DEVELOPMENT OF PROTECTIVE AND FEEDING FACILITY IN THE ARTIFICIAL REEF FOR STOCKED ROCKFISH AND GROUPER JUVENILES

Kyoko AOKI[1], Kazushi SOGO[1], Keiji KIMIGAWA[2], Hiroshi KAWATA[3], Noritsugu YAMAJI[3], Masashi MIYAGAWA[4] and Yoshihiro SUENAGA[5]

[1] SUNX CO., LTD
2171 Kaniwa, Miki, Kagawa, JAPAN
aoki@sunx.ne.jp
[2] Kuroshio Marine Tech. CO., LTD
[3] Nihon Kogyo, CO., LTD
[4] Kagawa Prefectural Fisheries Experimental Station
[5] Faculty of Engineering, Kagawa University

ABSTRACT

Cultured Oblong rockfish, *Sebastes oblongus*, and Red spotted grouper, *Epinephelus akaara*, have been released for stock enhancement in Seto Inland Sea in Japan to improve declining fisheries for these high valued species. However, released cultured juveniles are vulnerable to intense predation due to their sluggish movement and lack of predator avoidance behavior. This juvenile predation has resulted in a poor recovery rate for the stocking project in Kagawa Prefecture over the last twelve years. To address this problem, we developed and tested a new protective shelter module that can be placed in a standard artificial reef unit to provide enhanced nursery habitat for released juveniles. The newly designed reef shelter modules function by providing both shelter from predation and food for the juveniles. Internal size-restricted shelter spaces allow juveniles to hide and escape their larger predators. The abundant porous substrate provided is readily colonized by an abundant benthic community that provides food for juveniles. By increasing stocked juvenile survival, these dual function modules may improve the return-on-investment for stocking programs.

INTRODUCTION

In the Seto Inland Sea, the water quality and habitat conditions have become seriously degraded by pollution and habitat loss over the last 40 years. The fish catch of the Seto Inland Sea is decreasing despite recent improvements in water quality. Several factors have contributed to the degradation. For example, seaweed beds, tidal flats and shoal habitats have disappeared. During the rapid economic growth in Japan, (especially the post-WWⅡ period) industrial and domestic wastewaters were discharged without treatment and the shoal areas were reclaimed for high priority economic development projects. As a result, the Seto Inland Sea used to be called "Dying Sea."

To improve the environment of the Seto Inland Sea, the water quality control measures were amended. Due to reductions in volume and Chemical Oxygen Demand (COD), the quality of discharged wastewater has improved, but the aquatic environment in the Seto Inland Sea has not. The loss of seaweed beds, tidal flats and shoals has altered the normal material cycle of the Seto Inland Sea, especially organic matter. Harmful algal blooms, oxygen deficient water and the accumulation of sludge that is rich in organic matter have become serious habitat problems. These conditions have caused significant adverse impacts on fish catch. The disappearing seaweed beds are especially serious (Ministry of Agriculture, Forestry, and Fisheries, 2003) as these typically provide sheltered nursery areas for juvenile fish.

Public projects to release cultured rockfish and grouper juveniles for stock enhancement have been carried out around the Seto Inland Sea. However, because of their sluggish movement and defenseless behavior, juvenile survival has been very poor (estimated at less than 1%).

To improve the survival of cultured juvenile and thus promote stock enhancement, juveniles need both shelter to protect them from predators and access to sufficient food. The objective of this study was to develop the artificial habitat facility that can protect and feed them effectively. We conducted field experiments to examine the performance and functioning of newly design shelter modules.

MATERIALS AND CONSTRUCTION OF THE FACILITY

The facility (the shelter module) consists of plates made from porous concrete. The paper by Miyagawa et al. (2013) and Kimigawa et al. 2011 clearly indicated that the most appropriate porosity of the plates for promoting benthic fouling is 30 % and the gap between plates is 3cm. Therefore, in this study, we made the plates with a porosity of 30 % and fixed the plates so that the gaps between them were 3cm.

Elevation and plate view of the shelter using porous plates is shown in Figure 1.

Figure 2 shows the concentration of prey organisms on the shelter after 120 days from installation.

Figure 3 shows the number of the predators that were able to penetrate the gaps and the number of the surviving juveniles (Miyagawa et al. 2008 and 2013, Yasuoka et al. 2007 and 2011).

