DEVELOPMENT OF FUKURO FUNORI (GLOIOPELTIS FURCATA) BREEDING REEF USING AN ARTIFICIAL SUBSTRATE

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ABSTRACT

With the decline in fishery production and progress of the aging of fishermen, facilities that enable safe fishing activities for the elderly and systematic production have been called for in the fishing industry in recent years. While high-quality fukuro funori (*Gloiopeltis furcata*) produced in the coastal waters off Kamiiso Town, Hokkaido, is an important source of income in winter, production has dramatically decreased in recent years. Consequently, there is strong demand for the development of a breeding technology that can be employed to achieve higher productivity and greater workability than the existing breeding method in which natural stones are used. Fukuro funori belongs to the Rhodophyceae class, and is distributed on rocks in the upper parts of the intertidal zones on the Sea of Japan coast. The species is an important resource used for food and manufacturing. The purpose of this study was to develop a fukuro funori breeding reef for effective use of an unused area of water (intertidal zone). A preliminary survey was conducted on five substrates made of different materials, which were placed in the sea at the test area. The survey results show that the most suitable substrate for adhesion and growth is nutrient-salt-eluting-type porous concrete utilizing coal ash waste. An examination was also conducted regarding methods of structuring, and arrangements for breeding facilities, taking the working environment of the elderly into account. Furthermore, commercialization of the substrate was promoted based on the results of the preliminary survey, and its effectiveness, including economic effect, was confirmed.

Keywords: Artificial substrate; Intertidal zone; Seaweed breeding reef; Unused fishing grounds; fukuro funori

INTRODUCTION

Due to the decline in fishery production and the aging of the fishing population, the fishing industry has recently been in need of facilities that allow elderly fishermen to safely engage in fishery activities and contribute to the household, as well as those that enable systematic fishery production [1]. In the coastal waters off Kamiiso Town, Hokkaido, high-quality fukuro funori (*Gloiopeltis furcata*) is produced and serves as an important source of income in winter. The amount of production, however, is small and work efficiency is low. Therefore, there has been a strong demand for the development of a breeding technology using artificial structures to achieve higher productivity and greater workability for elderly fishermen than the existing breeding method, which uses natural stone.

This research aimed to develop a breeding reef for fukuro funori (hereinafter referred to as funori reef) that enables effective utilization of unused waters (intertidal zone). The structure and arrangement for breeding facilities were studied and commercialized, taking into consideration an artificial substrate that was most suitable for epiphytic growth and as a working environment for the elderly.

PRELIMINARY SURVEY ON EPIPHYTIC STATE OF FUKURO FUNORI

The development of funori reef requires an understanding of the proper depth zone where fukuro funori becomes epiphytic. To this end, investigations into the epiphytic state of fukuro funori were carried out through visual observation and surveying at an intertidal zone used as a fishing ground in the waters off Kamiiso Town, Hokkaido.

As a result of investigations, in terms of epiphytic water depth of fukuro funori, the depth zone where fukuro funori grows abundantly in the intertidal zone of D.L.-40～100 cm was D.L.-20～+60 cm. It was also established that this depth zone had a great number of natural shore reefs where spores of fukuro funori could become bottom-seated.

Although the target area of this research is located in the vicinity of the aforementioned fishing ground, it is a flat rock area not used for other fishery activities and the ground is lower than the depth zone where fukuro funori remains epiphytic (Fig. 1).

