine full-time employees (including three owners) were hired to run the three cage offshore production system. Among them, one salaried person is in charge of an office work and the other five people are used as divers. Diver operations include repair and maintenance, feeding, harvesting and stocking. Salary per worker was US$2,200 per month and the total annual labor cost total was US$237,600, which includes US$79,200 that represents the opportunity costs of the three owners' time devoted to the project. Part time labor was used for stocking, harvesting and miscellaneous tasks. A total of 16 part-time employees were hired: one carpenter, five for stocking and harvesting, and ten divers. The total part-time labor costs were US$10,860. For future years, we assumed that labor costs varied with a standard deviation that was 10% of the observed costs from the actual operation.

The initial investment for the operation was US$869,273. The three submersible cages and associated gear (e.g., anchors, buoys, regular fish nets, harvest/stocking bin, spar, and rims etc.) cost a total of US$809,103, 93% of the initial capital outlay. Additional items included US$16,170 for nursery nets (2%), a feed storage warehouse for US$ 4,000 (0.4%), scuba gears at US$20,000 (2.3%); and a truck, US$20,000 (2.3%). All asset costs are annualized using straight-line depreciation. Annual operating expenses include the cost of fingerling, feed, energy, labor (including owners/managers), lease rent, interest, insurance, repair/maintenance, depreciation, and supplies, and are summarized in Table 6. The largest costs contributing to annual operating expenses of US$1,043,056 during full operation are fingerling (26%), feed (22.9%), full-time labor including farm owners opportunity cost (22.8%), and depreciation (10.5%). These costs represent 82% of total annual operating costs. This indicates fingerling and feed have the largest potential for reducing annual operating costs.

Recurring energy costs (US$14,400) consist of fuel for boats and trucks. Lease rent cost of US$41,250 per year includes the full-time lease of a boat and additional lease costs for boats and trucks rented temporarily during the time of stocking fingerlings and harvesting. Interest is incurred from US$150,000 that is borrowed from NFFC with a 2.8% interest rate during the life of 2 years. Due to the short production history of offshore farming, it is difficult to estimate an exact repair/maintenance costs. Thus, the cost of maintenance is a provisional estimate that is charged at US$10,000 per cage (Kam, *et al*., 2003).

Results and Analysis

Baseline Scenario

The baseline model suggests that the production of rock bream offshore farming is profitable over a 10-year time horizon (Table 3). A 10-year cash flow based on an 8% discount rate indicates a positive NPV of US$3,151,402 (ranging from US$2,159,171-US$4,111,452). In addition, the IRR value was high at 18% (ranging from 12%-28%). At this level of performance there is virtually no risk of economic failure; all the iterations remained solvent throughout the time horizon and all had a positive return. The price of rock bream in this scenario is assumed to have a mean on US$12.94/kg and a standard deviation of $2.46 for all ten years.

Market Price Scenarios

Two alternative scenarios of rock bream prices over the ten years were analyzed (Table 4). These scenarios were developed based on prior experience with other Korean farmed species. Scenario one mimics the price path of flatfish and rockfish, which decreased by about 5% per year once farming began. The second scenario reflects what happened to average annual prices for sea bream and other breams with the onset of aquaculture. For breams, prices initially increased

Table 3. Results of the baseline model

Performance Indicator	Min	Mean	Max	Coefficient of Variation
Net Present Value (NPV)	2,159,171	3,151,402	4,111,452	14.51
Internal Rate of Returns (IRR)	0.12	0.18	0.28	19.34
Ending Net Worth	3,238,416	3,938,428	4,685,190	9
Ending Total Debt	0	0	0	0
Leverage Ratio (debt/equity)	0.00	0.00	0.00	0.00
Equity/Asset Ratio	1.00	1.00	1.00	1.00
Average Annual				
Cash Receipts	1,369,010	1,495,614	1,630,364	3
Cash Production Costs	945,043	984,030	1,019,412	1
Net Cash Income	389,469	511,583	632,868	11
Net Income	308,344	430,459	551,744	13

Table 4. Results of different price scenarios on the performance of offshore rock bream culture.

Performance Indicator	Scenario 1		Scenario 2	
	Mean	CV[4]	Mean	CV
Net Present Value (NPV)	1,131,419	35	3,805,201	12
Internal Rate of Return (IRR)	0.01	300	0.24	15
Ending Net Worth	2,099,660	12	4,231,567	7
Annual				
Cash Receipts	1,194,617	3	1,673,018	3
Cash Production Costs	977,103	1	1,021,986	1
Net Cash Income	217,514	19	698,474	8
Net Income	136,389	31	617,349	10

[4] CV = coefficient of variation

by almost 6% annually for the first four years as demand expanded, but prices decreased by 5% as production increased in years six through ten. When Aquasim was run using the first scenario the mean NPV decreased by 62% to US$1,131,419. The IRR decreased from a mean of 18% and a range of 12%-28% to a mean of 1% and a range of 0%-8%. The mean net annual income dropped accordingly from US$430,459 to US$136,389. The effect of changes in market price of Scenario 2 is summarized in Table 4. The mean NPV increased from US$3,151,402 of the baseline model to US$3,805,201 when the price increased by 6% annually for the first 4 years and then decreased by 5% for the later 6 years. The IRR also increased from 18% (12%-28%) in the baseline model to 24% (15%-33%). The mean net annual income rose accordingly from US$430,459 to US$617,349.

Survival Rate Scenarios

The results above are based on the actual performance of the Korean rock bream aquaculture operation, but we feel that the survival rates experienced may represent an overly optimistic scenario. While the results may represent actual survival rates under ideal conditions, it is likely that problems would arise over the ten year time horizon that would result in periodic mortalities at a much greater level than observed. To capture the possibility of occasional larger scale mortalities, we change the minimum survival rate for the triangular distribution of survival from 90% to 25%, but keep the most likely value at 97%. We also run a scenario in which the minimum survival rate in the first year is 25%, but the minimum survival rate increases 5% a year over the ten year time horizon. This scenario is used to simulate the effect of increasing skill and knowledge by the operators which make it less likely for there to be a major mortality as experience is gained. For comparison, we also run a scenario where the most likely survival rate is lowered from 97% to 85%, with a minimum of 70% and a maximum of 97%.

Of the survival rate scenarios run, only the one representing a decrease in the minimum survival rate to 25% over the entire time period significantly lowered the probability of economic success of the enterprise, from 100% in the baseline scenario to 76%. The internal rate of return for the operation drops to only 3% and has a high coefficient of variation of 75% (Table 5). The probability of economic success increases to 97% if the minimum survival is allowed to increase by 5% per year, but the internal rate of return is a modest 8% with a coefficient of variation of 75%.

Combined Price and Survival Scenario

To obtain a more realistic and conservative scenario for rock bream offshore aquaculture in Korea, we combine the two price scenarios with the scenario of a minimum survival rate of 25% that increases 5% per year. The most likely survival rate remains at 97% with a maximum of 100%. Results from the two model runs are given in Table 6. For the declining price scenario,

Table 5. Results of different survival scenarios on the performance rock bream culture.

Min, Mean, Max Survival (%)	25, 97, 100		25(+5%/yr), 97, 100		70, 85, 97	
Performance Indicator	Mean	CV	Mean	CV	Mean	CV
Net Present Value (NPV)	504,669	157	1,235,332	53	1,717,098	23
Internal Rate of Return (IRR)	0.03	157	0.08	75	0.09	45
Ending Net Worth	1,982,738	30	2,648,968	17	2,898,548	10
Annual						
Cash Receipts	1,150,761	9	1,268,728	6	1,311,277	4
Cash Production Costs	946,798	2	958,759	2	963,022	2
Net Cash Income	203,963	46	309,970	22	348,254	13
Net Income	121,860	81	228,847	30	267,130	17

Table 6. Results of combining price scenarios with survival scenario (25+(5%/yr), 97%, 100%)

	Price Scenario 1		Price Scenario 2	
Performance Indicator	Mean	CV	Mean	CV
Net Present Value (NPV)	-533,005	-126	1,828,001	38
Internal Rate of Return (IRR)	0.00	0	0.14	50
Ending Net Worth	982010	49	2,904,044	16
Annual				
Cash Receipts	1,008,643	7	1,314,568	6
Cash Production Costs	958,689	2	757,752	2
Net Cash Income	49,953	127	356,816	20
Net Income	-33,289	-209	275,692	25

the added risk due to a lower minimum survival rate results in only a 22% probability of financial success of the enterprise. The average net present value is negative. The modeled firm has sufficient capital and profitability in the first three or four years to avoid bankruptcy 92% of the time. The situation is much improved for the scenario where initially prices rise and then decline because the price rise offsets the lower survival in the early years. For this scenario, probability of financial success is again near 100% with a 14% IRR. The results are more variable than the price scenario or survival rate scenario alone.

Sensitivity to Feed and Fingerling Costs

Fingerling and feed costs are the first (26%) and second (23%) largest percentages of average annual operating cost expenditures in the baseline model. Because of their importance, we briefly examine sensitivity of the baseline model results to different assumptions about fingerling and feed costs using total production costs and internal rate of return as the primary indicator of farm performance. Kam et al. (2002) discuss the important role of having a ready and appropriately priced source of seed for a successfully aquaculture production industry. If seed is difficult to come by, this will be reflected in higher fingerling costs to the producer. Fingerling costs are varied in 10% increments from -20% of the baseline value to a 50% increase over the baseline. The feed cost range examined is a little narrower, ranging from -20% to a 20% increase over the baseline.

Figures 2 and 3 show the effect of changing fingerling and feed costs on overall production costs and IRR. IRR is slightly more sensitive to assumptions about fingerling costs which is not surprising given that it makes up a slightly higher percentage of the annual operating costs. IRR for a 20% decrease in fingerling costs increases to 21%, and for a decrease of 20% in feed costs, IRR increases to 20%. A price increase of 50% for fingerlings reduces the IRR to 11% and a 20% price increase for feed reduces the IRR to about 16%. For a 20% decrease in fingerling price, it is indicated that the production cost per kilogram of rock bream decreased by US$0.46/kg, from US$9.02/kg of the baseline model to US$8.56/kg. Accordingly, the resultant changes for the 10-year mean IRR yields about 3% more than the baseline model, from 18% to 21%. On the other hand, a fingerling cost increase of 50% corresponds to US$135,493 annual cost increases in production cost. That is, the production cost per kilogram of rock bream increased by 13%, from US$9.02/kg in the baseline model to US$10.21/kg. The resultant changes for the 10-year mean IRR yields about 7% less than the baseline model, from 18% to 11%.

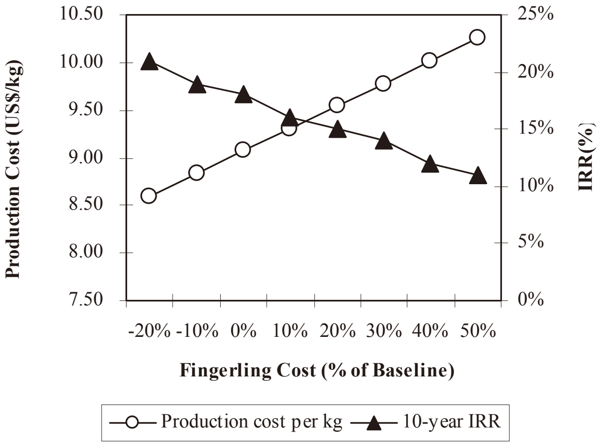

Fig. 2. Results of sensitivity analysis of different fingerling costs.

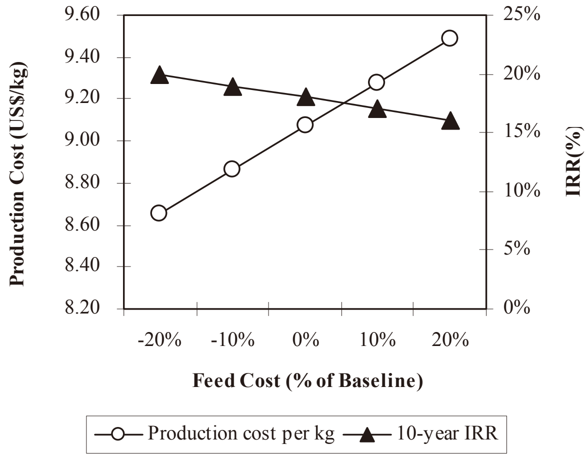

Fig. 3. Results of sensitivity analysis for changing feed costs.

Discussion

Data collected from the Korean offshore aquaculture farm for rock bream suggests that under ideal conditions this enterprise could be low risk and highly profitable. The combination of extremely high survival rates, fast growth to market size, and a high market price are the major factors contributing to the predicted success. However, if the na_ve assumption about constant market prices for the ten year planning horizon is replaced with a more realistic expectation of price declines as the industry expands, growers will face lower returns and higher risk. A better understanding of the market situation in Korea is necessary to evaluate which of the three price scenarios is more likely to occur: the baseline scenario of constant high price; the optimistic scenario of higher prices in the first few years, and then declining prices; or the pessimistic scenario of immediate price declines as the industry grows.

The price decline scenarios that investors choose to believe become more important when more realistic assumptions about fish survival rates in these systems are introduced. The one year experience with this operation off the coast of Jeju Island experiences almost no mortality or loss of fish. This demonstrates that with luck and ideal conditions, these systems perform very well. What is not captured in this single observation is the small chance of a major disaster that would cause a large loss of fish. Nets can be torn and fish escape, storms can cause problems and human error, particular with a new technology can lead to large mortalities. Although these systems are designed to minimize these risks, they still exist, and when something does go wrong, it can have a big impact. We chose to model this by extending the left tail of the triangular distribution of fish survival so that there was a small chance that only 25% of the fish would survive during a production cycle. Even when keeping the most likely survival rate as high as 97%, this introduction of increased risk had a profound effect on the results. Only if compensated for by higher fish prices in the first five years of production, does the performance of the operation remain economically viable. If instead, a scenario of fish prices falling from the baseline level holds, the operation has virtually no chance of being financially successful.

We briefly touched on other factors such as feed and fingerling costs which can affect the financial performance and probability of success of the operations. While they both have similar effects on internal rates of return and net present value, predictions about the time path of these costs will be affected by different factors. Fingerling costs and production will be much more of a local issue. A growing offshore rock bream industry should lead to expansion of fingerling production, economies of scale and cost-saving technological advancement. Some of those cost savings might be offset by increased demand for rock bream seed. Feed costs are much more susceptible to world-wide changes in fish meal and grain markets, and thus, are less dependent on local market conditions..