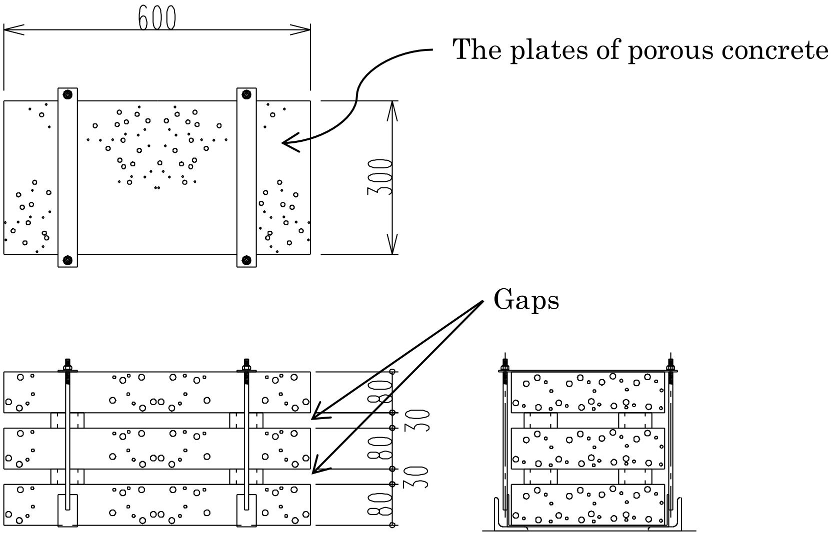


Figure1. Elevation and plate view of the shelter

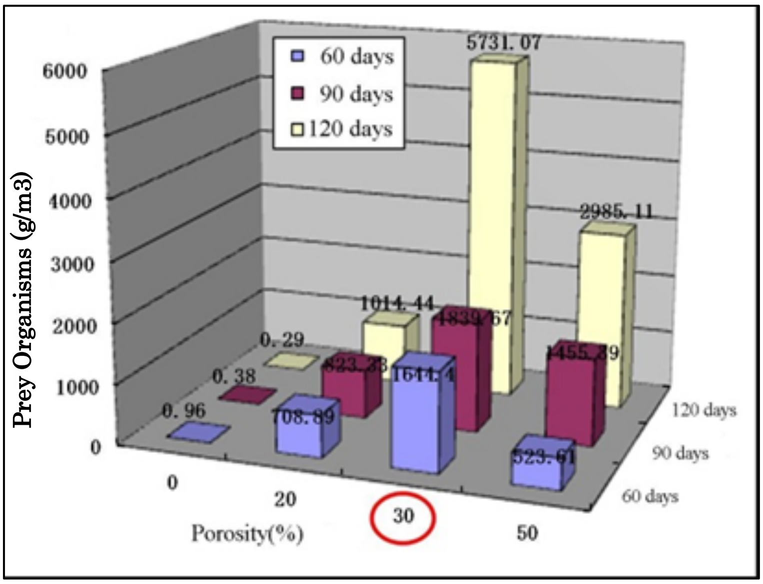


Figure 2. The number of prey organisms on the shelter and its porosity (Miyagawa et al., 2013 and Yasuoka et al., 2007, 2011)

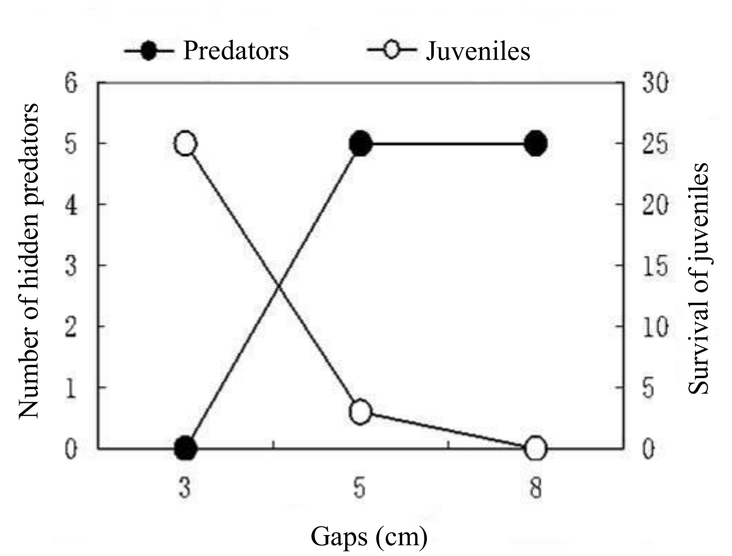


Figure3. Number of the predators that were able to penetrate the gaps and number of the surviving juveniles (Miyagawa et al., 2013)

METHODS

Miyagawa et al. (2013) and Nagatomi et al. 2013, carried out the experiments in a large tank (H120mm × W2000mm × L5000mm) with the shelters that had 3cm gaps. In the experimental area, (with the shelters) most of the juveniles (Oblong rockfish) survived. In the control area, (without the shelters) two-thirds of the juveniles were lost to predation. Similarly, in the field experiments, the efficacy of the new shelter was compared with the control area which used existing technology constructed with 1 ton natural rocks (rock reef volume was 52 m3 and void volume was 22 m3) to confirm the lab findings. The experiments were carried out in the Seto Inland Sea and additional data was collected and evaluated to determine the efficacy of the shelters as a protective and feeding facility. Our experiments used Red spotted grouper but the shelter and food requirements are similar for rockfish.