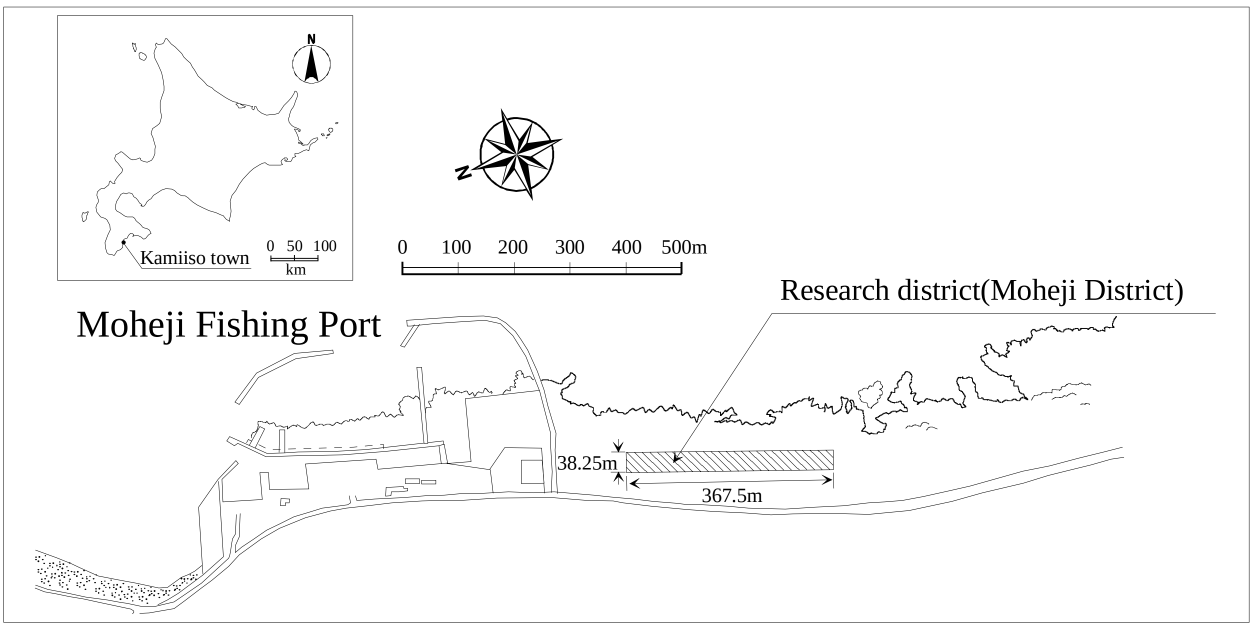

Figure 1. Research locations

As mentioned above, we concluded that unused fishing grounds would be available as an epiphytic substrate of fukuro funori by installing an artificial substrate in the intertidal zone by taking the aforementioned appropriate depth zone into account.

FIELD TESTS USING TEST REEFS

Aiming to select a substrate suited for the epiphytic growth of fukuro funori, test substrates of different materials were chosen for field tests. Test reefs were stand-alone reefs consisting of base concrete (W=1.5 m, L=2.0 m, H=0.2～0.6 m) and substrate test panels. As indicated in Fig. 2, they were inclined and positioned with the seaward side low and the landward side high.

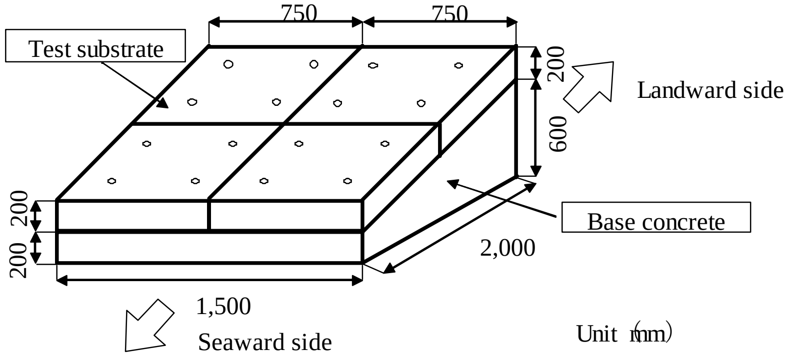

Figure 2. Profile of test reef (schematic diagram)

Five types of test substrates were prepared: ① concrete; ② ceramic block; ③ FRP plate; ④ natural stone; and ⑤ cellular concrete made by mixing concrete and used desulfurizing agent, which gradually elutes nutrient salt 2）(hereinafter referred to as cellular concrete). With regard to substrates ①, ② and ⑤, comparative studies were also carried out on panels after surface roughening by washing finish.