Our initial results are encouraging that offshore rock bream culture can provide a significant return on investment. However, as was demonstrated, there is no escaping the uncertainties in fish prices and other factors that can impact performance. The excitement that often accompanies any discussion about the potential for offshore aquaculture needs to be tempered by these economic realities. It has potential, but it is far from a sure thing.

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An Economic Evaluation of Various Roles and Functions of Propagation and Aquaculture: A Case Study

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Abstract I performed an economic evaluation of various roles of aquaculture, apart from its primary role in supplying marine products. I defined these secondary roles as provision of food security, environmental improvement, exchange between urban and fishing communities, maintenance of traditional culture, and formation and maintenance of local communities.
In 2005, aquaculture without the use of prepared feeds removed 6,090 metric tons of nitrogen and 595 metric tons of phosphorus from Japan's coastal seas. The economic value of the reduction in pollution was equivalent to 1,298 hundred million yen by the replacement cost method (the cost of sewage treatment for that amount of waste). From the results of a questionnaire-based investigation of the general public, I estimated by the CVM (Contingent Valuation Method) that non-use value of seaweed grounds around Japan was 553 to 2,109 hundred million yen.

Key words: aquaculture, roles and functions, replacement cost method, CVM

Introduction

Various examples of propagation and aquaculture functions from the literature were examined, and economic estimates were made of some of those examples. The aquaculture industry has various functions. Each of them has been explained on the basis of the classification of the work of Tamaki (2004).

Food security

Unlike ordinary fishing, where fish are caught as a natural resource, aquaculture can reliably supply selected fish species with the help of appropriate technology. Some life stages used for stocking, such as those of yellowtail, oyster, or common scallop, may have to be taken from natural resources, but others, such as red sea bream, shrimp, or laver, can be artificially produced. Even when culturing natural larvae and fry, taking special care of life stages at which the organisms have a high natural mortality rate can reduce the death ratio and minimize loss of resources.

In addition, aquaculture produces the types of products that are particularly in demand. In fact, certain species are characterized by high production ratios, such as 100% for laver, oysters, pearls and common scallops (including fisheries catch by propagation) ; 94% for Undaria, 85% for red sea bream, 69% for yellowtail, 64% for shrimp(*Penaeus japonicas*), 47% for flatfish(*Paralichthys olivaceus*), 39% for globefish, and 34% for Laminaria. In freshwater culture, the values are 97% for eel, 88% for landlocked trout, 68% for carp, and 50% for sweetfish (*Plecoglossus altivelis*).

There are many fish species that would disappear from the market or be in very short supply if it were not for aquaculture (Figure 1). Given these circumstances, it is logical to conclude that aquaculture plays a major role in food security.

Environmental Improvement (Table 1)

Cultured seaweeds convert carbon dioxide in the seawater into oxygen through photosynthesis. They also prevent eutrophication of the

2009年8月10日受理（Received. August 10. 2009）
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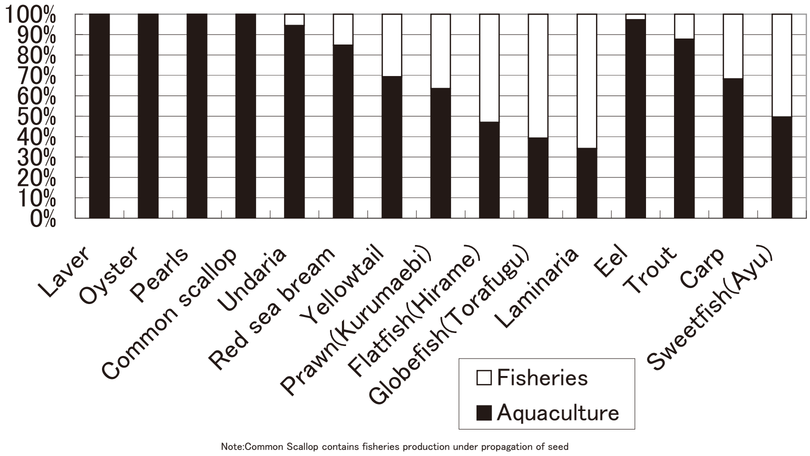

Fig. 1. Production Relation of Japanese Aquaculture in 2004.

Table1. Environmental improvements by aquaculture

Aquaculture species	Example
Seaweeds	Convert carbon dioxide in the seawater into oxygen Immobilizing nitrogen and phosphorus Provide shelter to young creatures
Bivalves and sea squirts	Filter sea water and reduce organics in the water
Silver carp and white crucian carp	Filter water and reduce organics in the water
Aquaculture facilities (rafts and net pens)	Provide shelter for natural fish Stop the fisheries operation of natural resources and provide nursary ground

Source:Tamaki(2004)

seawater by immobilizing dissolved nitrogen and phosphorus. On cultured seaweed grounds, unlike natural seaweed grounds, we can recover most of the immobilized nitrogen and phosphorus before the elements are eluted into the water.

Seaweed also provides shelter for young fish and the larvae of many other creatures, contributing to biodiversity.

In addition to the benefits obtained from seaweeds themselves, there are cases where the bamboo poles used in aquaculture for attachment of laver can serve as substrates for the larvae of short-necked clams, promoting favorable growth of shellfish. In waters where aquaculture facilities are set up, rafts and net pens can also provide shelter for wild fish. It is impossible to carry out seine fishing or trawl netting in the areas with rafts or net pens, thus promoting the preservation of marine resources.

When filter-feeding marine species, such as bivalves and sea squirts are cultured, they filter seawater and simultaneously reduce the level of organic compounds in the water. Silver carp and white crucian carp produced in freshwater culture feed on phytoplankton and do not need to be provided with prepared feed, thereby reducing the pollution load on lakes. One kilogram of silver carp filter a cubic meter of water and eat 20 grams of phytoplankton daily (Ibaraki Prefecture, 1996).

Providing Recreational Opportunities, Exchanges and Learning

Aquaculture promotes exchange between urban and fishing communities. For instance, a fisheries cooperative in Kagawa Prefecture has a cultured oyster ownership system in which consumers buy oyster spat. Later, they are entitled to experience the harvesting of the harvestable oysters or have the oysters delivered directly to them. In this system, an aquaculture rope with some 70 oysters attached is sold at 2,200 yen. Orders for some 1000 ropes are received annually. They even come from outside the prefecture, such as from Okayama or Tokyo. This cooperative has also discovered that many consumers prefer to come to get the oysters themselves rather than having them delivered. Another fisheries cooperative is advertising for purchasers of oyster culture ropes, at 2,500 yen each, but only accept orders from consumers within the same prefecture. In 2000, they received some 500 orders.

In Kagawa Prefecture, some culturists, including the said cooperative, have their own small restaurants that serve grilled oysters during the winter. A different cooperative offers "all the oysters you can eat" at 2,500 yen per person and, in 1999, achieved sales of 10 million yen. In Kanagawa Prefecture, a "hands-on experience" program that offers a course in *Undaria* culture was provided for 100 groups at a fee of 3,000 yen per group. Visitors took part in seeding of *Undaria* and studied the details of seaweed aquaculture and its environmental advantages, including how it purifies water. In November, they learned how to culture seaweed and in February experienced harvesting of the seaweed, took classes on the nutrients in *Undaria*, and learned how to use it in cooking.

There are also exchange promotion programs in which elementary and junior high school students visit a fishing village as one of their school excursion destinations and take part in various events alongside the people of the village to gain a closer and more personal understanding of how they live. Since the culture grounds are close to the port and located in calmer waters than in the case of offshore fishing, programs that feature actual experiences with aquaculture are very popular with city people and are seen as safe and accessible opportunities. It is a valuable experience for young people to actually feed cultured fish and see how shellfish species and seaweeds are cultured. They can actually see for themselves what the sea has to give them.

Another example is fishing ponds using the sea surface in Mie and Hyogo Prefectures, or fresh water in other prefectures. Fishing ponds are very popular among experienced anglers, not to mention beginners and children who tend to be seasick in open waters, because they can experience fishing in a safe and unthreatening environment. Many of the fish caught from the ponds are cultured species. Aquaculturists facilitate exchanges between cities and fishing villages by stocking fishing ponds and opening them to the public. Aquaculturists can also obtain a profit by selling fish for stocking the ponds.

Oyster culture rafts are ideal nests for black sea bream, a popular fish with anglers, for their shade and the plants and animals that cling to them. In Ishikawa Prefecture, oyster rafts are provided by some culturists for sport fishing.

A fishermen's cooperative in the Oki Islands, Shimane Pref., who know that large wild fish are attracted to their fish culture grounds, take anglers aboard recreational fishing boats to the waters near their aquaculture grounds. These anglers pay 10,000 yen per person for this experience and are allowed to take home up to three red sea bream. The cooperative had some 250 customers in five months in 2002.

Freshwater culturists often release cultured fish for sport fishing. According to the census, the total number of sport fishers in freshwater in 2003 was 7,770,000 (excluding those for bass). Thus, aquaculture plays numerous roles, including exchange between urban and fishing communities and provision of recreational opportunities to urban dwellers (Table 2).

Maintenance of Traditions (Table 3)

I have already pointed out as one of the features of aquaculture that it provides types of fish that would run short if we relied exclusively on natural resources. Providing these fish also helps keep alive Japanese culinary traditions. For example, it is a custom to enjoy eel on certain days in summer. Without aquaculture, however, the lack of eels would lead to this custom's disappearance. Red sea bream is very popular to the Japanese style wedding reception. Laver, indispensable for rice balls and sushi, is 100% supplied by aquaculture.

Table 2. Providing recreational opportunities, exchanges and learning

Area	Example
Kagawa Prefecture	Cultured oyster ownership system
Kagawa Prefecture	Small restaurants that serve grilled cultured oyster
Kanagawa Prefecture	Experience of brown seaweed(*Undalia*) aquaculture
Mie Prefecture and Hyougo Prefecture	Provide cultured fishes to "fish ponds"
Ishikawa Prefecture	Oyster culture rafts are provided for sport fishing
Shimane Prefecture	Takes anglers aboard recreational fishing boats to the water near their aquaculture grounds
Freshwater	Fishermen' s cooperative release cultured seeds for sport fishing
Fishing village	School excursion

Revised Tamaki(2004)

Table 3. Maintenance of traditions

Culture	Example
Maintain Japanese culinary traditions	Enjoy eel on specific days in summer Laver for Rice ball(Onigiri) and Rice roll(Norimaki) Sushi
Japanese garden	Fancy carp
Local festivals	Goldfish scooping

Revised Tamaki(2004)

Yellowtail, red sea bream, and common scallop are also essential ingredients for sushi and are supplied by aquaculture. Fancy carp (nishiki-goi) are an invaluable part of many Japanese gardens. Without aquaculture, "goldfish scooping," an essential and entertaining part of local festivals and a traditional festive pastime for children, would disappear. These aquarium fish species are also the products of aquaculture.

Formation and Maintenance of Local Communities

Aquaculture needs calm waters and clear freshwater and is thus often conducted in places far from major cities. The economy of many such places relies entirely on fisheries and related industries. Aquaculture helps dilute the otherwise concentrated populations in cities and settle people in remote areas by providing economic security. At the same time, it plays other associated roles, such as monitoring of national borders, preservation of national land and protection of the landscape.

Economic Evaluation of Various Functions

Economic evaluation of the removal of nitrogen and phosphorus by aquaculture without artificial feeding

When shellfish and seaweed are cultured, no artificial feeding is provided, but nutrient salts, such as nitrogen and phosphorus, are absorbed from the sea. Harvesting of cultured fish involves the harvesting of nitrogen and phosphorus from seawater. Their quantities may be estimated based on the production of major aquaculture products and their food composition table. According to this estimation, 6,090 tons of nitrogen and 595 tons of phosphorus were recovered from culture without artificial feeding in 2005.

The unit cost of recovering nitrogen and phosphorus, based on the Tokyo Metropolitan Sewerage Works Annual Report 2004, was calculated using the method adopted by Suidosha Co., Ltd. (2003) and the recovery cost of nitrogen and phosphorus was calculated using a replacement cost method. The results showed that the nitrogen recovery cost is ¥129.8 billion and the phosphorus recovery cost is ¥87.7 billion.

Table 4. The amount of removed nitrogen and phosphorus and estimated cost of sewage treatment of this amount of waste.

	Amount of production(2005)(100t)		Amount of nitrogen(t)	Amount of phosphorus (t)	cost of sewage treatment of this amount of nitrogen (million yen)	cost of sewage treatment of this amount of phosphorus (million yen)
Common scalop	4,907	(with shell)	5,299.6	515.2	112,958	75,985
Oyster	340	(without shell)	359.0	34.0	7,653	5,014
Other bivalves	20	(with shell)	21.6	2.1	460	310
Sea squirt	90	(with shell)	72.0	5.0	1,535	730
Laver	3,871	(wet weight)	134.4	14.7	2,864	2,169
Laminaria	450	(wet weight)	3.3	0.6	71	94
Undaria	637	(wet weight)	193.6	22.9	4,128	3,382
Nemacystus	130	(wet weight)	6.2	0.3	133	38
Total	10,445		6,089.8	594.8	129,802	87,722

Note : The content of nitrogen and phosphorus from Food composition Database Japan
The content of Other bivalves used Common scarop
The content of shell and internal organ of sea squirt used edible part
Wet seaweeds contain 90% of water
The content of *Laminaria* used 7 species average
The cost of seawage treatment used Suidosya(2003) and "Annual report of sewage of Tokyo in 2004"

Table 5. Methods of transplanting seeds

Methods		Breed of seaweed	References
Mother seaweed planting	Direct fixation	*Laminariales, Sargasso*	Nakazima(2003)
	Net fixation	*Sargasso*	Yoshikawa(1985･1986･1997)
	Laver net fixed in middle layer	*Sargasso*	Kagoshima Pref.Fis.Exp.Sta.(2006)
	Spore bags	*Laminariales, Sargasso, Gelidales*	Oshima Branch, Tokyo Fis.Exp.Sta(2004)、Tanaka(2002)、Nakabayashi & Akiyama(2004)、Chuyo Branch, Ehime Pref. Fis. Exp. Sta(2000)、Oita Fis. Exp. Sta.(2006)
	Rope fixation	*Laminariales*	Kikuchi(1976･1978)、Sawada et al(1981)
Seedling plantation	Seeding yarn	*Laminariales, Sargasso*	Nakashima(2003)、Nakahisa(1981)、Toyama(1981)
	Seeding block	*Laminariales, Sargasso*	Nakashima(2003)、Toyama(1981)
	Seeding net	*Sargasso*	Toyama(1981)

Since nitrogen and phosphorus are simultaneously recovered in sewage treatment, the higher cost of ¥129.8 billion may be used as the recovery cost of nitrogen and phosphorus by aquaculture without artificial feeding (Table 4).

