

水中ビデオカメラにより記録した広島湾におけるカキ筏の 魚類相

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Assessment of ichthyofauna at oyster rafts in Hiroshima Bay, Japan, using underwater video cameras

Atsushi TSUYUKI and Tetsuya UMINO*

Abstract: There is little information on fish communities around oyster farms, though oyster rafts provide habitats for fish and are important fishing grounds. We investigated the ichthyofauna at oyster rafts supporting *Crassostrea gigas* in Hiroshima Bay, using underwater video cameras. The fish species composition around the rafts was unique, consisting of identified 18 species, with low similarities to the fish community in nearby littoral areas. Several commercially important fishes, including black sea bream *Acanthopagrus schlegelii*, filefish *Thamnaconus modestus*, and surfperch *Ditrema temmincki*, aggregated at the oyster rafts throughout the year. The abundance of *A. schlegelii* (68%–85% relative abundance) accounting for most of the fish at the rafts, except in summer. The video recordings revealed that *A. schlegelii*, *T. modestus*, and *D. temmincki* preyed on the sessile organisms (probably mollusks, crustaceans and macroalgae) which had abundantly attached to the oyster wires. Thus, the large and persistent aggregations of fishes suggests that the oyster rafts efficiently function as an artificial reef in the regional ecosystem.

Key words: Hiroshima Bay; Ichthyofauna; Oyster rafts; Video survey

The culture of Pacific oyster *Crassostrea gigas* is an important, large-scale industry in Japan, where total production in 2015 amounted to 116,332 tonnes (with shells), valued at approximately 38 billion yen (Ministry of Agriculture, Forestry and Fisheries 2017). This industry is concentrated in Hiroshima Prefecture, which contributes about 60% to total production (Hirata and Akashige 2004). Since the 1960s, there has been significant expansion of oyster farming in Hiroshima Bay, with about 9,994 oyster rafts deployed there as of 2013. Many studies of oyster culture have focused on culture methods or the effects of environmental factors on oyster growth, hydraulic features, and shellfish poisoning. However, relatively little is known about the fish communities at oyster farms, as available studies are typically short-term or relate to only a few fish species (Sakai et al. 2013).

Previous studies indicate that areas around

oil jetty platforms and marine salmon farming structures may have higher densities and biomass of fish than adjacent natural reefs, due to the benefits of artificial constructions that allow fish to aggregate by enhancing the availability and settlement of food organisms (Rilov and Benayahu 2000; Dempster et al. 2009). Recently, oyster rafts in Hiroshima Bay have been considered for their potential to function as artificial reefs and their capacity as a local fishing ground. For example, such as about 400 individuals of the black sea bream *Acanthopagrus schlegelii* were observed around an oyster raft in the Buzen Sea (Nakamura and Nakagawa 2011). Tsuyuki and Umino (2017) used ultrasonic telemetry to demonstrate that *A. schlegelii* inhabiting the oyster-farming area in the bay are highly dependent on the spatial arrangement of the oyster rafts. Though the raft structure has been suggested to provide habitat for fishes, seasonal changes of fish fauna

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Graduate School of Biosphere Science, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8528, Japan

*Corresponding author: Tel, (+81) 82-424-7944; E-mail: umino@hiroshima-u.ac.jp (T. Umino).

associated with the oyster raft has been very limited so far. Thus, quantitative estimation of fish abundance at oyster rafts in Hiroshima Bay would be a key step to identifying their ecosystem function. The aim of this study is to reveal the seasonal changes in fish abundance and species composition around the oyster rafts in Hiroshima Bay in comparison with those observed in the littoral area by using a small underwater video cameras.

Materials and Methods

Study site

Hiroshima Bay is an enclosed bay located in the western part of the Seto Inland Sea in western Japan (Fig. 1). The average depth is 25.6 m, and the northern and western parts of the bay are subject to riverine inputs; mean annual sea surface temperature is 19°C, and ranges from about 9°C in March to 29°C in August; salinity averages 29 PSU, and fluctuates from 15 to 33 PSU (Gonzalez et al. 2008). The sea bottom of the bay is mainly composed of sand and rocks, and some of seaweed cover.