Test substrates were installed at certain intervals parallel with the coastline at the flat shore D.L.+0.2～+0.8 m within the habitat of fukuro funori (Photo 1). The period of installation was from mid-May to late June, when spores of fukuro funori are generated. Spores were artificially dispersed on the grounding substrates and epiphytic surveys were conducted over two years.

Photo 1. State of test reef installation

From January to April after the installation of test reefs, fukuro funori was sampled from the top surface of test substrates in all test blocks four times and the results, converted into average catch per square meter (calculated by the mean value each time), are described in Fig. 3.

In terms of epiphytic quantities of fukuro funori among these substrates, cellular concrete (rough surface finish) topped the list with approximately 0.8 kg/m^2, followed by ceramic block (biscuit fired) with approximately 0.5 kg/m^2 and natural stone with about 0.3 kg/m^2.

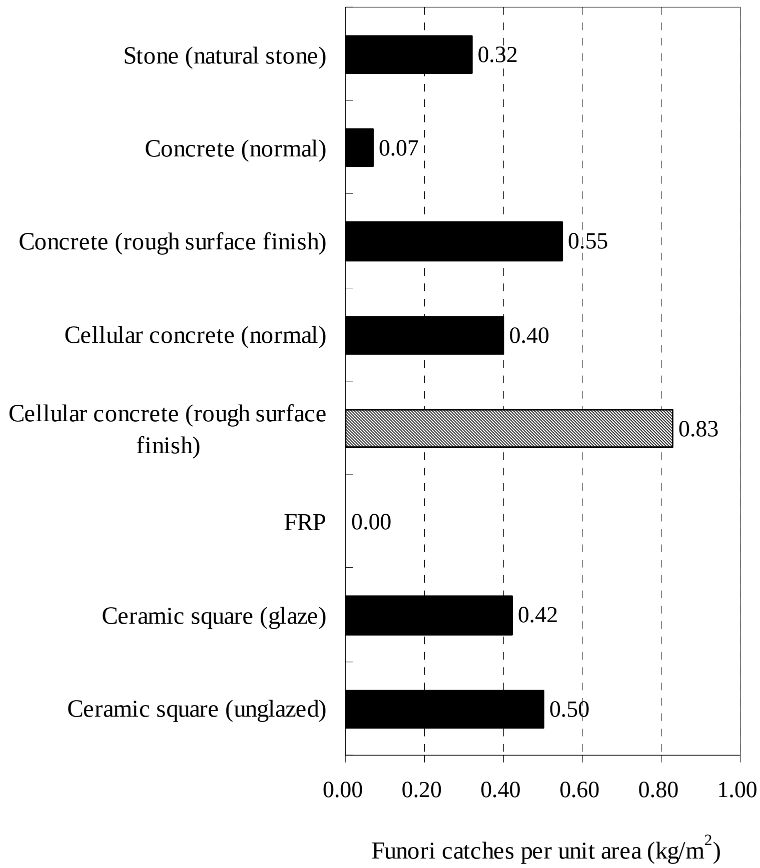

Figure 3. Substrates and average catch of fukuro funori

In addition, visual observation indicated the uniform epiphytic presence of fukuro funori on the surface of cellular concrete. On the surfaces of some test substrates, however, other types of seaweed (amanori or Porphyra, shiogusa or Cladophora, aosa or sea lettuce) were dominant, with fukuro funori epiphytic only in gaps and rims of the substrates. The following issues were specified during harvesting of fukuro funori:

① Since epiphytic fukuro funori is not uniform on natural stone, fishery efficiency declines.

② Epiphytic quantities of fukuro funori are small on ceramic blocks, concrete blocks and FRP plates (Photo 2).

With regard to substrate surface profiles, past research reported that the epiphytic nature of kelp, diatom, etc. is mostly observed on cellular concrete whose surfaces were washed [3,4,5,6].

This indicates that the epiphytic growth of fukuro funori is affected by the surface profiles of substrates, thus presumably resulting in more epiphytic quantities of fukuro funori on cellular concrete than on other substrates. Accordingly, cellular concrete as the funori reef substrate results in high epiphytic quantities of fukuro funori. Cellular concrete, which does not cause the appressorium of the fukuro funori to scale off during collection, was thus selected and commercialization of funori reefs was studied.