Economic evaluation of the functions of seaweed beds

Substrates for seaweed beds are sometimes constructed as part of public works in Japan. The Fisheries Agency creates seaweed beds with the direct aim of harvesting the grown seaweed and the indirect aim of increasing fish resources by offering cultured seaweed as food or as spawning grounds and rearing places for young fish. The agency also transplants seaweeds to restore dying beds and preventing rocky-shore denudation. The Ministry of Land, Infrastructure and Transport conducts public works, including the development of seaweed beds to compensate for beds lost due to industrial development or reclamation.

There are various methods of transplanting seaweeds, as shown in Table 5. When seaweeds are transplanted to denuded rocky shores, animals feed on them, preventing the establishment of young plants. For this reason, transplantation is often accompanied by the removal of sea urchins.

Mother seaweed plantings are particularly effective with Laminariales seaweeds, which generate large numbers of planospores. For *Undaria*, one gram of sporophylls releases 1 million to 10 million planospores; however, *Sargasso* has smaller numbers of productive cells to be discharged, and the discharge distance is short. Planting of *Sargasso* is therefore reportedly not as effective as of Laminariales (Tanaka, 2002). However, Nakabayashi and Akiyama (2004) report successful cases for *Sargasso*, in which the supply of 5 kg of mother seaweed, coupled with the removal of sea urchins, successfully restored a Sargassum horneri marine forest 6 m in diameter (about 28 m^2) centered on the installation spot of spore bags. At the Ehime Chuyo Fisheries Experimental Station (2000), they put *Hizikia fusiformis* in spore bags, placed them in the water, and successfully settled *Hizikia fusiformis* in the area within 1 to 1.5 m from the spore bags.

Questionnaire survey

Seaweed beds are known to have a range of functions. A questionnaire survey was conducted to find how the general public, other than those engaged in fisheries, value the seabed. The survey was conducted with people aged 20 or over who were visitors to the National Research Institute of Fisheries Science on October 22, 2005 and also to people with Internet accounts aged 20 or over on November 15 and 16, 2005. Out of 755 visitors on October 22 (including those aged 20 and over, who accounted for 66%), 292 answered the questionnaire. For the Internet questionnaire, a service contractor sent the questionnaire to a total of 3,000 people, who were selected at random from about 220,000 registrants (three times a total of 1,000 selected by gender and area), and received 1,367 valid responses, excluding abnormal answers. One thousand responses selected at random were then sent back to the author.

In one of the two questions on seaweed beds, the respondent was asked to select three functions that he or she regarded as most important. The other question was on how much they would personally be prepared to donate to a maintenance fund for seaweed beds to evaluate their value using the Contingent Valuation Method (CVM).

Concerning awareness of the seaweed bed functions, similar results were generated by both the visitor questionnaire and the Internet questionnaire. The top choice was *food for fish and shellfish and a nursing ground for the young fish*, followed by *maintenance of biodiversity, fixation of carbon dioxide, scenery with rich seaweed growth, absorption of nutrient salts*, and *place for biological observations*. Each alternative had only a single-digit rate for being selected for the top (Table 6).

CVM is often used in Japan to assess the value of public goods for which no market actually exists. In the questionnaire, to calculate the value of an imaginary market, the question was asked about how much the respondent would be willing to pay into an imaginary fund, or WTP (willingness to pay). To apply CVM, estimation was made based on the assumption that a person who selected a certain amount to donate would also be willing to pay any amount less than that. The amount was estimated by means of the least squares method using a semilogarithm of the acceptance rate = a + blog (amount of donation, Table 7). The amount obtained from the simple average of the answers and the amount calculated as the median of the equation estimated from the least squares method were extended to the Japanese population aged 20 or older. As a result, the maintenance cost of seaweed beds was evaluated as between ¥55.3 billion and 210.9 billion (Table 8). That amount may be regarded as the evaluated "non-utility value" held by the general public for maintaining a variety of ecosystems by maintaining seaweed beds. The value may represent the view of the general public about the "non-utility value" of the

Table 6. Awareness of seaweed bed functions

	Visitors to the NRIFS open day				Internet			
	First	Second	Third	Total	First	Second	Third	Total
Food for fish and shellfish and a nursing ground for the young fish	44%	20%	13%	77%	38%	28%	17%	83%
Maintenance of biodiversity	34%	20%	14%	68%	33%	32%	19%	84%
Fixation of carbon dioxide	20%	12%	14%	45%	21%	21%	29%	70%
Scenery with rich seaweed growth	7%	6%	10%	22%	3%	4%	8%	16%
Absorption of nutrient salts	6%	9%	11%	26%	3%	10%	16%	29%
Place for biological observations	6%	4%	10%	20%	2%	4%	7%	14%

preservation of diverse ecosystems achieved by the maintenance of seaweed beds. "Non-utility value" here includes "the value of simply being there," which makes people feel privileged by just knowing there are a variety of ecosystems and the "value of endowment" in which people may not obtain any direct benefits but can leave a variety of ecosystems to future generations. Two biases are assumed: the sample bias and strategic bias.

The Science Council of Japan said in 2004 that for various functions of fisheries and fishing communities, if investigations are conducted on many such functions, particularly using CVM, the research on them will reveal the importance of their economic value, which will then feed through to government policy. In that sense, evaluation based on CVM is in line with the policy of the Science Council of Japan.

The Internet questionnaire also asked about any marine or seashore recreation that the respondents had engaged in from 2000 to 2005, or wanted to do in 2006, and the questionnaire result data were used to estimate the pricing functions for the seaweed bed fund. Consequently, responses such as *want to clean up the beach next year*, Cleaned *up the beach, did beach seine fishing, want scuba diving next year, went bird watching at the beach*, and *age* were found to be significant as parameters. Only the value for *cleaned up the beach* was negative. The reasons for this may be that they carried out a cleaning activity, so they thought that they did not want to pay into the fund, or their experience of beach cleaning, in which enormous amounts of seaweed had washed ashore, had made them think it unnecessary to donate anything to the fund (Table 9).

Comparing the amount of donations to the fund, visitor respondents gave amounts that were 50 to 70% higher than the average amount suggested by Internet respondents. This indicates the high awareness on the part of visitors of the importance of seaweed beds or the successful results of education by means of posters or pamphlets.

Table 7. Estimated with semilogarithm formula
(Acceptance rate =a+b log(amount of donation)

	Parameter	Estimate	Standard Error	t-statist	P-value
Internet	a(constant)	1.316	0.089	14.848	[.000]
	b(Amount of donation)	-0.130	0.013	-10.118	[.000]
NRIFS open day	a(constant)	1.813	0.183	9.930	[.000]
	b(Amount of donation)	-0.192	0.026	-7.262	[.000]

Table 8-1.
Results of the questionnaire survey about "Maintenance fund for seaweed beds" (yen)

	Internet	NRIFS open day
Average	1,334	2,055
Median	539	946

Table 8-2.
Extended to the Japanese population aged 20 or older (billion yen)

	Internet	NRIFS open day
Average	136.9	210.9
Median	55.3	97.1

Note : 102,636,961 (2005/3/31)

Table 9. Estimate the pricing functions for the seaweed bed fund

Parameter	Estimate	Standard Error	t-statistic	P-value
constant	4.029	0.588	6.847	0.000
want to clean up the beach next year	0.592	0.169	3.505	0.000
cleaned up the beach	-0.404	0.241	-1.679	0.093
did beach seine fishing	0.724	0.241	3.007	0.003
want scuba diving next year	0.290	0.134	2.170	0.030
went birdwatching at the beach	0.391	0.281	1.389	0.165
age	0.654	0.163	4.004	0.000

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Risk and Risk Management for Feed and Seed for Marine Fish Raised in Off-shore Aquaculture

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For open ocean aquaculture of marine fish, the provision of feed and seed occurs externally to the actual fish culture operation. How such external activities are conducted and applied determines the potential ecological impact for the industry as a whole. Ecological risks associated with marine aquaculture may be addressed using a framework similar to that used for assessment of risks in other areas of our lives. The use of a framework developed for the World Health Organization (WHO) for assessment of risk to human health from various threats has been proposed for assessment of risk to the environment from marine aquaculture (Nash et al. 2005). The identification and characterization of risk are the first steps in determining what risk management strategies might be the most productive in developing supplies of feed and seed for offshore aquaculture that are low risk and will be stable and dependable over the long run. For each risk, the WHO risk assessment framework may be applied to focus research and development on strategies that could be used to reduce or eliminate risk. In most cases, multiple options exist for risk reduction, however I suggest that risk management strategies that improve economic gain and reduce or eliminate multiple ecological risks, are preferred and have a much higher chance of resulting in meaningful improvements. Furthermore, strategies which allow improvement, or change over the long term, provide more flexible and ultimately sustainable solutions. In most cases, research is needed to develop better risk management strategies. Up-front costs associated with research, development and implementation often limit application of risk management strategies to industries large enough to afford such costs even if there are long-term economic benefits associated. This is especially true when governments do not fund such research and development.

Potential up-stream ecological impacts associated with feed and seed from culture of marine fish include over-fishing due to demand for wild juveniles for grow-out, and harvesting industrial fisheries for feeds (Nash et al. 2005). Stated as a simple equation, risk of over-fishing (R) is a function of fisheries management (M) with the effectiveness of management subject to demand [$R = f(M)$]. On some low scale of harvest (low demand), fisheries management has been shown to be effective, however management can only produce some fraction of what exists naturally, and wild fisheries are not able to increase production beyond naturally set limits. At harvest levels higher than a stock can recover from, over-fishing occurs. When there is a high demand, fisheries management becomes increasingly difficult so alternatives need to be found that reduce or eliminate demand for both wild feed and wild seed. Management to reduce the risk of over-fishing due to feed includes the development of alternative protein and lipid sources (especially long chain n-3 fatty acids) and for seed, the development of hatcheries. In both cases, complete replacement leads to elimination of the risk due to activities associated with offshore aquaculture and partial replacement leads to demand reduction potentially to sustainable levels at least until the industry grows again. In addition, hatcheries and alternative feedstuffs can provide economic benefits (in the way of lower prices and better quality) and thus have a greater potential for adoption by industry once a critical size of an industry is reached.

Potential downstream ecological risks associated with feed include organic loading and benthic

2009年8月10日受理（Received. August 10. 2009）
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impacts. In this case risk (R) is a function of the quality and quantity of feed used (F), the organism under culture (O) and management (M) within the context of the specific site chosen for offshore aquaculture [R = f(F x O x M)]. Activities which improve 1) the efficiency of the diet (for example moving from wet fish to pelleted feeds, defining nutrient requirements, improved pelleting technologies, better feed formulation, feedstuffs processing and so on), 2) the efficiency of the organism (species choice, selective breeding, improved husbandry, and so on) and/or 3) the management systems (optimal feeding regimes, improved fish health management, protection from predators and diseases, better husbandry, improved systems engineering, and so on), will reduce environmental risks. In most cases, these efforts will also improve economic return once a critical level of production is reached by the industry.

Downstream risks associated with seed are associated with the potential ecological and genetic impacts of escapes on conspecific wild stocks if the cultured fish is native or ecological impacts on native species if the escapees are non-native. For the sake of this paper I will only deal with the first risk. Risk (R) associated with the escape of a native species is a function of the number of escapes relative to the number of wild conspecifics (Pe/Pw), the differences in genetic structure between the wild and escaped organisms (ΔG) and the fitness (Fe) of the escapees to reproduce in the wild [R=f(Pe/Pw)(ΔG) (Fe)]. Risk associated with escapes can be managed at the hatchery by several strategies. For example, either raising fish with the same genetic make-up as wild stocks where ΔG = 0, or by domestication of the farmed species which reduces escapees' fitness (Fe) in the wild. In this case, economic gains would favor domestication and not maintaining a wild stock genotype. Risk can also be reduced by raising sterile fish (where Fe = 0) which may or may not be economically beneficial, or by maintaining a low number of escapes (for example by better engineering or management practices) relative to the size of the wild population. Note that the converse is also a possible strategy, risk can be reduced by maintaining wild stocks at high levels relative to the number of escapes. This may be addressed by industry by raising a portion of the species they produce under stock enhancement protocols for release (likely to have negative economic implications). An approach that combines several of these strategies may be the most effective.

Risks can be interactive and need to be viewed as a set for a given activity to guide management and research. Often new risks can be created when a different risk is solved, or the choice of a risk management strategy that reduces or eliminates one risk may or may not also reduce or eliminate another risk. For example, the development of a hatchery to reduce the risk of over-fishing to provide seed, potentially creates the genetic risk of escaped fish on their wild conspecifics. If wild fish were used, then ΔG = 0 and the genetic risk from escapees would not exist. This has led some to call for only using local fish as broodstock for hatcheries producing seed for offshore aquaculture and actively maintaining a wild-like genetic make-up in the hatchery. However to do this would forgo the positive ecological risk reduction that selective breeding can produce in terms of seed that uses feed resources more efficiently, that makes better use of alternative feedstuffs, has better disease resistance and so on. Maintaining a wild genotype for fish used in offshore aquaculture would also forgo economic gains and puts environmental and economic goals at odds, reducing the chance for adoption and meaningful environmental risk reduction.

Governments can create win-win situations by fostering research and development where ecological risk management and economic gains are in line and both considered. In the case of feed and seed, this would include development of high quality compound feeds from alternative feedstuffs, and hatcheries with associated selective breeding programs for new and existing marine fish industries. Governments can hasten and improve the potential for the adoption of preferred risk management strategies by first identifying those strategies that provide the best overall options and then by funding the up-front research and development costs to put those practices in place.

References

Nash, C. E., P. R. Burbridge, J. K. Volkman. (eds.) 2005. Guidelines for ecological risk assessment of marine fish aquaculture. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-71, 90 p

Ecological Risk Assessment of Marine Fish Aquaculture

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The following is taken in its entirety from NOAA Technical Memorandum NMFS-NWFSC-71, entitled: "Guidelines for Ecological Risk Assessment of Marine Fish Aquaculture", edited by Colin E. Nash, Peter R. Burbridge, and John K. Volkman. It was prepared from technical contributions by the editors and Kenneth M. Brooks, Stefano Cataudella, Brett R. Dumbauld, William T. Fairgrieve, John R. M. Forster, Robert N. Iwamoto, David F. Jackson, Sadasivam J. Kaushik, Michael B. Rust, Philip A. D. Secretan, Karl D. Shearer, Ole J. Torrissen, and Masashi Yokota, at the NOAA Fisheries Service Manchester Research Station International Workshop, 11-14 April 2005. The technical memorandum is available online (http://www.nwfsc.noaa.gov).