Oyster rafts (8 m wide $\times$ 16 m long) in the bay are each hung with 600 oyster wires (called *ren* in Japanese; length 10 m), each with about 37–40 oyster collectors, providing a complex underwater structure (Hirata and Akashige 2004). These wired *rens* are submerged at a depth of either 0–10 m or 7–17 m, which is ideal for the growth and maturation of *Crassostrea gigas* based on the availability of phytoplankton, a suitable water temperature, and minimization of periphyton growth. The rafts are laid out in rows 5–10 m apart, tied together with lines, and

anchored at each end of the line; two or more rafts are also tied together. Visibility measured using a Secchi disk and was about 7 m in the oyster farming area.

Underwater video survey

To determine fish species composition and abundance under the oyster rafts, we deployed small underwater video cameras (GoPro Hero3; GoPro Inc., California, USA) at three positions (Fig. 2). All video recordings were 60 min long and were taken during the daytime (08:00–17:00 h). We counted the number of individual fish observed in each video recording. To avoid bias during counting of the damselfish *Chromis notatus notatus* (i.e. counting the same individual twice as it moved in and out of a rock hole), we considered the maximum number of individuals that appeared on the monitor during the entire video recording. Small-sized fishes (<10 cm TL) were not included in the assessment because of the difficulty in achieving a rigorous count. Fish species were identified by referring to the work of Masuda et al. (1988).

The video surveys were conducted seasonally: in spring: May 2016, summer: August 2016, autumn: October–November 2015, and winter: March 2016. To enable a detailed examination of the fish species composition under the oyster rafts, we set up video cameras at three sections of the assemblages: at depths of 5–10 m (upper section of oyster wires), 10–15 m (lower section of oyster wires), and 15–20 m (sea bottom beneath the raft). In each season, six or seven oyster rafts were surveyed, except in autumn 2015, when one camera was lost and only five

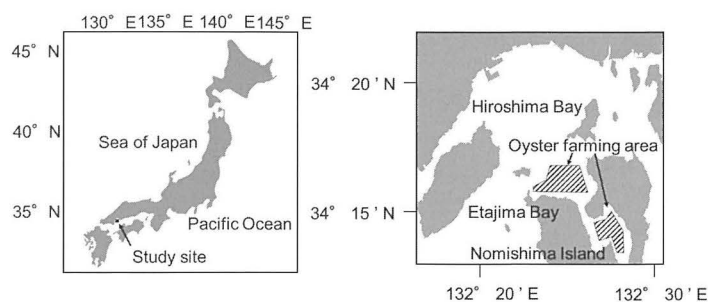


Fig. 1. Location of the study site at Hiroshima Bay, Seto Inland Sea. Shaded boxes on the close-up map show the oyster farming areas at Etajima Bay and Nomishima Island.

rafts were surveyed. As a control site, the littoral area of Etajima Bay was surveyed (Fig. 1). There, we selected four to six typical littoral sandflat subtidal zones, at depths of 5–10 m, and likewise conducted seasonal video surveys: in spring: May 2016, summer: August 2016, autumn: December 2016, and winter: March 2016. However, the video survey in autumn was conducted along the west coast of Noumishima Island.

Data analysis

The video material was used to identify fish abundance and numbers of species. Species diversity was calculated using the open-ended Shannon–Weaver index (Doi and Okamura 2011). The different community indices were natural log-transformed ($\ln(x+1)$) and compared four locations (i.e. the three sections at the oyster rafts and in the littoral area) in different seasons, using a two-way ANOVA followed by Scheffé's test.

Nonparametric multivariate techniques were used to compare the fish assemblage structure. A similarity matrix was constructed using fourth-root transformed data and the Bray–Curtis similarity index. A nonmetric multidimensional-scale ordination plot was constructed to visually explore patterns in the fish assemblages associated with the oyster rafts and the control site, to reveal relationships among the fish assemblage structures (Clarke 1993; Doi and Okamura

2011). This multivariate analysis was performed using the statistical package PRIMER 7 (Plymouth Marine Laboratory, Plymouth, United Kingdom).