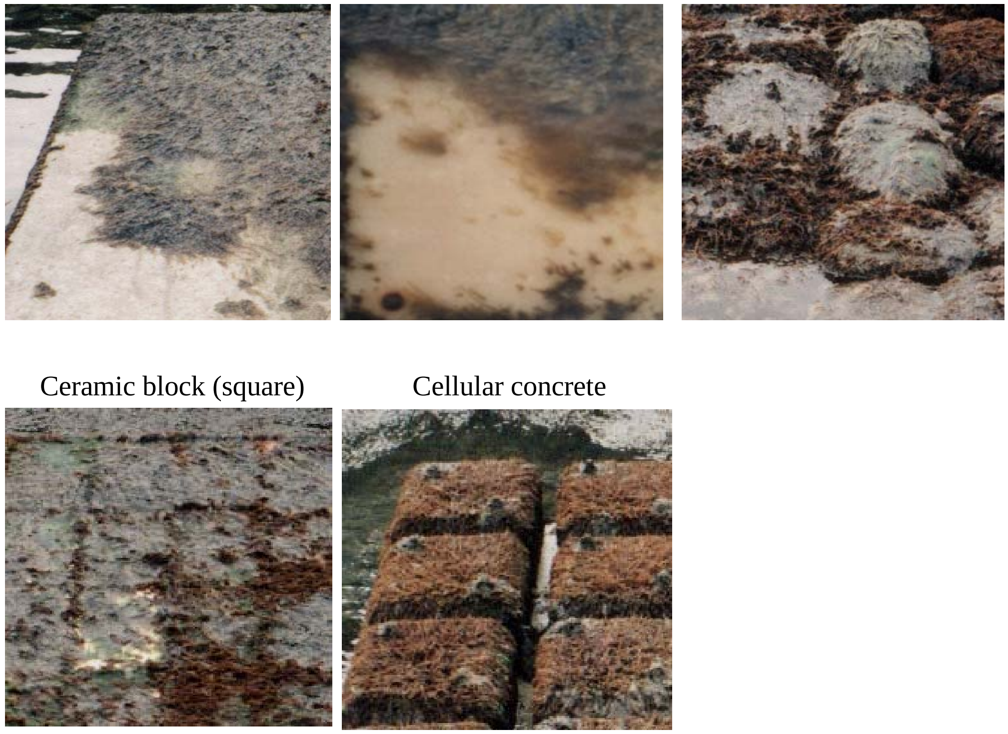

Photo 2. Epiphytic state of test reefs

REQUIREMENTS FOR ESTABLISHMENT OF FUNORI REEFS

Selection of substrate

As the substrate to be used for funori reefs, cellular concrete was adopted for the following reasons: ① Fukuro funori germinates early and its epiphytic volume is the greatest; ② Strong adhesion of the appressorium causes little scaling off due to factors such as external force; ③ Due to the early initial growth, epiphytic volume is uniform and other types of seaweed scarcely take hold. The compressive strength of cellular concrete is almost the same as concrete (design strength: 18 N/mm^2; proportioning strength: 24 N/mm^2).

Profile and structure

The cellular concrete employed during field tests used the panel-type (W=0.3m, L=0.3m, H=0.15m) substrate. Since results showed that some inter-panel gaps were not utilized, however, cellular concrete was used only for the upper part, i.e. epiphytic side.

The funori reef resembled a mound created by joining flat slopes and was a stand-alone reef (Fig. 4).

This structure of combined slopes had a larger epiphytic area of fukuro funori than that of the horizontal plane on the test reef. This will ultimately enable increased catches. The slope structure also alleviates burdens on the body when elderly fishermen engage in fishery work, which is considered to contribute to improving fishing efficiency. Furthermore, being a stand-alone reef makes facility maintenance and management easier.