Introduction

The Environment and the Intervention of Marine Aquaculture

Few, if any, human interventions in the environment fail to have impact. In some cases interventions are potentially so damaging that they must be eliminated. On the other hand, the majority of human interventions are purposeful and designed to be of benefit to humans, so it is necessary that they proceed responsibly, sharing equitably in the use of nature's vital resources. It is thus important that these interventions are carefully managed with good stewardship to ensure that benefits can be achieved over time frames of many decades.

Aquaculture, together with fisheries and agriculture, has long been a provider of food for human consumption. For over three millennia it has been a necessary and often the only source of animal protein for pastoral communities living at subsistence levels. But within the last century its history has dramatically changed, and science and technology have propelled modern aquaculture into semi-intensive and intensive farming systems. These systems have greatly increased its degree of exposure to the environment. Consequently, although aquaculture remains a crucial cornerstone of rural life in many countries, its modern practices and array of commercial end-products are, to the rest of the world, dependent more on human life style decisions governed by social choice.

Fortunately, an important factor in social choice as aquaculture emerges in the twenty-first century is not only to minimize the impact of all human interventions on the environment but also to sustain the existing integrity of its many ecosystems in perpetuity. This has become a challenge to all resource-based industries, not only marine aquaculture. There are innumerable aquatic ecosystems in which aquaculture intervention is feasible. Each and every ecosystem has its own very specific and desired values, and therefore for the stewards of these resources to set specific goals around these values it is necessary for them to know in advance 1) what integrity means for each ecosystem and what specifically needs to be protected; and 2) which ecological resources and processes have to be sustained and for what reason. Compared with that of terrestrial ecosystems, comprehensive knowledge of aquatic ecosystems is severely constrained. Partly this is because much of the ecosystem lies below water and is thus not readily observable, but also the need for extensive

2009年8月10日受理（Received. August 10. 2009）
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environmental research of marine ecosystems is only now becoming recognized in many countries.

Many aquatic and terrestrial ecosystems can be said to be equally fragile, but the factors differ as do the mechanisms available for remediation. Most human interventions in aquatic ecosystems, such as mineral extraction, fishing, and now aquaculture, may induce more lasting far-field effects unless properly managed. Nonetheless, these and any other industries that integrate with open waters, such as tourism and recreational boating, all have a right to exist equitably as stakeholders; the effects on the aquatic ecosystem by one should not eliminate the existence of another.

In enabling aquaculture to share aquatic resources responsibly, the stewards of these resources are faced with many options. Invariably these options cannot be quantified adequately, and thus managers must estimate their potential ecological risks through individual risk assessments. Nonetheless, although ecological risks are a paramount concern, the final decision is frequently decided by other factors brought to bear by social choice, such as economic benefits to a local community, or issues of public health.

Using the Guidelines Document

Before any decisions can be made with regard to the siting or operation of a marine aquaculture facility, the first responsibility of risk managers, and that includes both managers of resources as well as managers of aquaculture operations, is to draw their conclusions from all information provided by the risk assessors that a perceived risk to a particular ecosystem has validity or not, and if so to estimate its degree of adverse effect. This may or may not be a straightforward task. In some cases the information reported to them by the risk assessors may be an excellent combination of field and laboratory data to compare with recognized benchmarks of stress, while in others it may be no more than the long-time experience of practitioners.

Irrespective of the final detail, it is important that the information is considered, collected, analyzed, characterized, and reported in a structured fashion. This ensures that the risk assessment report is not only complete as far as it can be (Table 1), but also that it can be compared directly with similar risk assessments made by other individuals elsewhere.

These guidelines for the risk assessment of marine fish aquaculture attempt to facilitate the

Table 1. Possible contents of a risk assessment report.

- Description of the preliminary objectives and plans
- Description of the environmental setting for the planned development
- Description of the proposed aquaculture practice and species to be cultured
- Review of the conceptual model and the assessment end points
- Discussion of the major data sources and analytical procedures used
- Review of the stressor response and exposure profiles
- Description of the risk to the assessment end points, including risk estimates and adversity evaluations
- Review and summary of major areas of uncertainty, and their direction, and approaches used to address them, such as:
  - Discussion of the degree of scientific consensus in key areas of uncertainty
  - Identification of major gaps and, where appropriate, indicate whether gathering additional data would add significantly to the overall confidence in the assessment results
  - Estimation of the risk probability by combining numerical data
  - Discussion of science policy judgments or default assumptions used to bridge information gaps and the basis for the assumptions
  - Discussion of how elements of quantitative uncertainty analysis are embedded in the estimate of risk

work of risk assessors and risk managers to achieve these objectives. In brief, the guidelines:

- identify the 10 areas of substantive risk in the interaction between marine fish aquaculture operations and the environment;
- identify the biological end points or entities and their attributes, both locally and far field, that might be affected in those areas of risk;
- identify methodologies for measuring or monitoring the effects of exposure to each area of risk;
- provide a common framework, or step-by-step process, to estimate the degree of potential adversity of each area of risk, together with its mitigation; and
- provide a concept of the physical and environmental demands of marine fish aquaculture sites, and a matrix to suggest different orders of relevance for the application of each area of risk in different global ecosystems.

In planning a risk assessment, it is recommended that the risk managers and risk assessors, together with others with experience in marine fish aquaculture, first review the areas of risk identified as priorities in the guidelines, and establish their relevance in their own geographic region and to the particular local ecosystem where marine aquaculture facilities are to be sited. It is very probable that not all areas of risk will be applicable to every development site, and therefore a matrix has been developed as part of the guidelines to suggest some of the more common differences (see "Near-field and Far-field Effects"). For those that are important, the respective templates (as described in Appendices A-J of the full document) can be used.

Ecological Risk Assessment of Marine Fish Aquaculture

Framework

For more than 20 years, countries have been developing national guidelines for environmental risk assessment. At first their focus was predominantly on environmental risks to a single species (humans) and one end point (human health), but later nonhuman-oriented environmental risk assessments were included. These not only considered the risk to entire communities and addressed any number of selected end points, but they also included the possible effects of nonchemical stressors.

In order to accommodate the sudden burst of different views and approaches to environmental risk assessment by its member countries, the United Nations (UN) World Health Organization (WHO) developed a common analytical framework. The WHO Framework is adopted here for developing Guidelines for Ecological Risk Assessment of Marine Fish Aquaculture (this technical memorandum) because it provides a generic analytical framework that has been widely reviewed and accepted by international experts in UN-sponsored workshops.

The WHO Framework (Figure 1) represents the scope of the guidelines for undertaking ecological risk assessments. It represents a three-dimensional figure, with planes surrounding the actual risk assessment to depict the total process. These planes represent the continuum for all those who are involved in the decision-making process, and includes not only the interactions between risk managers and risk assessors (the scientific and technical experts), but also their interaction with stakeholders who may be affected by any decision. For marine aquaculture, participating stakeholders are typically the fish farmers and their trade associations, waterfront property owners, recreational users of waters, other fishing and aquaculture bodies, and environmental advocacy groups. The extent of stakeholder interaction, and at what point it is considered in the decision-making process, is the prerogative of the decision-maker, and varies from one country to another in accordance to the regulatory, legal, and decision-making climate. Furthermore, stakeholders might perform their own risk assessments with or without the help of technical consultants, with differences arguable in court.

The risk assessment process is itself divided into three segments. These segments represent three distinct phases of work, but once again there is a continuum of interplay between the persons

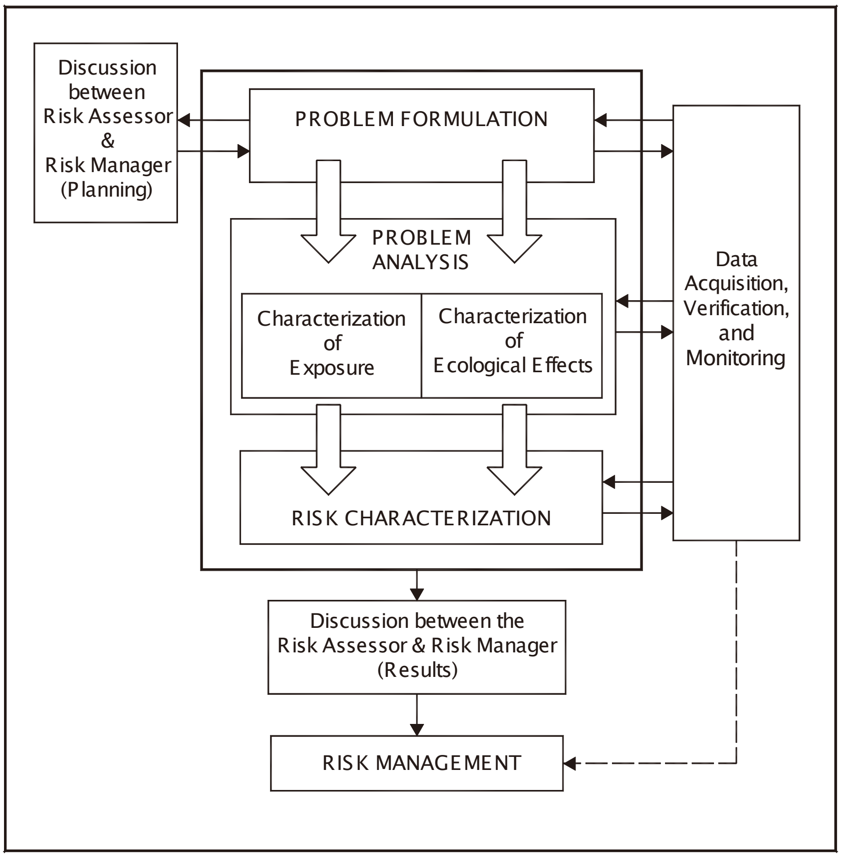

Fig. 1. The WHO framework for ecological risk assessment.

involved.

The following sections describe in broad terms a generic risk assessment process but without direct application to any specific category of risk. Detailed processes can be found for all the principal categories of risk from marine fish aquaculture in Appendices A-J of the full document.

Problem Formulation for Marine Fish Aquaculture (Phase 1)

The first phase is problem formulation, or the identification of key factors to be considered in the risk assessment. Here all the necessary plans are made by the risk managers and risk assessors to determine how the analysis will be performed. These include, for example:

- the scope, focus, and sources to be considered (such as the type of marine aquaculture, and species);
- the biological or ecological end points and their attributes that are the concern for protection (such as sea grass preservation, maintenance of water quality, avoidance of low dissolved oxygen, avoidance of eutrophication, etc.);
- a conceptual model or diagram of how the system being assessed is thought to be organized; and finally,
- the plan for analyzing the information and conducting the rest of the assessment.

Problem formulation can be a long and difficult process. It depends on the degree of familiarity with the particular field of aquaculture, how contentious are any issues, and finally who is involved. Unfamiliar problems, such as the location of marine fish cages in the migratory routes or breeding grounds of cetaceans, unquestionably take longer to formulate compared with, say, the location of a land-based marine fish hatchery adjacent to an existing recreational marina or fish processing plant.

Modern marine fish aquaculture has been evolving for almost 50 years. Consequently, considerable experience has been building with regard to any real or perceived impact on marine ecosystems all over the world. Most of the practical knowledge and experience by fish farmers themselves has never been recorded, although some has been documented in gray literature, but a considerable volume of scientific and technical research can now be found in peer-reviewed journals. With this growing background information to draw on, it is possible for risk managers and risk assessors to undertake a very comprehensive problem formulation.

For the purpose of these guidelines the possible observed or perceived effects of marine aquaculture have been summarized in 10 categories (Table 2). Within these broad designations it is not possible to include all the possible effects which might be identifiable globally, and consequently the guidelines concentrate on the sources of effects, and the end points or entities of concern together with their attributes, of known importance to the majority of marine ecosystems. A risk assessment can include any number of other effects, but practical experience suggests that the 10 categories and their contents illustrated here provide a strong starting point. The biological end points of these possible effects are generalized in the following paragraph.

Biological end points of marine fish aquaculture and their attributes can be described in collective terms (such as the species abundance of the infauna), or very specifically by location (such as the discovery of giant tubeworms at hydrothermal vents). They may also be assessed generally (such as by the presence of certain species in the epifauna), or by specific measurements (such as by n, μg/g, or μg/L).

The end points identified in these guidelines for protection from marine fish aquaculture activities may include:

- the species richness and abundance of the seston, nekton, or infauna,
- the abundance of a specific species in the seston, nekton, or infauna,
- the species richness and abundance of the epifauna,
- the abundance of a specific species in the epifauna,
- the abundance of a specific species of marine mammal, reptile, or bird,
- the immune resistance of demersal and pelagic fishes,
- the number and fitness of the natural (conspecific) population,
- the fitness of another fish population, and
- the abundance of the industrial fisheries.

The choice of species may be guided by whether one is looking for a surrogate for system stressors, system response, or protection of some desirable biological attribute. Thus, one might measure a toxic phytoplankton species because of the desire to avoid blooms of harmful or nuisance species, or one might choose a species that is indicative of degraded environmental condition (e.g., capitellid worms or the presence of *Beggiatoa* spp. in sediments), or one might measure sea grass distribution because of its high protection status.

Problem Analysis for Marine Fish Aquaculture (Phase 2)

Problem analysis is the second phase of risk assessment when all available scientific information relevant to the issue is collected and applied. For the most part it is carried out by technical experts. Problem analysis is divided into two parts. The first is the analysis of exposure, which predicts or measures the spatial and temporal distribution of a stressor and a point of concern; the second is the analysis of effects (sometimes called the exposure response), which identifies and quantifies any adverse effects caused by a stressor.

Characterizing the Background of an Aquaculture Site

It is important to know the characterization of the marine site(s) where the stressor originates and where it may have its adverse effects. Therefore the first step is a baseline survey, or stock-taking, of information about the near field, and in some cases the far field. The survey is in two parts, namely, collecting information through a literature search followed by assembling current information and data by field work.