Experiment Ⅰ

We constructed 4 artificial reef units and each unit had 4 blocks. We equipped 4 shelter modules per block on upper part of it. The plan view reef unit shape is octagonal as shown in Figure 4. We installed these reef units near Ibuki Island as shown in Figures 5 and 6. These reefs were installed on the west side of the island and natural rocks were installed on the east side as the control area. One year after installation, we released about 5,000 cultured juvenile Red spotted grouper on both the experimental artificial reefs and control area, respectively.

We investigated juvenile fish abundance monthly at each site for four months. It was possible to count the released juveniles exactly because they were marked with fin clip before release.

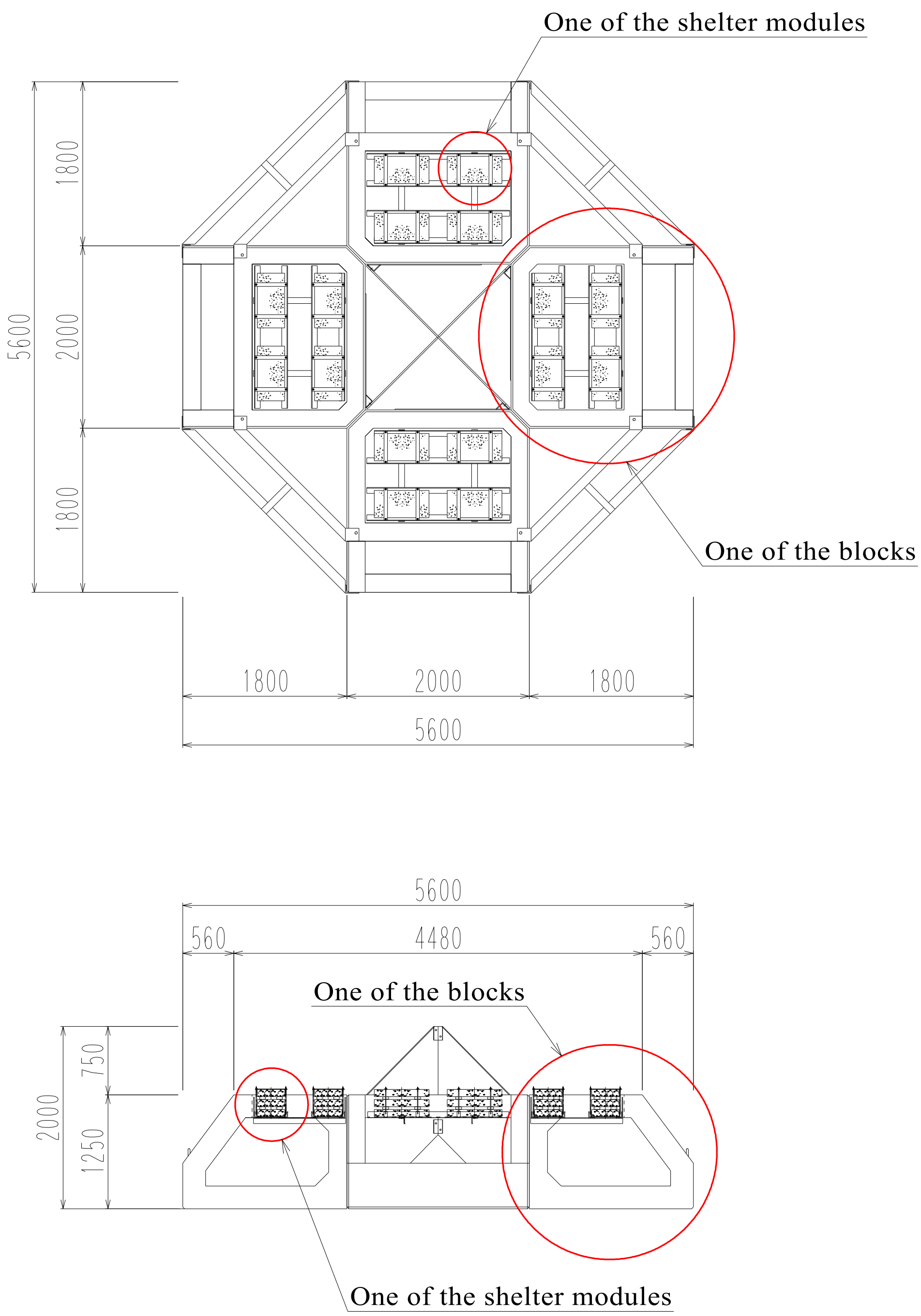


Figure 4. The artificial reef unit which is equipped with the shelter modules (16 sets)

