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

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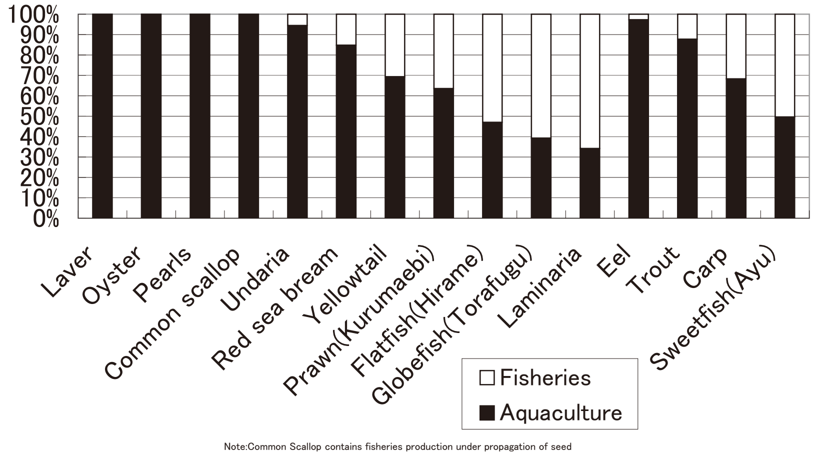

Fig. 1. Production Relation of Japanese Aquaculture in 2004.

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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