Historical information

A valuable part of the baseline survey is a

Table 2. Categorization of observed or perceived effects associated with marine fish aquaculture, and the identifiable sources of the stressor.

Effects	Sources
1. Increased organic loading	• Particulate organic loading o Fish fecal material o Uneaten fish feed o Debris from biofouling organisms o Decomposed fish mortalities on the farm • Soluble organic loading o Dissolved components of uneaten feed o Harvest wastes (blood)
2. Increased inorganic loading	• Nitrogen and phosphorus from fish excretory products • Trace elements and micronutrients (e.g., vitamins) in fish fecal matter and uneaten feed
3. Residual heavy metals	• Zinc compounds in fish fecal material • Zinc compounds in uneaten feed • Copper compounds in antifouling treatments
4. The transmission of disease organisms	• Indigenous parasites and pathogens • Exotic parasites and pathogens
5. Residual therapeutants	• Treatment by inoculation • Treatment in feed • Treatment in baths
6. Biological interaction of escapes with wild populations	• Unplanned release of farmed fish • Unplanned release of gametes and fertile eggs • Cross infection of parasites and pathogens • Planned release of cultured fish for enhancement or ranching
7. Physical interaction with marine wildlife	• Entanglement with lost nets and other jetsam • Entanglement with nets in place, structures, and moorings, etc. • Attraction of wildlife species (fish, birds, marine mammals, reptiles) • Predator control
8. Physical impact on marine habitat	• Buoyant fish containment structures and mooring lines • Anchors and moorings
9. Using wild juveniles for grow-out	• Harvest of target and nontarget species as larvae, juveniles, and subadults
10. Harvesting industrial fisheries for fish feed	• Increased fishing pressure on the shoaling small pelagic fish populations

search of existing literature of water and sediment quality parameters. These include, for example, data on water temperatures, salinity, dissolved oxygen, stratification, bottom currents, water depth, background nutrient concentrations, phytoplankton species and chlorophyll, sediment grain size, and organic matter content. In those cases where information is not available, then a program of data collection should be initiated to fill the gaps. It is hard to be prescriptive about spatial and temporal scales of measurement, but measurement of some water quality parameters may need to be taken on a weekly basis during seasons of high phytoplankton productivity.

Some additional information might be available on the background levels of contaminants in both the water and in the sediments. These include, for example, metals, and organics such as hydrocarbons, pesticides, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs), etc. This information is particularly important (and more likely to be available) in near-shore coastal areas where there are significant anthropogenic inputs from agricultural and urban areas. In open waters there is little potential for the accumulation or discharge of these types of contaminants, and the need is reduced.

Finally, any documentation providing a broad description of the natural history of the area, together with any reports or local knowledge of the potential for noxious phytoplankton blooms or the prevalence and intensity of known parasites are potentially useful. Information on the incidence of blooms and parasites is more likely if there are commercial shellfish resources in the area.

Current information

A typical baseline survey of current information for the lease area will include most of the items from the following checklist:

1. Identification of sensitive habitats. These may include, for example, beds of macroalgae and eelgrass, coral reefs, commercially valuable shellfish beds, spawning grounds and breeding areas, migratory pathways of aquatic species, rocky reef communities, and all other structures valuable as nurseries. Such habitats within 500 m of a proposed intensive farm site should be mapped, with the intention of avoiding them whenever possible.
2. The background physico-chemistry of the sediments. This may include, for example, total volatile solids (TVS) or organic matter content, redox potential (Eh), sediment grain size (SGS), free sulfide ($S^{=}$), and the two inorganic metals copper and zinc.
3. An inventory of the species and abundance of the macrobenthic communities. This may be carried out by stratification, or by the type of habitat.
4. The hydrographic variables, such as currents, tides and residence times, including acoustic doppler current profiler (ADCP) data collected over at least one lunar cycle, and bathymetry within 500 m of the proposed site.
5. A profile of water quality, including temperature, salinity, and the potential for stratification as a function of season (pycnoclines and haloclines).
6. A profile of primary productivity, including major species (including any toxic species), chlorophyll (Chl_a), phaeophytin, and dissolved oxygen (DO).
7. If possible, underwater surveys recorded on a video or a series of photographs to provide an overall, semiquantitative assessment of the benthic environment of the site, especially in deep water.
8. Finally, identification of activities by other resource users, such as marine sanctuaries, marine protected areas, fishing grounds, recreational areas, navigational channels, oil and mineral extraction, military training areas, and approved dumping grounds, etc.

The grid on which this information for the baseline survey is to be collected depends on the homogeneity of the system. A regression approach is recommended with single samples collected at intervals on four orthogonal transects beginning at the center of the proposed farm location. Samples should extend at least 500 m from the center. If video surveys are conducted first, the grab collections can be focused in areas where samples are possible, namely soft to mixed substrates. About 24 samples are adequate.

The profile of the macrobenthic community can be reduced in cost by using the smaller petite ponar grab (with a 0.0225 m^2 footprint) rather than the more standard van Veen grab (0.1 m^2).

Near-field and Far-field Effects

Effects of aquaculture interventions on the ecosystem are spatial and temporal. They can be localized and immediate, or distant and sometime in the future. However, both near-field and far-field effects have to be considered in the risk assessment process.

Near-field effects

The near field can be defined as that area encompassing the limit of directly measurable effects. In the marine environment, the majority of human interventions, such as sand mining, dredging, drilling, waste disposal, fish processing, and recreational boating, etc., all have instant near-field effects, particularly on the sediments and their benthic communities in the immediate vicinity of the source. Consequently, because of the long history of these activities in marine waters, the extent and diversity of their effects are well known. They can be measured with accuracy, and the particulate data and benthic biological data linked in a number of empirical or mechanistic models to assess potential risk.

With regard to the relatively recent intervention of aquaculture in the marine environment, and its most localized and instant impact of wastes and contaminants accumulating on the bottom sediment beneath fish enclosures or in solution, there is a wealth of comparative information about the measurement of near-field effects on which to draw. For example: 1) in terms of sedimented organic waste, the near field describes that area in which statistically significant differences (t-tests, ANOVA, etc.) or significant clines (statistically significant coefficients on dependent variables in linear or nonlinear regression analysis) in either physico-chemical or biological end points associated with aquaculture-related effects can be demonstrated at the peak of farm production; and 2) in terms of reduced concentrations of dissolved contaminants or effects of metabolic waste, the near field describes that area in which statistically significant increases or decreases in the end point of interest can be measured in comparison with local reference conditions.

Because of the extent of good data, near-field effects are generally assessed using local computer models to predict the deposition of organic material released by the producer. The DEPOMOD computer modeling tool, for example, models benthic enrichment effects by combining particle tracking with empirical relationships between the spatial distribution of solids and changes in the structure of the benthic community.

Near-field effects are usually limited or managed by regulatory authorities setting performance standards, which are appropriate for the location or the region as a whole. Typically, under the terms of a permit or license, the producer is responsible for conducting the necessary monitoring and complying with the management practices adopted to enable the performance standards to be met.

Far-field effects

Far-field effects are those effects that occur outside that area where statistically significant clines in relationship with the source cannot be measured. These are cumulative effects that normally can only be detected by long-term monitoring programs at locations not directly influenced by local effects. Assessment of far-field effects associated with aquaculture becomes increasingly important as the industry expands.

The maximum spatial extent of far-field effects is a hydrologic unit that includes all inputs potentially affecting the unit. It may include, for example, a single bay, several bays, or an entire estuary or delta. Far-field effects become increasingly difficult to measure in open bodies of water, such as those offshore where aquaculture may occur. However, even in large open bodies of water the same definitions could be applied.

Because of the vast scope of far-field effects, their potential is normally best assessed through computer models. These are monitored by consortiums of contributors to the cumulative effects in coordination with some level of government. Management of far-field effects is normally a public function in cooperation with all the contributors. With regard to organic loading, for example, from a number of marine fish farms into a bay 10 km distant, the regulatory authority may set Total Maximum Daily Loads (TDML) for the far field of interest (the bay), and apportion the TMDL to individual producers or farm complexes. The authority then manages the far-field effects by manipulating the respective TMDLs to meet one stated objective.

Risk Characterization for Marine Fish Aquaculture (Phase 3)

Risk characterization is the final phase when the two analyses of exposure and effects are brought together. It is best performed using models developed to estimate effects from hypothetical risks.

In a number of fields, such as the pharmaceutical industry or chemical engineering, risk characterization can be straightforward. The point estimate of exposure is compared with the point estimate of the threshold of effects, and if the ratio is greater than one then an effect is assumed. It can be taken further with an exposure-response model, when the distribution of the exposure and effects can be shown to accumulate over a period of time. However, in the marine aquaculture industry the process of risk characterization is complicated by the fact that most of the effects are interactive. Such complexity could be dealt with by modeling, but quantifiable information for many aspects of marine aquaculture is extremely scarce. Consequently, for risk characterization the only recourse at present is either to make use of a mechanistic model for a particular site, providing the assumptions are reasonable and that the model can be adequately calibrated and validated, or to rely on all existing information and especially the classical "dose and response" laboratory information.

In assessing a risk it is important both to qualify and quantify, where possible, the associated uncertainty. For example, the uncertainty could be described by probabilistic factors, by semiquantitative factors, or entirely qualitative factors, such as high, medium, or low. Whatever factors are chosen, it is important to include the uncertainty with any risk assessment. In addition, it is important to explain any assumptions which were used in the analysis, the scientific uncertainties, and their strengths and weaknesses.

Risk characterization is carried out by scientific and technical experts, but it is not limited to them. Risk assessors and risk managers are again actively involved in the process, as during problem formulation. This is because issues might have arisen which necessitate a reiteration of problem formulation and a repeat of the problem analysis.

Risk Communication

A final responsibility for everyone involved in managing risk is risk communication. This is an ongoing process at the local level and usually involves a government agency, represented by risk managers, industry and other stakeholders, and the public at large.

The objective of risk communication is to maximize the transparency of every activity related to the risk through interaction with the broadest range of interested parties (Figure 2). This objective includes risk identification, analysis, assessment, implementation of the decision, and subsequent monitoring. It is important that the communication process is begun as soon as possible, preferably with an announcement of the project itself.

Risk communication is carried out in a variety of ways. Productive communication is invariably conducted at public hearings when, in theory, everyone listens carefully to each other without any prejudgment of the issue. But this is not always the case, and it is important for the risk managers representing government agencies at such hearings to maintain public trust by their independence and impartiality. Good communication is also achieved by regularly circulating published materials.

Some aspects of risk assessment are scientific and very technical, and therefore it is important that the data and all methods of collection, any models and assumptions that have been applied, and any conclusions drawn are reviewed by peers.

Monitoring for Subsequent Risk

Decisions can be made by the risk manager based on the historical and current information gathered by the team of risk assessors and stakeholders. If the potential risk is assessed as being unlikely, or small, then the risk manager can authorize the project to go ahead. However, it is important that the baseline does not change in such a way that the risk can in fact occur at a

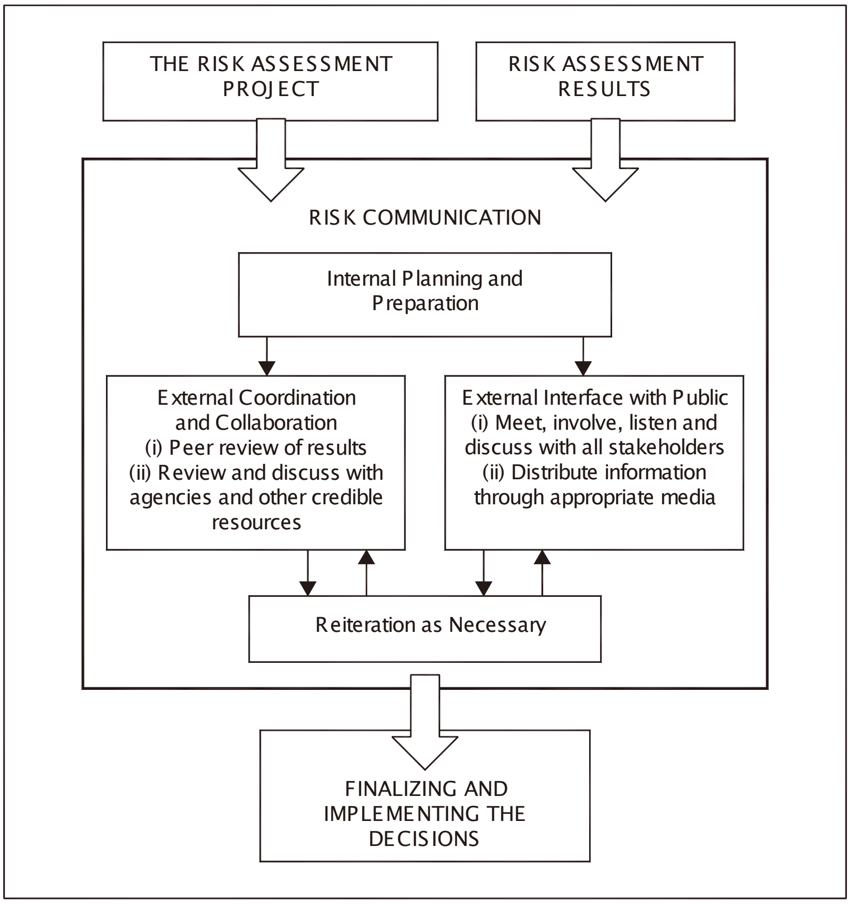

Fig. 2. The process of risk communication for the project and the results.

later time, and therefore the risk manager usually qualifies any decision with the requirement for the continual monitoring of certain site parameters. The task of carrying out the monitoring program may be the responsibility of the regulatory agency, the owners or managers of the project in question, or both.

It is important that any monitoring program is designed around the measurement of:

- standards identified by national legislation and regulation, and
- those parameters relevant to the indication of any increasing risk to the biological end points that have been identified.

Fundamental also to every monitoring program is an exact specification of the methodology. This, for the most part, should have been established during the baseline survey. In other words, reference stations and site stations will be located and fixed along transects on the seabed or at set surface or mid-water distances from identifiable points (such as the perimeter of a facility), and all based on the predominant direction of the current. In addition, the frequency and methods of sampling will be specified, and the methods of analysis will be identified together, where necessary, with laboratory instrumentation.

Global Application of the Framework

Physical Demands of Marine Fish Aquaculture

For the foreseeable future, intensive marine fish aquaculture will be limited to waters of the continental shelf, which is often defined as lying above the 200-m contour. However, for the practical reasons of engineering cost, operational management, and profitability, marine fish aquaculture takes place reasonably close to shore, provided that water quality conditions are suitable.