Figure 5. Location of Ibuki Island, Kagawa, Japan and experimental sites (1)

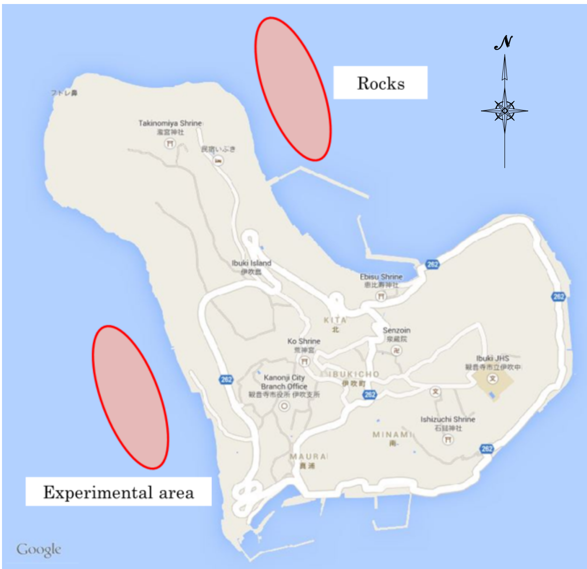


Figure 6. Experimental area (4 Artificial Reef Units) and control area (Natural Rocks)

Experiment Ⅱ

In this experiment, we made two types of blocks (Type Ⅰ and Ⅱ shown in Figure 8) one each, which were components inserted in the octagonal artificial reef unit frame. We set 6 shelter modules in the upper part of the one of the two (Type Ⅰ). Type Ⅱ blocks each have 6 shelter modules in upper and lower sides as shown in Figure 7. The shelter module used for Experiment Ⅱ is smaller than that used for Experiment Ⅰ.

We installed the blocks and released 5,000 juvenile Red spotted grouper on the same day in Abu, Yamaguchi, Japan as shown in Figures 8 and 9. After releasing, we estimated the number of fish at the site for 5 months (October 2013 to February 2014). The counting of juveniles was conducted by diving survey and their behavior was recorded using video camera.

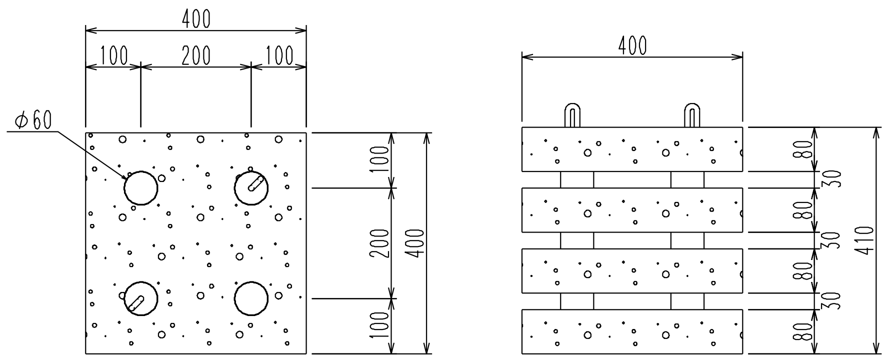
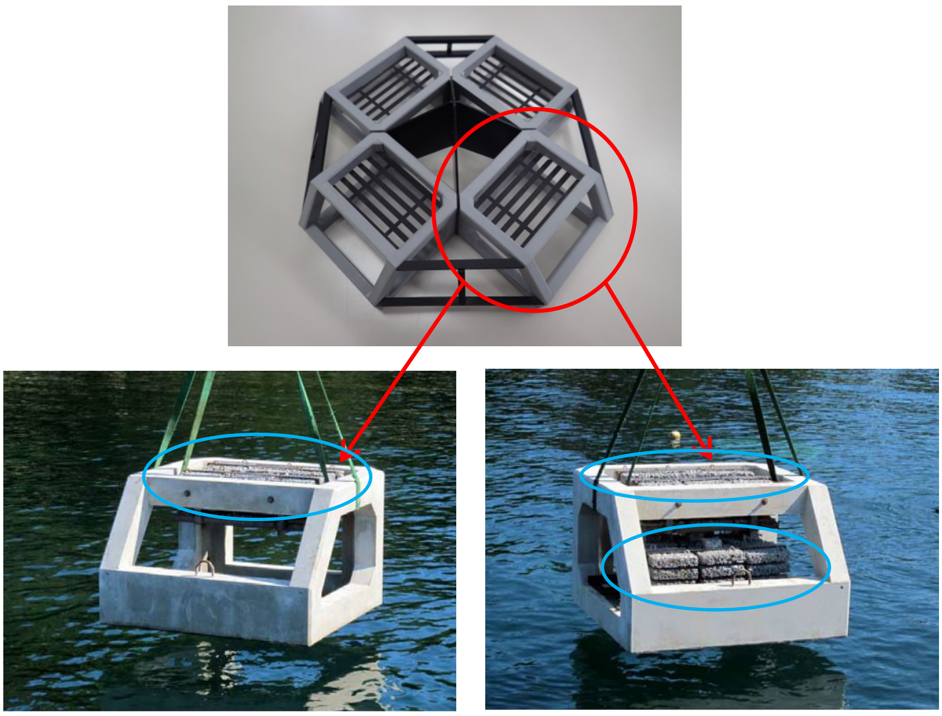