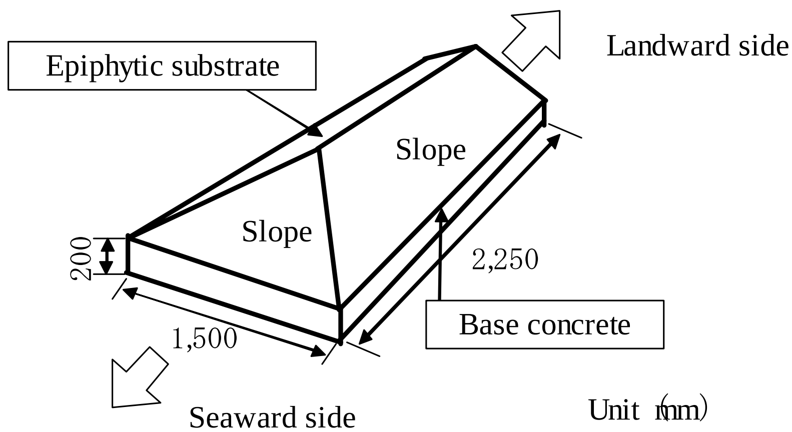

Figure 4. Profile of funori reef（schematic drawing）

The funori reef consisted of unreinforced concrete in the lower part and cellular concrete in the upper grounding substrate. It was created by separately manufacturing and then coupling the upper grounding substrate and the lower base concrete (Fig. 5).

Although the fabrication (deforming and translocation) and establishment of the funori reef requires lifting lugs, the reinforcing bars rust due to seawater and the rust, together with volume expansion, ultimately destroys concrete. In addition, lifting lugs conventionally exposed to surfaces may cause workers to tumble and sustain injuries during harvest work, for example, and therefore should be exposed to concrete surfaces as little as possible. To this end, it was decided to use the DH anchor.

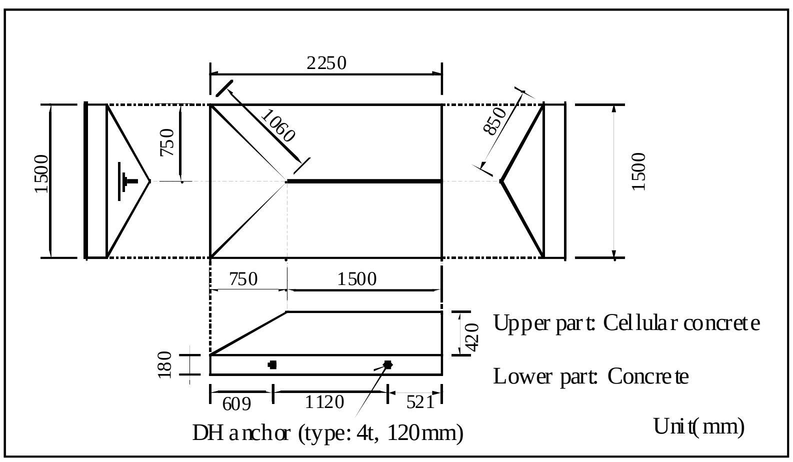

Figure 5. Structural drawing of funori reef

Strength & stability

With regard to the strength and stability of funori reef, the proportion of base concrete required, the weight required to withstand ocean waves and the withdrawal resistance of lifting lugs were calculated.

Proportion of concrete

The funori reef was installed at sea and in splash zones, and was more consistent with a wave-dissipating block than an ordinary toe-protection block. According to "Surface Scaling of Coastal Structures by Frost Damage in Hokkaido" by the Hokkaido Civil Engineering Institute Concrete Research Committee (presentation material in April 1981), high durability is required especially in cold, snowy areas like Hokkaido, due to the repeated exposure to freezing and thawing in winter. In the aforementioned material, the following items were identified as methods of minimizing surface scaling:
①When the unit cement content reaches 290 kg/m3 or more, scaling degrees become smaller.
②Scaling degrees are small when the water-cement ratio is 48% or less.
③Away from the shoreline, scaling degrees become smaller. When the distance from the shoreline is 16 m or more, scaling rarely occurs.
④When the number of freezing and thawing cycles exceeds 60, scaling occurs suddenly.
Taking these items into account, the proportion of the upper concrete, which becomes the intertidal zone, was set at 48% or below in water-cement ratio and the maximum dimension of coarse aggregate was established at 15 mm to ensure that surface washing effects would be fully demonstrated. In addition, the proportion of base concrete, which remains underwater, was set to satisfy the requirements of C-4, as described in Table I which shows requirements by reference number.