Selection of a location depends on the proposed fish farming system and practice. Again, because of the investment cost, only intensive fish production is economically feasible, and the options are floating net-pen complexes and buoyant individual cages designed to remain at the surface or to be submerged as required. Net-pen complexes are therefore usually located in coastal estuaries, sounds, and lagoons that have rapid marine water exchange, have some shelter, and provide anchorages that are less than 40 m deep. Individual buoyant cages can be located in less-sheltered waters, and submersible cages can be deployed in deeper water to avoid storms. However, submersible cages have limitations. Although wave energy attenuates with depth, the scale of each unit is limited by potential fatigue of the materials, the capacity of the automated feeders, and the need for regular surveillance and service operations by scuba divers. Scuba divers can operate safely down to a depth of 30 m, but operate most economically around 10-15 m, and working in pairs. Currently, submersible cages are being operated at depths of less than 100 m, but this may still be up to 30 km offshore.

Net-pen complexes are anchored by many separate cables, depending on their formation and size. Additional lines may anchor predator nets. Individual buoyant cages are anchored by four discrete lines which maintain tension all around continuously. Single-point anchor systems have also been used, but at some time the line will become slack, which puts a burden on the cage/line interface. The preferred substrate for the anchors themselves is sand or mud. Anchors can be bolted into rocky substrates, but the practice is costly.

Buoyant cages are designed to operate in currents up to 90 cm/sec, or about 1.74 knots. This is above what is desirable for the fish, which, when confined in strong currents, expend too much energy maintaining their position in the cage instead of growth.

Environmental Demands of Marine Fish Aquaculture

Successful marine fish aquaculture depends on a synergism between the aquaculture site and the farmer. The environmental qualities or parameters of the site must be conducive to the life history and physiology of the species of fish in culture, and the operator must provide an appropriate living space for the fish, meet all their nutritional requirements, and maintain their health.

Site selection for an aquaculture facility is therefore a critical task. It is made difficult because the range of marine ecosystems in which it may be located is diverse, and the suitability of their physical and chemical properties depend significantly on the species and culture practice to be implemented. For example, there are different site demands for submersible cages containing cobia 3-5 km from the coast of Puerto Rico, pens for growing-out tuna in coastal waters within 2 km of the shoreline of Australia, and enclosures for rearing sea bream in shallow marine embayments in the Mediterranean.

The hydrodynamics, nutrient levels, types of pollution, and other environmental parameters found in these locations are all very different. Consequently, there will be differences in the biological end points and their attributes resulting from aquaculture operations that characterize the potential risks to the environment. For example, the risk of eutrophication and change in species diversity in the benthic environment in the poorly flushed lagoons of the Mediterranean is higher than the offshore waters of either Puerto Rico or Australia where there are greater depths and high water exchange rates.

Because of all these differences, each ecological risk assessment has to be tailored to an individual location, and an individual species and aquaculture practice. However, the categories of potential ecological risks and their fundamental methods of assessment are common, and it is only their relative importance that will vary.

A Matrix Approach to Guide the Application of Risk Assessments

In selecting a suitable site for marine fish culture, the ideal requirement is a pollution-free environment in the epipelagic zone with good water quality parameters. Primarily this means year-round high ambient levels of oxygen combined with salinities and temperatures that are between the middle and upper end of the ranges tolerated by the respective farm species, and maintained by a modest current and average tidal rise and fall. Unfortunately the ideal cannot always be found, and the parameters are so diverse that most sites are selected for reasons somewhere between ideal water quality parameters and operational cost and convenience.

As marine fish aquaculture is still in its infancy in most countries, and the locations where it is practiced at the present time are few, for the purpose of these guidelines it is proposed to classify the typical marine aquaculture environment into categories of biogeographical regions or zones and categories of marine epipelagic ecosystem. The definitions of the zones and categories are as follows:

The two biogeographical zones suitable for marine aquaculture (as illustrated in Figure 3) are:

- Temperate waters (10-18℃). Typically cold waters with intrusions of some warmer waters from the subtropics. Temperate waters can be rich in nutrients and highly productive (waters off Australia being an exception), and consequently characterized by low light intensity levels. Temperate waters often support substantial fisheries, together with their dependent populations of birds and marine mammals.
- Tropical waters (>18℃). Typically warm waters with intrusions of some colder waters from the subtropics. Tropical waters are biologically very rich but nutrient poor and characterized by high light levels. Tropical waters often support migratory populations.

The three epipelagic ecosystems are:

1. Offshore waters. Typically 3 km or more from the coast, or up to 100 m in depth, and suitable for submersible cages.
2. Coastal waters. Typically less than 3 km from the coast, or up to 30 m in depth, suitable for submersible cages and floating cages, with strong tidal interchange.
3. Inshore water bodies. Typically semienclosed but large coastal sounds, lagoons, and estuaries, relatively shallow in depth, suitable for floating cages and fixed enclosures, with good tidal flushing.

The 10 categories of risk can then be evaluated in broad terms against each of the 6 generalized marine ecosystems in the form of a matrix (Table 3). The objective is to indicate probable differences in priority relative to each type of ecosystem, and to assist risk managers and risk assessors with their problem formulation. However, the information presented in the matrix does not rule out the uniqueness of some ecosystems, and this most always be considered.

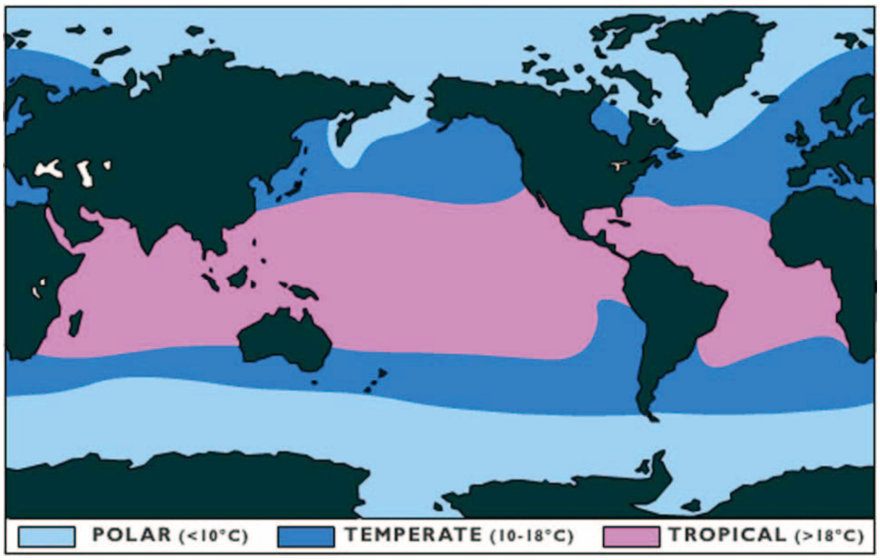

Fig. 3. Broad biogeographical zones for marine aquaculture (courtesy of the Gulf of Maine Research Institute).

Table 3. Matrix to guide the application of risk assessments in the waters of different biogeographic zones.

Category of observed or perceived risk	Epipelagic ecosystem in temperate waters (10–18°C)			Epipelagic ecosystem in tropical waters (>18°C)		
	Inshore	Coastal	Offshore	Inshore	Coastal	Offshore
1. Increased organic loading	*****	**	*	*****	***	*
2. Increased inorganic loading	*****	**	*	*****	***	*
3. Residual heavy metals	*	*	*	**	*	*
4. Transmission of disease organisms	***	**	**	***	**	**
5. Residual therapeutants	**	*	*	**	*	*
6. Biological interactions of escapes with wild populations	**	**	*	**	**	*
7. Physical interactions with marine wildlife	**	**	*	**	**	*
8. Physical impact on marine habitat	**	*	*	**	*	*
9. Using wild juveniles for grow-out	**	**	*	***	***	**
10. Harvesting industrial fisheries for fish feed	**	**	***	***	***	***

Key: Potential for ecological change without management action
***** Significantly high
**** High
*** Medium
** Low
* Little or none

Risk Assessment Example

Biological Interaction of Escapes with Wild Populations

Risk Hypothesis

Escaped farmed fish, or their gametes liberated from a farm, may pose a risk to wild populations when they interact biologically. Potentially deleterious genetic impacts are perceived to be:

- interbreeding and
- competition for mates or nesting sites.

Potential ecological risks from escaped farm fish are perceived to be:

- competition for habitat and forage,
- increased predation (if piscivores),
- the introduction of exotic pathogens and parasites, and
- amplification of endemic pathogens, some of which may be antibiotic-resistant.

All these possible risks are believed to pose a greater threat to natural populations (conspecifics of the escapees) than to other fish populations at large.

Background Experience

The practices of both freshwater and marine fish culture for stock enhancement or ranching have benefited from years of effort to improve the cultured stocks. In addition to the results of traditional genetic techniques used by hatchery managers, such as trait selection, inbreeding, and out-breeding, there are also the genetic influences of simply surviving in the wild. On the other hand, commercial fish culture is a relatively new field and the present generations of farmed species are still closely allied to the original wild parents. Fish populations bred in captivity have already been subjected to similar stock-improvement practices which, however small, have probably begun to change their genetic makeup. Consequently, when cultured fish are released intentionally or escape from farm enclosures into the ecosystem, they carry with them a genetic profile that can have a deleterious effect should they interact again with natural populations.

There are a number of ways for biological interactions to occur in an aquatic ecosystem where aquaculture activities are practiced. Firstly, farmed fish can escape directly from net-pens and other enclosures due to human error, damage from a catastrophic natural event such as a severe storm, or following damage to the structure by a predatory marine mammal. Secondly, some species of finfish and shellfish that spawn freely in captivity and produce pelagic eggs may release fertilized gametes into the surrounding environment. Thirdly, domestically cultured fish and shellfish raised in hatcheries can be released intentionally on a large scale in annual stock enhancement or sea-ranching programs, leaving them to migrate freely and interact with wild populations.

There is evidence that farmed fish are capable of breeding with their conspecific natural populations in the wild. Therefore escapees may present a genetic threat to a locally adapted natural population through intraspecific hybridization, resulting in a reduction in overall reproductive fitness and recruitment to the wild population. Some interspecific hybridization might also occur should farmed fish escape into an ecosystem where there are very closely related species. The use of reproductively sterile farm fish has been proposed as one means of preventing genetic interactions with wild populations, and consequently reducing their ecological impacts, but this practice is still a matter of priority research.

The introduction of exotic pathogens by the transfer and escape of farmed fish is an issue of lessening concern. This is because most countries have adopted the international protocols regarding the movement of terrestrial and aquatic species for almost any reason, and they have stringent regulations in place regarding the importation of exportation of fish or their eggs specifically to minimize the risk of transferring exotic diseases. Such precautions, however, have not always been effective. Wild fish are the reservoirs of a wide variety of common pathogens, and when certified disease-free fish or shellfish are introduced into an area for the first time they are infected by these dormant pathogens and cause the same diseases endemic to these fish in their native habitat.
Outbreaks of disease can occur at fish hatcheries, and transfer of infected fish may facilitate disease transfer between stocks. However, as the occurrence of endemic pathogens in wild fish is common, it is difficult to determine the extent that pathogen transfer occurs. Similarly, it is difficult to determine the extent to which amplification of endemic diseases occur. It has been suggested that populations of sea lice (such as *Caligis* and *Lepeophtheirus* spp.) are transferred and amplified between farmed salmon and their wild populations, but no scientific evidence has been found (see Appendix D).

Building the Conceptual Model

Escapes may occur with varying frequency and intensity. Therefore, the two sources of biological interactions from the escape of cultured fish or their gametes from aquaculture facilities are catastrophic releases, or periodic natural events such as storms, and chronic releases. Their impact, however, is modified by a number of things, amongst which importantly are the numbers and the genetic characteristics of both the escapees and their resident indigenous wild populations.

Catastrophic releases are unique as they are rare and not planned, and they could involve a large number of escapees. Invariably they can be avoided or controlled if appropriate guidelines are followed for risk management (disaster prevention) and the subsequent recovery of inadvertently released animals. Although it may be impossible to anticipate the occurrence of a 100-year climatic event, a range of possible disasters can be avoided with the selection of a site concomitant with the engineering technology, and away from shipping and navigation lanes and fishing grounds, for example. The effects of a catastrophic release may also be reduced by having a plan and the appropriate equipment for retaining or recapturing escapees.

Chronic releases may be planned or unplanned and may involve large numbers or small numbers of escapees. Planned releases include stock

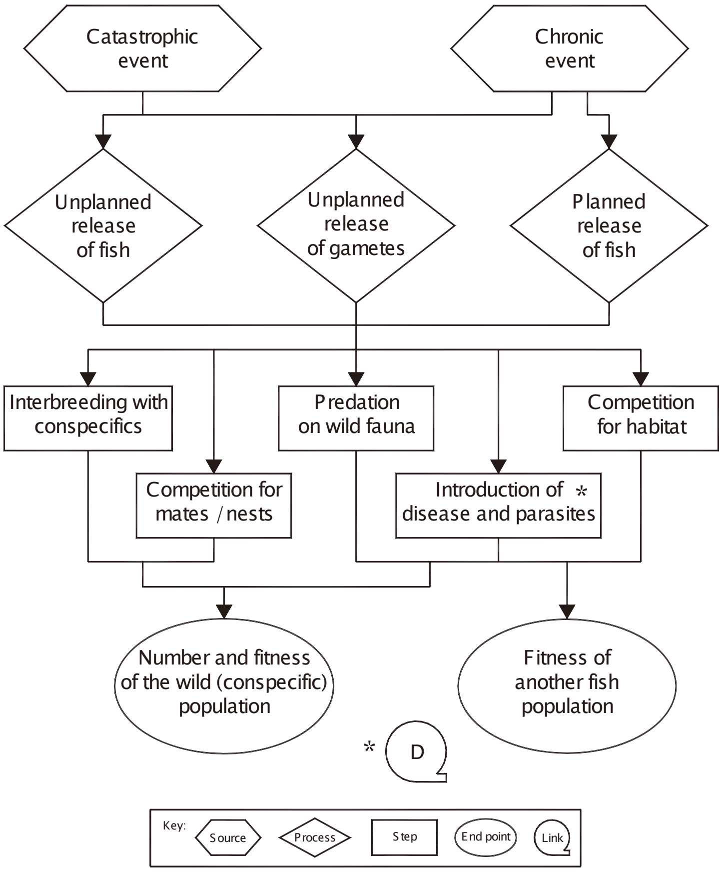

Fig. F-1. A conceptual model for biological interaction of escapes with wild populations.

enhancement and ranching programs by fisheries managers; unplanned releases include the loss of a few fish through a hole in a net made by a predator, or the release of fertilized gametes from a captive stock as a consequence of uncontrolled breeding.