Figure 7. The second type of the shelter



Type I :HBP4-1　　　　　　　　　Type II :HBP4-2

Figure 8. Two kinds of blocks which were installed in Abu, Yamaguchi, Japan

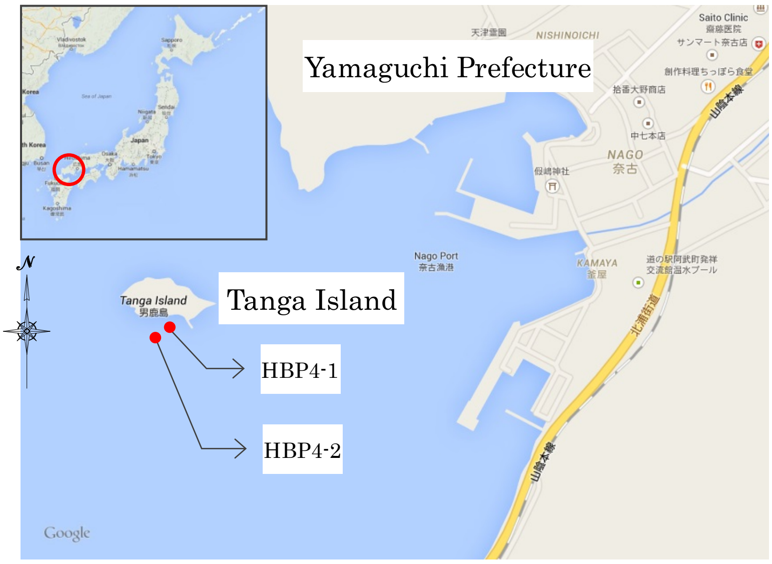


Figure 9. Experimental site (2) (Abu, Yamaguchi, Japan)

RESULTS AND DISCUSSION

Experiment I

The fish count results are shown in Figures 10 and 11. The numeric data for each site are the number of marked juveniles captured divided by the number of fishing effort (4 hours per day) in the experimental area. The number under the ratio is the average of fisheries catch. Using this average ratio, we evaluated fish yield rate and used this as an index of how well the shelter and food increased the survival of juvenile fish. Figure 10 shows the result of fisheries catch during four months. Figure 11 depicts catch for each period. There are seasonal changes, but there are some common points in all periods. The number of captures is higher in southwest area of the island. Compared with control area, there is little variation in numbers. We postulate that the released juveniles have settled in the experimental habitat area and that the shelters have reduced predation and provided food. Based on the higher number of juveniles observed on the experimental site, we postulate that survival is greater where shelters are present.

Figure means Catch Per Unit Effort (CPUE)