Table I: Requirements of concrete proportion by reference number

Application	Upper concrete	Base concrete
Reference number	-	C-4
Specified concrete strength(N/mm^2)	18	18
Slump(cm)	8	5
Air content	4.5	4.5
Maximum W/C	48	55
Gmax (mm)	15	40
Used nominal strength	27	24
Used nominal strength	47.0	51.7

Mass required to withstand ocean waves

To study the stability of funori reef against wave power, stability calculation of structures was conducted. As the offshore wave used for the calculation, the wave with a return period of 30-years in the target waters was used: 5.2 m in waveheight; 11.5 seconds in period; and 1/50 in sea-bottom gradient.
Given that the funori reef was installed in the intertidal zone, calculation was carried out while taking breaking waves into consideration.
Calculation results indicated that the unit mass whereby no tumbles or slides occurred at the design flow velocity of 1.31 m/s in the breaking wave zone was 2.932 t.
c) Withdrawal resistance of lifting lugs
Lifting lugs are necessary for deforming works during the fabrication of funori reef, for translocation works during transportation and during installation at sea. In this regard, the withdrawal resistance of concrete during operations was studied.
Lifting lugs were used at four locations on the sides of the base concrete of funori reef, and utilization of scales was considered for lifting purposes. The maximum load per location during translocation and installation by lifting was 5.36 KN and 10.84 KN, respectively, and it was decided that a 4 t (39.2 KN) DH anchor be used, taking into consideration the bending (shearing) load of 21.68 KN during lifting.
Considering the safety factor of 2.5, the allowable withdrawal resistance of the DH anchor was 163.6 KN, and it was confirmed that the said resistance satisfied the maximum load of 10.84 KN.

Installation & layout requirements

The most important requirements for the installation of funori reef are the growing conditions of fukuro funori, and the details are as follows:
① Choose locations with relatively flat submarine topography, considering the growing depth of fukuro funori (D.L.-0.2～+0.6m) as well as the conservation and workability of facilities.
② Since the bottom sediment of installation locations is rock, unify the installation level of grounding substrates through excavation in order to lay the facilities in a growth depth zone appropriate for fukuro funori.
The layout requirements taking into account the workability of fishermen are explained below:
① Adopt a staggered arrangement to prevent seawater surrounding funori reefs from becoming stagnant. Considering the fact that outboard motor boats enter the waters at high tide for the maintenance of facilities, retain a distance of at least 1 m on all four sides of each reef.
② Regarding orientation, ensure that the triangular slopes face the seaward side to release sand and other impurities which mix into the upper part of the substrate by overflow.

COMMERCIALIZATION OF FUNORI REEF

In FY 2001, three years after the preliminary survey concerning the creation of funori reefs commenced, the developed funori reefs were adopted as the nation's Fishing Port and Fishing Ground Functional Advancement Project, leading to the commencement of funori reef construction as the first public works project.
The project was executed at the Moheji District, located in the waters on the right bank of Moheji Fishing Port. Specifically, the location was an unused fishing ground that had a flat rock area in an intertidal zone. Regarding the water depth zone where funori reefs were installed, the flat shore was excavated to unify the height of grounding substrates in accordance with the range D.L.-0.2～+0.6 m, luxuriance depth subject to fishery production.
Over the three years from FY 2001, when construction was initiated, to FY 2003, a total of 488 reefs were installed and arranged in a strip layout: four reefs covering 38.25 m in the offshore direction (2.25-m intervals) and 122 reefs covering 367.5 m in the coastal direction (1.5-m intervals) (Fig. 6).
The period of funori reef installation was from May to June, when fukuro funori generated spores, and spores were dispersed after installation. After the funori reefs were installed, epiphytic surveys were carried out during the fukuro funori fishing period (December – April). The survey results were verified by measuring epiphytic amounts per unit area.