Chronic releases, even due to predator attacks, are therefore often seasonal, but their potential effects for detrimental genetic and ecological interactions may be accumulative. On the other hand, the effects of planned releases of cultured fish are often minimized simply because they are target fisheries for commerce or recreation, and this reduces their potential to interact with the natural population.

Regardless of the manner of escape, escapees may affect the natural population in a number of ways. The most important and direct consequence is interbreeding, followed by the indirect consequence of competition for mates and nesting sites. The effects of interbreeding are a reduction of genetic variance between the two populations, and out-breeding depression. Some other indirect consequences in the short-term may be through competition with all species for forage and habitat space, by predation on endemic fish populations, and the introduction of bacterial or viral pathogens or parasites. The effects of these processes can be a reduction in the genetic integrity of a community or an ecosystem, and they may of course be positive or negative to both. In brief, the outcome can be a reduction in the numerical or genetic strength (fitness) of the wild population, and possibly a reduction in fitness in other fish populations.

Analysis and Characterization

The biological end points and their attributes for protection are:

1) the numerical or genetic strength (fitness) of the wild (conspecific) population, and
2) the fitness of another fish population.

Modern methodologies for measuring the size and genetic parameters of fish populations are all now carried out at the molecular level by analyzing markers, such as mitochondrial DNA and microsatellites. Consequently the techniques are sophisticated and require laboratories well-equipped with costly instrumentation. Protein electrophoresis continues to be a reliable method to detect genetic variation by identifying differences in protein allele frequencies between stocks. More recently, however, protein electrophoresis has been complemented by studies of the genome and the genetic information that can be carried and detected in a small piece of material, such as tissue from liver or muscle, for DNA identification.

Fitness of the Wild Population

Genetically effective population size (or N_e) is the most important factor to sustain a high level of genetic variation within a fish population. This is because in the actual total population (N), only a proportion (the N_e) will pass on their genetic profile to the next generation. If the total population is reduced for some reason, such as the suggested competition with cultured fish, then its original genetic profile may drift further and further away from the original. By measuring this drift, then the genetically effective population size can be calculated and conclusions drawn from the results.

However, calculating the genetically effective population size is not particularly simple. A difficult starting point is having a uniform population, so that selected fish are representative of that population with the same genetic diversity and any local adaptations. For marine fish this is made easier by the fact that few species have been subjected to the same practices of hatchery propagation, restocking, and enhancement as have freshwater fish and anadromous fish, and therefore have little or no introgression.

N_e can be estimated directly by sampling a population at two or more points in time, and separated by a specified number of generations, and it is possible to estimate Ne by the changes in allele frequencies in the interval between sampling. The usefulness of this temporal method has been increased significantly by a technique to extract genetic information from stored samples, which are usually otoliths and scales, where they exist. The polymerase chain reaction (PCR) technique can target a DNA molecule in small and old samples and amplify its genetic information. Unfortunately, fisheries biologists archived material more from freshwater and anadromous fishes than marine fishes, and therefore comparative material might be difficult to obtain.

Fitness is a measure of breeding success or survival. Relative lifetime fitness (%) is therefore the breeding success or survival of one generation to the next. However, the simplicity of this calculation is masked by several possible variables associated with any planned or unplanned releases, such as the number and timing of the release, and the suitability of the receiving ecosystem.

Annual demographic data about the population in question is also important, such as the year-class strength of successive generations. Here, there is potentially more information available for marine species than freshwater species, as demographic data has been required for some time by fisheries managers. It is also important to know when a population has substructures, as these can influence allele frequency changes and misdirect any conclusions.

Fitness in Another Population

The same procedures will be used to determine any reduced fitness in another fish population.

Biological Opinion

Escaped farm fish are not in the economic interest of producers, and there continues to be improvements in the design and operations of marine fish farms to prevent escapes occurring altogether. As many regulators now require notification of escapes, existing records show that the incidence and numbers of escapees continue to decline. However escapes can and do occur, and the escapees may interact biologically with the wild population by changing their genetic integrity or profile, introducing new or unusual genotypes, or by eroding their reproductive fitness, particularly if they are originally from nonlocal stock or selected by the breeders for certain farm traits.

Fortunately the statistical chance of these interactions occurring is affected by a number of factors, the most important of which is opportunity. Escapees are rarely sexually mature, as they are harvested by the commercial growers before nutritional energy is directed to the development of gonads. The few that might be selected as future broodstock at harvest time would be moved elsewhere-usually to a land-based hatchery. Therefore, at the time of escape, escapees are not necessarily mature enough to breed. Secondly, the escapees might not last long enough to mature in the wild and interbreed. There is considerable evidence for a variety of species that the majority of escapees, being raised in captivity on a daily routine of artificial diets, invariably remain in the vicinity of the site to be recovered or fall easy victims of predators. Thirdly, the timing of the escape might not be coincidental with the natural breeding season of the wild population. Catastrophic events may be large but they are also very rare, and chronic events may be continual but usually involve very few fish. Consequently the timing of an escape, the numbers of escapees, and the size of the wild population are all variables which play a role in defining the opportunity for biological interaction.

This is not the same for a planned release of cultured fish from a hatchery, or an unplanned release of fertile gametes from captive adults on a farm. Such events involve the release of a large number of juveniles or gametes that could mature and breed, or a few mature breeders in a restocking program in the hope that they will breed. The opportunities for biological interactions from planned releases of juveniles or broodstock, or unplanned releases of fertile gametes, are obviously considerable, and may be magnified further by the degree to which they have been selected to enhance certain traits.

The potential genetic effects of biological interactions of planned and unplanned releases may also be modified by the population structure of the wild population. For populations with a high degree of local adaptation, among which genetic variability is partitioned at the population level or on a geographical basis, then the natural population structure is particularly at risk from interbreeding with escaped conspecifics. This applies to species of Atlantic (*Salmo* sp.) and Pacific (*Oncorhynchus* sp.) salmon, which are highly structured, and some Mediterranean species, such as sea bass (*Sparus auratus*).

Because of the apparent continuum of the marine environment, it has been thought for some time that most populations of marine fish species are not structured, and therefore their capacity to exert genetic effects is greatly reduced. Species such as the sea bream in the Mediterranean, for example, appear to lack structure at the population level, and gene flow across the range of such species appears extensive. Although farmed sea bream outnumber wild fish, the presence of an undifferentiated stock reduces the potential for adverse interactions. However, the increasing interest in the genetics of marine fish species for fisheries management, and increasing skills in DNA analysis, now suggest subpopulations of some marine species might in fact have remained localized for sufficient time to have developed small genetic differentiation that now are detectable. This adds to the genetic implications for releases and escapees mixing with a subpopulation of conspecifics, although, as noted above, escapees tend to remain close to the culture site, therefore selection of broodstock within the vicinity of the site would be an appropriate practice to reduce this possibility.

There is evidence that fish reared in captivity can lose any natural undiminished capacity to capture prey, and when released or escape they do not compete for forage too well. Escaped fish when recaptured invariably have empty stomachs.

In summary, ecological risks from the biological interactions of unplanned releases with wild populations can be greatly reduced, as they cannot be deleted altogether, by good management practices, such as:

- careful choice of the site;
- constant vigilance of all structures, moorings, and anchorages;
- regularly cleaning nets and predator nets;

- maintaining all navigational requirements (lights and foghorns);
- conducting any transfers with great care; and
- having a plan for escape recovery.

Genetic risks from the biological interactions of unplanned and planned releases with wild conspecific populations can be reduced by:

- selecting broodstock from within the ecosystem of the site;
- selecting marine species for farming, which have little or no substructure; and
- raising sterile animals.

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The Measures for Sustainable Marine Aquaculture in Japan

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Abstract Marine aquaculture in Japan has developed steadily since the 1960s, and it occupies an important position in the Japanese marine fisheries at this stage. In 2004, it accounted for 21.4% of the total production and 29.0% of the total value. Accordingly, the achievement of sustainable marine aquaculture is one of the important issues when considering Japanese fisheries policy. This paper outlines several measures and a basic plan related to sustainable development of Japanese marine aquaculture..

Key words: sustainable aquaculture, regulation, seafood safety

Outline of Marine Aquaculture in Japan

Aquaculture has a very long history in Japan, beginning with nori seaweed culture in the 16th century. The artificial feeding of marine species was said to initiate in 1927 with yellowtail in Kagawa Prefecture. The aquaculture of yellowtail was suspended in World War II, but had come back in the decade following the War. And new aquaculture technologies were gradually applied to an increasing number of species. At present, it is said that about 30 species are cultivated in Japan; a part of those comprise most of the domestic production. In 2004, cultivated nori, oysters and coho salmon accounted for 100% of the domestic supply of those species, and cultivated yellowtail and red sea bream account about 70 or 80% of the domestic supply of those species. Aquaculture and fisheries production levels in Japan during 2004 are presented in Table 1.

In 2004, marine aquaculture production in Japan amounted to 1.2 million metric tons valued at 436 billion yen and represented 21.4% of the total Japanese marine fisheries in volume and 29.0% of the total in value (Table 2).

Dividing Japanese marine fisheries into four major sectors: distant-water, offshore, coastal and aquaculture, aquaculture production exceeded that of the distant-water fishery and was nearly equal to coastal fisheries. The value of aquaculture production has exceeded that of the distant-water fishery since 1988 and that of the offshore fishery since 1992 (Figure 1).

Today, marine aquaculture is a major food production industry in Japan. Some big companies, e.g., Nihon Suisan, Maruha and foreign-affiliated firms such as Norwegian companies have entered into aquaculture through subsidiaries. Aquaculture products generally meet the tastes of consumers and consist mainly of medium- to high-quality products. As marine aquaculture continues to develop and expand, protecting the marine environment from the effects of water pollution is vital to the health of the industry. At the same time, Japanese consumers have been concerned about "Anzen" and "Ansin" on food including cultured seafood since the discovery of outbreak of Bovine Spongiform Encephalopathy, i.e., BSE in Japan. In English, "Anzen" can be translated into "safety" and "Ansin" can be translated into "trust." Accordingly, aquaculture policy of Japan has to

2009年8月10日受理（Received. August 10. 2009）
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Table 1. Rate of Aquaculture to Total Fishery Production in 2004

Species	Aquaculture (A) (ton)	Fishery (ton)	Total (C) (ton)	A/C
Yellowtail	150,101	66,345	216,446	69.3%
Red Sea Bream	80,957	26,161	107,118	75.6%
Coho Salmon	9,607	–	9,607	100.0%
Olive Flounder	5,241	5,917	11,158	47.0%
Globefish	4,329	6,704	11,033	39.2%
Scallop	215,203	313,800	529,003	40.7%
Oyster	234,151	–	234,151	100.0%
Kuruma Prawn	1,818	1,044	2,862	63.5%
Nori(Laver)	358,929	–	358,929	100.0%
Wakame Kelp	62,236	3,673	65,909	94.4%
Konbu Kelp	47,253	91,122	138,375	34.1%

Source: MAFF

Table 2. Position of Aquaculture in Japan in 2004

		Volume 1000 ton	Value Billion Yen
Marine Fishery	(A)	5,670	1,500
Distant-water Fishery		535	169
Offshore Fishery		2,406	396
Coastal Fishery	(B)	1,514	500
Aquaculture	**(C)**	**1,215**	**434**
Inland Fishery		106	103
Fishery		60	51
Aquaculture	(D)	46	52
Total	(E)	5,776	1,604
C/A		21.4%	28.9%
(C+D)/E		21.8%	30.3%
C/(B+C)		44.5%	46.5%

Source: MAFF

point to the preservation of the environment of aquaculture grounds and the safety of aquaculture products.

Measures for Conservation of the Environment of Aquaculture Grounds

In the course of aquaculture development, environmental problems have occurred. The fact is that aquaculture grounds, the environmental condition of which is suffering from excessive

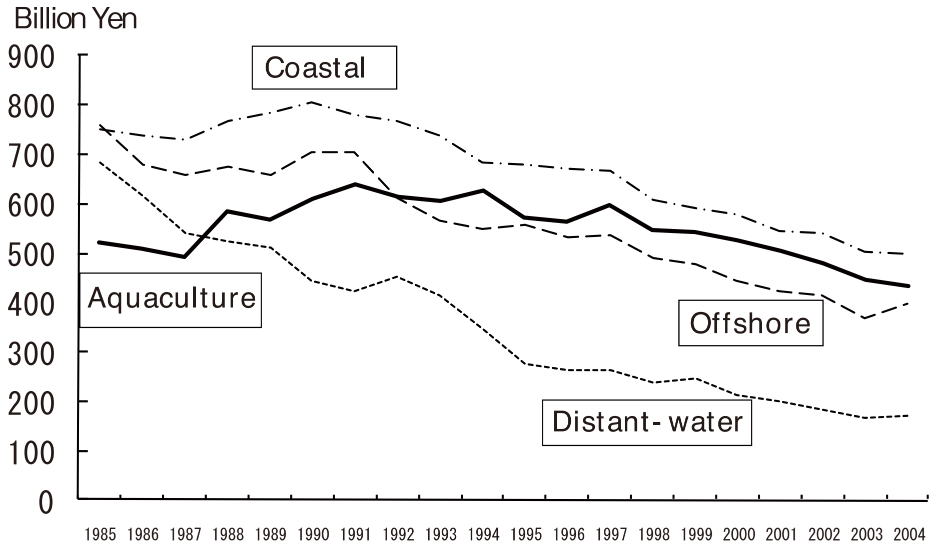

Fig. 1. Trend of the value of Japanese Fisheries.

organic sediment, are expanding. Excessive organic loading of the sediments is primarily caused by high-density farming and excessive feeding, both of which are aimed at increasing production. In order to resolve the situation, the "Law to Ensure Sustainable Aquaculture Production" was established in 1999 with a view to facilitating voluntary actions by fishermen to promote sustainable aquaculture by improving and maintaining environmental conditions, and by preventing the spread of fish diseases.

According to the law, the Minister for the Ministry of Agriculture, Forestry and Fisheries shall develop a "Basic Guideline" which establishes criteria for environmental indicators required for sustainable utilization of aquaculture grounds. The "Basic Guideline" established thus far contains the following three categories as the criteria:

1. Water quality.
2. Sediment condition on the bottom of aquaculture grounds.
3. Health condition of cultured fish, including mortality rate of cultured fish by diseases.