= Number of Red spotted grouper catch / The day of fishing effort

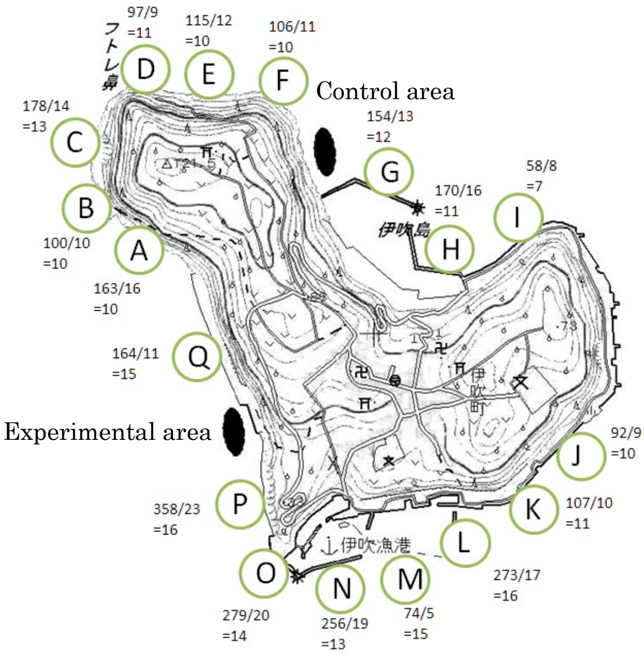
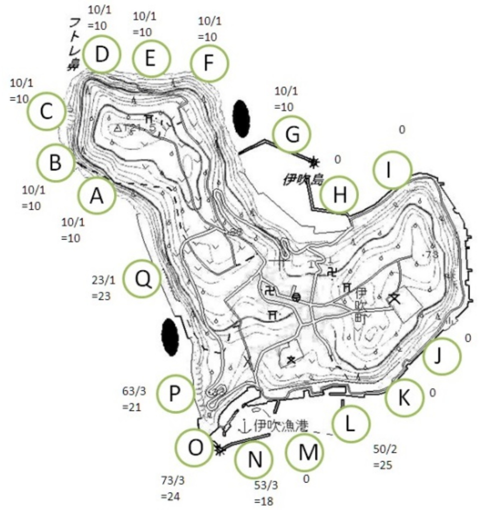
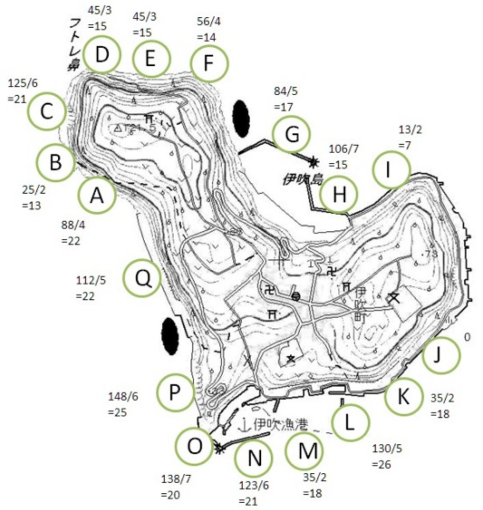


Figure 10. Overall results for four periods

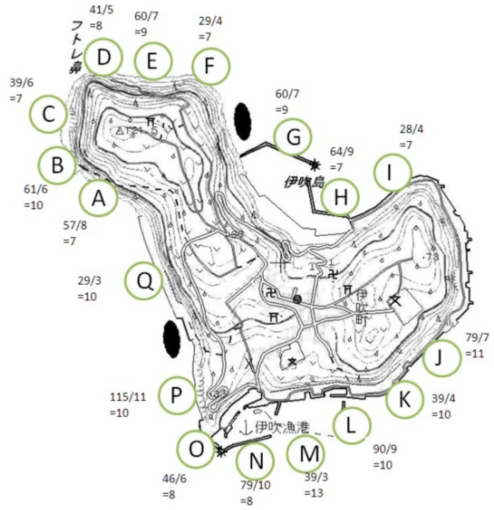
(June 26-September 19, 2013 2,745/223=12)



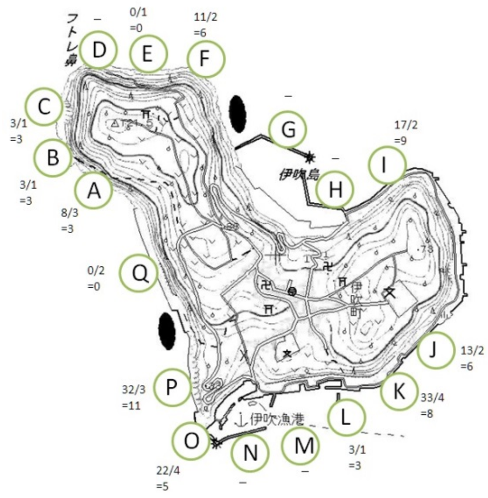
June 26-29, 2013 335/19=18



July 7-29, 2013 1,310/69=19



August 3-27, 2013 956/109=9



September 10-19, 2013 144/26=6

Figure 11. The results for each fishing period

Experiment II

Tables 1 to 5 show the results of observed fishes aggregated in and around the blocks. The number of fish species observed gradually decreased with decreasing water temperature. The number of released juveniles (Red spotted grouper) observed also decreased with decreasing water temperature. However, their number began to increase again in December. It is assumed that there were initially no abundant epibenthic prey and seaweeds for juveniles because the blocks were installed on the same day the juveniles were released. Even if the juveniles were able to take refuge and hide in the shelter, when they became hungry, they would have to go exit to find food. This suggests that we should delay the release of juveniles until such time as the benthic community has adequately developed on the shelter modules. In addition to fish, some shellfish that consume seaweeds, such as horned turban (*Turbo cornutus*) were observed. From this finding we suggest that the shelters have high seaweed spore adherence due to its porosity.

The results indicate that the juveniles utilized the shelters in spite of the lower water temperature. As long as the food is available on the shelters, the fish returned.