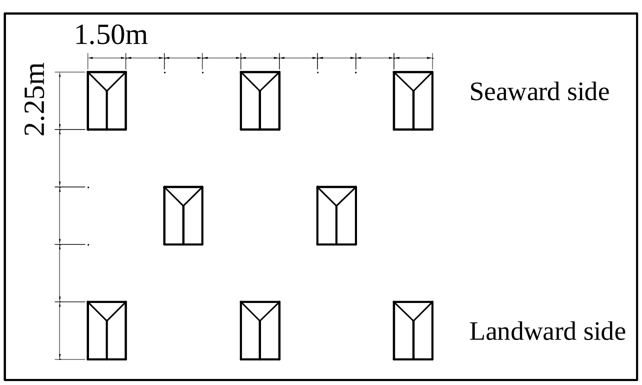

Figure 6. Layout of funori reefs

PROJECT IMPLEMENTATION EFFECTS

During the epiphytic survey conducted in February 2003 following the installation of the commercialized funori reefs, the epiphytic condition of fukuro funori was verified through visual observation. As a result, it was confirmed that fukuro funori covered the entire grounding substrates, and that fukuro funori was growing on all installed funori reefs (Photos 3 & 4). In December 2003, the first harvest of fukuro funori growing on the funori reefs began. The estimation of the average catch (calculated using the average value each time) during one fishing season (December – April) based on the epiphytic amount of fukuro funori on the developed funori reefs was approximately 1.1 kg/m^2, an increase of 37% from the preliminary survey results (approximately 0.8 kg/m^2).

Currently, fukuro funori is harvested by six teams consisting of six to seven people each using the joint collection method. They alternate harvesting fukuro funori at low tide from January to March. The daily harvest is limited to 100 kg due to production regulations.

Photo 3. Installation conditions of funori reefs

Photo 4. Epiphytic condition of fukuro funori

As of FY 2003, fukuro funori was shipped for 1,000 to 3,000 yen per kg. More than 10 kg is harvested daily per person, therefore it is possible to earn 10,000 yen or more for approximately two hours' work.

Starting in FY 2004, funori reefs as large as those in the Moheji District have been constructed in the Tobetsu District, located in the same waters. According to estimates, both districts will be able to achieve a production output of approximately 25 million yen upon completion.

CONCLUSIONS

Major findings of this research are as follows:
(1)Funori reefs or artificial structures using substrates with a high percentage of epiphytic fukuro funori were developed, which enabled effective utilization of unused fishing grounds.
(2)Depth zones with abundant fukuro funori and workability during the harvest of fukuro funori by elderly and female fisherpersons were taken into consideration while the installation and layout of funori reefs were studied, respectively.
(3)During the epiphytic survey carried out after the installation of funori reefs for commercialization, epiphytic fukuro funori was confirmed on the entire grounding substrates.
(4)As a result of estimating the average catch per fishery season based on the epiphytic amount of fukuro funori on the developed funori reefs, it has become possible to harvest 37% more than the amount harvested during the preliminary survey.
(5)Increased production of fukuro funori, whose unit price is high, has become possible, making it achievable to secure stable fishery incomes during winter, i.e. fishing off-season.

Issues to be addressed are as follows:
(1)Since depth zones and oceanographic conditions required for growth of fukuro funori differ significantly depending on the water and area, sufficient preliminary surveys and study of the profiles and weight of funori reefs are imperative for any similar project.
(2)Due to the fact that the range of water depths where fukuro funori grows is small in Hokkaido – 10-20 cm in the Sea of Japan and 40-80 cm in the Pacific, high installation accuracy is required.
(3)Commercialization has enabled large amounts of fukuro funori to be produced according to plan; however, it is necessary to develop new means of distribution and processing as well as marketing outlets without triggering the collapse of the pricing system.
Continued investigation into effects of funori reefs is necessary because the number of years elapsed since the project execution is small and, generally speaking, the standing stock of seaweeds fluctuates significantly every year.

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