Each fisheries cooperative that conducts aquaculture, will voluntarily establish an "aquaculture ground improvement program" individually, or in cooperation with a neighboring cooperative or cooperatives, for its or their aquaculture grounds, based on the "Basic Guideline." The "aquaculture ground improvement program" shall indicate the goal of the improvement and indicate measures to be taken for the improvement of environmental conditions, and shall also be authorized by a prefectural Governor (Figure 2).

To be concrete, an "aquaculture ground improvement program" for fish aquaculture shall report fish population density in the fish preserve, promote the use of assorted feeds and avoid using harmful materials for livestock and so on. The program for seaweed contains weed population density in the seaweed preserve and avoids using harmful materials for livestock and so on. When the "aquaculture ground improvement program" is not carried out, the Governor recommends the cooperative to develop thep rogram in case its aquaculture ground is recognized to be conspicuously deteriorated, and can make it public if there no compliance.

In the past, farmers used fresh fish as feed, but this leads to environmental degradation because of wastage. Now, according to the guideline and programs, the use of fresh fish as feed and assorted feed of a type that mixes fish with dry ingredients that is made into moist pellets has been decreasing. The use of dry pellets which do not incorporate fresh fish has increased in Japan (Figure 3).

The Acid Volatile Sulfide in mud of seabed has decreased after establishment of the "aquaculture

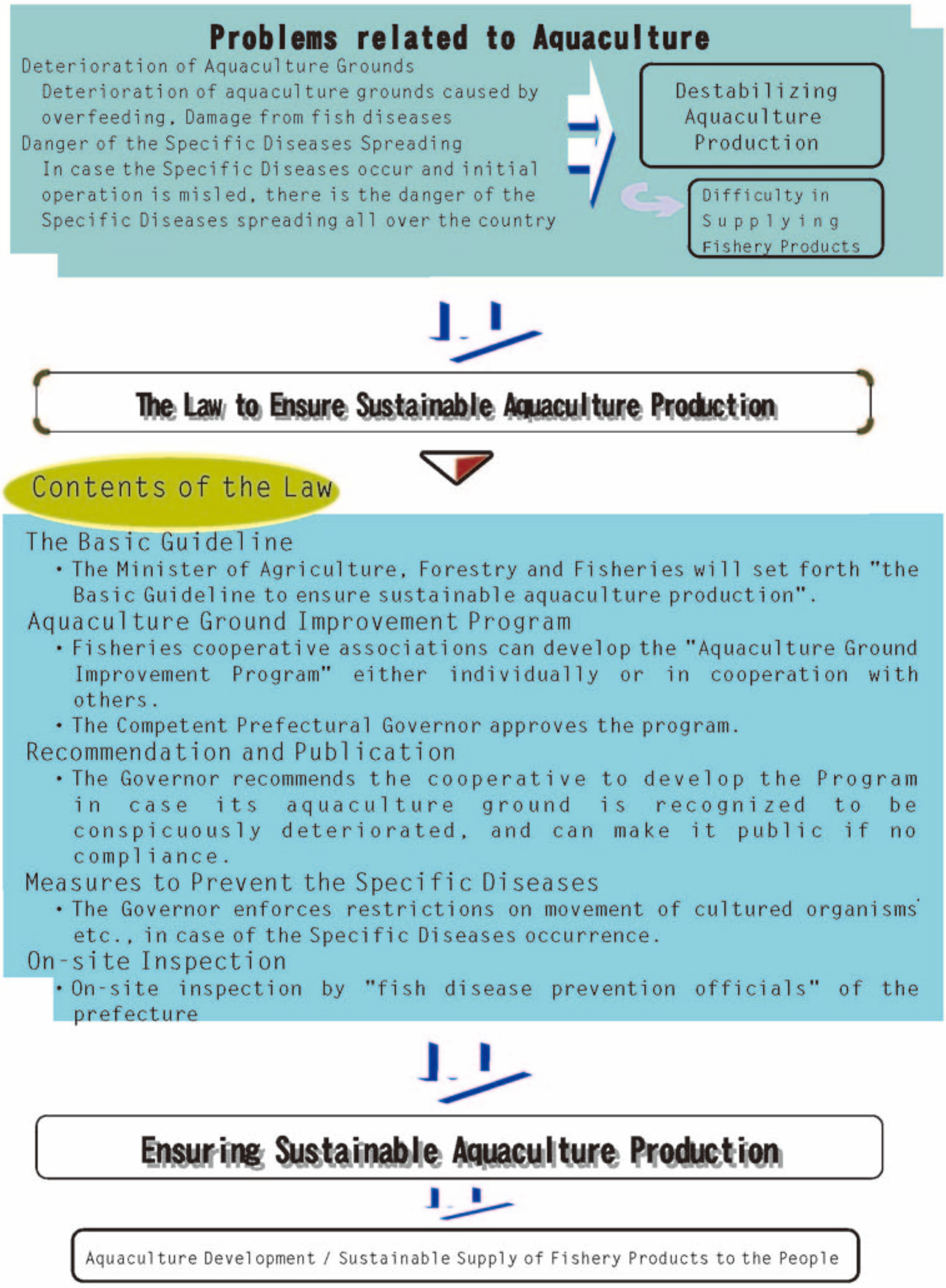

Fig. 2. Conceptual flowchart of the law to ensure sustainable aquaculture production.

ground improvement program" (Figure 4). This is just one example of how the environment of many aquaculture grounds has been improved since the establishment of the "aquaculture ground improvement program."

Currently, nearly 85% of the production of cultured fish is farmed on aquaculture grounds where the "aquaculture ground improvement program" has been established (Table 3). The Fisheries Agency has promoted sustainable aquaculture production by establishing and implementing the "aquaculture ground improvement program" for all aquaculture grounds around Japan.

Measures for Ensuring Food Safety

In aquaculture, residual medicines brought on much criticism because it is said that aquaculture farming uses to much medication. To resolve this matter, the amount and usage of medications are

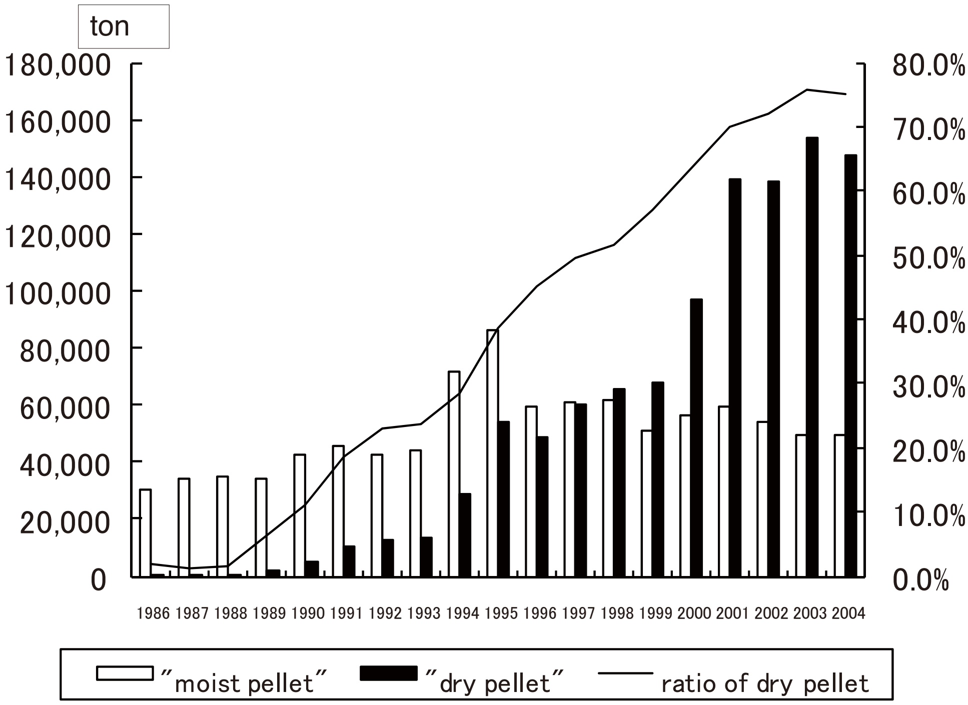

Fig. 3. Trend of production of assorted feed: distinct by form.

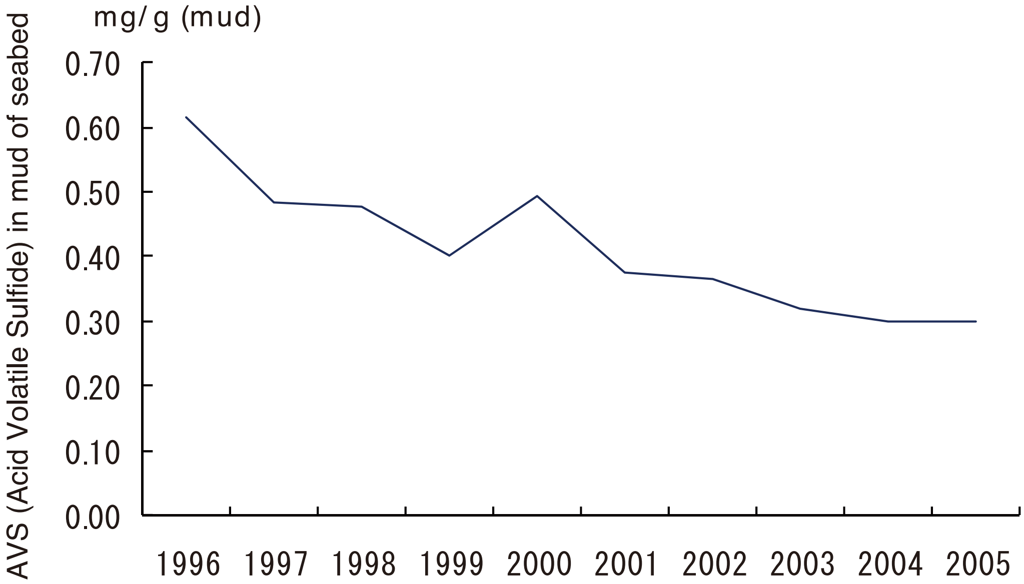

Fig. 4. Example of improvement of aquaculture ground.

governed by the "Pharmaceutical Affairs Law." This law regulates the usage of medicine, e.g., antibiotics, in conjunction with all aquatic animals. Recently, the development of vaccines for fish diseases has changed the situation with respect fish diseases. Furthermore, Governors can prevent the movement of cultured organisms in case of specific diseases outbreaks, and fish disease prevention officials use medicines and vaccines in accordance with "Law to Ensure Sustainable Aquaculture Production." As a result, the amounts of damage caused by fish diseases and the sales volume of medicines for fish diseases have declined.

On the other hand, the quality of farmed fish is not ranked high by the public because it is felt

Table 3. Settlement of "Aquaculture Ground Improvement Program"

number of "Program"	Cover Ratio*		
	Fish	Shellfish	Seaweed
367	84.4%	48.3%	65.7%

*:"Cover ratio" is calculated as follows;
Volume in the aquaculture ground settled of "Program" / Total aquacuture volume × 100

to be much too oily. This problem is caused by the excessive feeding of fresh sardines. Today, the quality of farmed fish is improved by the promoting the use of assorted feeds, especially dry pellets. But the consumer's deep-seated distrust has not been easily dispelled. Therefore, supplying correct information to consumers about the way fish are produced in aquaculture is very important for increasing the market for farmed fish. Many consumers who visit fish farms say that they have changed their opinion about farmed fish and that their misunderstandings were wiped away (Figure 5).

InJapan, consumers have been concerned about

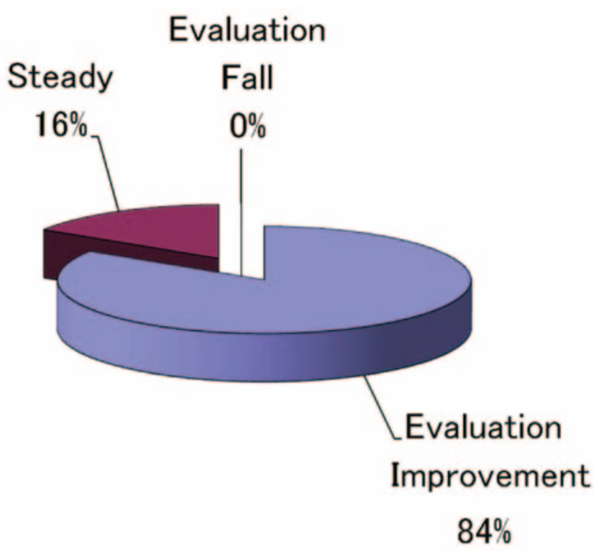

Fig. 5. Change of evaluation of consumers on aquacultured fish after communication with farmers.

the safety of food since 2001 when there was an outbreak of BSE in Japan. Now, there are two key words associated with food: Those are "Anzen" (safety) and "Ansin" (trust). Consumers demand the information about the production so they can judge whether a food is "Ansin" or not. No information means it is not "Ansin." In any case, it is thought to be important for aquaculture to farm fish properly according to the laws and regulations and supply information about production widely. Therefore, the introduction of a traceability system has been favorably received by consumers. It is quite possible that farmed fish for which there is no access to information about production will be excluded from market since consumers will not buy them. Supplying information may become very important to achieve sustainable aquaculture production in Japan. A new type of Specific Japan Agriculture Standard with Production Information was established in 2003. In that program the validity of production information is certified by Registered Certifying Bodies. Now, there are three Standards with Production Information for beef, pork and agricultural products. MAFF's staffs have been working for introduction of the standard for cultured fish. The private sector, including farmers and retailers, are interested in the traceability system. Some groups consisting of farmers and retailers or farmers by themselves have already established and are applying a similar system on their own.

Conclusion

Marine aquaculture provides various nutritional, social, and economic benefits to society. Aquaculture is and will continue to be an increasingly important food production industry for Japan. The Japanese experience is evidence how uncontrolled industrial growth, including aquaculture itself, can pollute coastal waters and destroy valuable aquaculture food resources, but this can be prevented by proper regulation. On the other hand, the environments that were damaged can be recovered through proper management and great effort. Furthermore, acquiring the confidence of consumers is very important for sustainable aquaculture production. Regulation alone may not produce consumer confidence; that can only be gained through the provision of accurate information on production methodology and product healthfulness.