Table 1. The species and number of fish (October 2013)

The first survey　　October 5, 2013(24.0℃)

Block	Order	Family	Species	Length(cm)	Number of fish
HBP4-1	Perciformes	Serranidae	*Epinephelus akaara*	5	9
		Blenniidae	*Petroscirtes breviceps*	5	15
		Carangidae	*Trachurus japonicus*	10	100
		Girellidae	*Girella punctata*	5	3
		Labridae	*Halichoeres poecilopterus*	10 ～ 20	30
			Halichoeres tenuispinnis	10 ～ 15	20
			Pseudolabrus japonicus	10 ～ 15	5
		Pomacentridae	*Chromis notatus notatus*	5 ～ 10	5
		Apogonidae	*Apogon semilineatus*	7	50
		Leiognathidae	*Nuchequula nuchalis*	4	3
	Scorpaeniformes	Scorpaenidae	*Pterois lunulata*	25	1
			Sebastiscus marmoratus	15 ～ 20	3
			Number of kinds	12	
HBP4-2	Perciformes	Serranidae	*Epinephelus akaara*	5	11
		Blenniidae	*Petroscirtes breviceps*	5	10
		Carangidae	*Trachurus japonicus*	10	300
		Girellidae	*Girella punctata*	5	2
		Labridae	*Halichoeres poecilopterus*	10 ～ 15	20
			Halichoeres tenuispinnis	10 ～ 15	10
		Pomacentridae	*Chromis notatus notatus*	5 ～ 10	5
		Apogonidae	*Apogon semilineatus*	7	100
		Leiognathidae	*Nuchequula nuchalis*	4	5
	Scorpaeniformes	Scorpaenidae	*Pterois lunulata*	25	2
			Sebastiscus marmoratus	15	2
	Tetraodontiformes	Monacanthidae	*Stephanolepis cirrhifer*	3 ～ 5	10
			Number of kinds	12	

Table 2. The species and number of fish (November 2013)

The second survey — November 13, 2013(19.5℃)

Type	Order	Family	Species	Length(cm)	Number of fish
HBP4-1	Perciformes	Serranidae	*Epinephelus akaara*	5 ～ 6	5
			Epinephelus akaara	6 ～ 8	3
		Siganidae	*Siganus fuscescens*	3 ～ 7	10
		Labridae	*Halichoeres poecilopterus*	10	1
			Halichoeres tenuispinnis	3 ～ 10	20
		Apogonidae	*Apogon semilineatus*	4	4
	Scorpaeniformes	Scorpaenidae	*Sebastiscus marmoratus*	6 ～ 7	1
			Number of kinds	6	
HBP4-2	Perciformes	Serranidae	*Epinephelus akaara*	5 ～ 6	3
		Siganidae	*Siganus fuscescens*	3 ～ 7	10
		Blenniidae	*Petroscirtes breviceps*	6	1
		Carangidae	*Trachurus japonicus*	8	50
		Labridae	*Stethojulis interrupta terina*	3	1
			Halichoeres poecilopterus	10	1
			Halichoeres tenuispinnis	8	30
		Apogonidae	*Apogon semilineatus*	4	5
	Scorpaeniformes	Scorpaenidae	*Sebastes inermis*	10	10
			Sebastiscus marmoratus	3 ～ 4	2
	Tetraodontiformes	Monacanthidae	*Rudarius ercodes*	3	5
			Number of kinds	11	

Table 3. The species and number of fish (December 2013)

The third survey — December 7, 2013(18.0℃)

Type	Order	Family	Species	Length(cm)	Number of fish
HBP4-1	Perciformes	Serranidae	*Epinephelus akaara*	6	3
		Labridae	*Halichoeres tenuispinnis*	7 ～ 10	30
			Pteragogus aurigarius	9	1
			Number of kinds	3	
HBP4-2	Perciformes	Serranidae	*Epinephelus akaara*	6	2
		Labridae	*Halichoeres tenuispinnis*	7 ～ 10	15
	Scorpaeniformes	Scorpaenidae	*Sebastiscus marmoratus*	5 ～ 10	3
	Tetraodontiformes	Monacanthidae	*Rudarius ercodes*	3	5
			Number of kinds	4	

Table 4. The species and number of fish (January 2014)

The forth survey — January 14, 2014(13.5℃)

Type	Order	Family	Species	Length(cm)	Number of fish
HBP4-1	Perciformes	Serranidae	*Epinephelus akaara*	4	3
			Number of kinds	1	
HBP4-2	Perciformes	Serranidae	*Epinephelus akaara*	7	8
		Labridae	*Pseudolabrus sieboldi*	10	1
			Halichoeres tenuispinnis	1	1
			Halichoeres tenuispinnis	3 ～ 5	10
		Pomacentridae	*Chromis notatus notatus*	5	4
	Beryciformes	Monocentridae	*Monocentris japonica*	5	1
			Number of kinds	5	

Table 5. The species and number of fish (February 2014)

The fifth survey February 6, 2014(12.5℃)

Type	Order	Family	Species	Length(cm)	Number of fish
HBP4-1	Perciformes	Serranidae	*Epinephelus akaara*	8	6
		Pomacentridae	*Chromis notatus notatus*	8	5
			Number of kinds	2	
HBP4-2	Perciformes	Serranidae	*Epinephelus akaara*	8	2
		Labridae	*Pseudolabrus japonicus*	12	2
		Pomacentridae	*Chromis notatus notatus*	8	10
	Scorpaeniformes	Scorpaenidae	*Sebastiscus marmoratus*	7	1
			Number of kinds	4	

CONCLUSIONS

Field experiments conducted in the Seto Inland Sea area, confirm the effectiveness of the provided shelter materials. The previous artificial reefs did not provide the same level of protective and feeding functions as the currently modified reef units with shelter modules. The new shelter modules improve the conditions of these functions. Following are some merits of this approach.

1) The shelter can be installed manually within existing artificial reefs without the requirement for a crane-barge. The installation work is rather easy and quick.
2) It is not necessary to construct new artificial reefs. Simply installing the new shelter modules within existing artificial reef units improved shelter and food functions are created.
3) As a result of 1 and 2 above, the cost of modifying the shelter characteristics of an existing reef is less than installing new reefs, making this a cost-effective approach.
4) The height of the gap and the number of plates can be adjusted to the target species or growth stage as required.
5) For the analysis of the adhered prey epibenthos and seaweeds, the shelters can be recovered and brought to the laboratory easily with minimal loss.
6) Due to the shelter module's porosity, spores of seaweeds settle in high density and the shelter is thickly covered with them providing microhabitat for other food species.

Some further issues to be considered.
1) It is necessary to allow enough time for the epibenthic community to develop on the shelter before releasing juveniles. If not, the shelter effectiveness is reduced due to lack of forage available for juveniles.
2) Additional experimentation is needed to establish the most effective gap heights under long-term field conditions.

3) Further investigations are needed for other target species and different life stages to confirm the effectiveness of the shelter system over the target species life cycle.

ACKNOWLEDGEMENTS

We would like to express sincere thanks to Mr. K. Takasago (President of Takasago Fishery Co, LTD.), Mr. K. Sogo, (President of SUNX Co. LTD) and Mr. T. Kogane, (The Fisheries Research Agency, Tamano Division, a national research and development agency,) for their valuable comments and suggestions.
This research is supported by Grant-in-aid scientific research of the Ministry of Education, Culture, Sports, Science and Technology.

REFERENCES

1) Japan Ministry of Agriculture, Forestry and Fisheries, 2009: Fisheries Policy Outline for FY2009, pp.52-53.

2) Kimigawa, K. and A. Suenaga, 2011: Stability Calculation Report of Sea-Mark Reef Consideration of Sea Bottom Slope, pp.4-6.

3) Ministry of Agriculture, Forestry, and Fisheries, 2003: Guideline for the Planning of Fisheries Port and Fisheries Ground, Chapter 5, pp.180-182.

4) Miyagawa, M., Tochino, M., Aminaka, M., Fujiwara, M., Suenaga, Y. and Kakegawa, H. 2008: Research on the safer shelter for released fish juveniles, Proceedings of the Pacific Congress on Marine Science and Technology, 2008, pp.8-14.

5) Miyagawa, M., Kameyama, T., Fujiwara, M., Yasuoka, K., Matsuuchi, Y. and Suenaga, Y., 2013 : Development of protective shelter for stocked rock fish juveniles, Annual Journal of Japan Society of Civil Engineering in the Ocean Engineering, Vol.68, No.2, pp.1221-1226.

6) Nagatomi, T., T. Kameyama, N. Yamaji, H. Kakudo, M. Matsushima and Y. Suenaga 2013: Study on The Coefficient of Static Friction of the Artificial Reefs, Recent Advances in Marine Science and Technology 2012, pp.20-28.

7) Yamanaka, M., K. Yasuoka, T. Nagatomi, H. Kakegawa and Y. Suenaga, 2011: Research on Improvement of Bottom Sediment Environment by Porous Material, Proceedings of the 34th IAHR World Congress 2011, pp. 3160-3167.

8) Yasuoka, K., Y. Suenaga, T. Hoshino, H. Kakegawa and Hee-Do Ahn 2007: Research on the Relationship between Prey Abundance and Fish Aggregation. PACON International, Proceedings of Pacific Congress on Marine Science and Technology, pp.86-95.