Results

Ichthyofauna of the oyster rafts and the littoral area

A total of 16,110 individual fish were identified, representing 28 species from 19 families. The overall species composition differed between the oyster rafts and the littoral area, but a seasonal difference was not apparent (Table 1). We identified a total of 24 fish species in the littoral area, with the dominant species being *Halichoeres tenuispinis*, *H. poecilopterus*, *Ditrema temmincki*, and *Mugil cephalus cephalus*. Eighteen of 24 species were identified near the oyster rafts, where *Acanthopagrus schlegelii*, *Thamnaconus modestus*, and *Sebastes* cf. *inermis* were dominant. The oyster farming area had a greater abundance of *A. schlegelii* than the littoral area, and this species accounted for 68%–85% of all fish counted near the upper and lower sections of the oyster wires, except in summer, when it comprised 13%–58%. *Oplegnathus fasciatus*, *Plectorhinchus cinctus*, and *Rhyncopelates oxyrhynchus* were observed only in the oyster-farming area. The 2-dimensional nMDS indicated a distinction between the oyster-farm-associated and

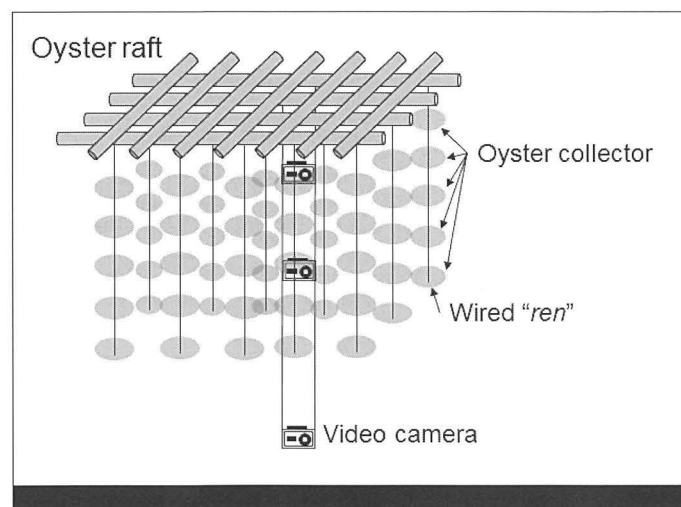
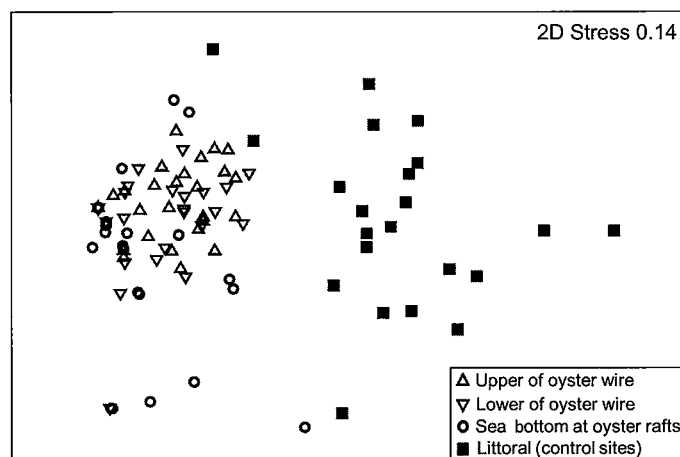


Fig. 2. Schematic diagram of the oyster rafts. Three video cameras were deployed on three different sections of the assemblage, at depths of 5–10 m (upper section of oyster wires), 10–15 m (lower section of oyster wires), and 15–20 m (area above the sea bottom).

Table 1. Fish species and abundance (mean $\pm$ SD) near the upper section (UO) and lower section (LO) on the oyster wires, near the sea bottom beneath the oyster rafts, and in the littoral area

Family	Species	Spring				Summer			
		UO (n=7)	LO (n=7)	Bottom (n=7)	Littoral (n=7)	UO (n=7)	LO (n=7)	Bottom (n=7)	Littoral (n=6)
Sparidae	<i>Acanthopagrus schlegelii</i>	228 $\pm$ 114	81 $\pm$ 42	2 $\pm$ 2	2 $\pm$ 6	141 $\pm$ 95	103 $\pm$ 76	8 $\pm$ 14	1 $\pm$ 1
	<i>Pagrus major</i>	1 $\pm$ 2			0.3 $\pm$ 0.5	1 $\pm$ 2	2 $\pm$ 5	0.3 $\pm$ 0.5	0.5 $\pm$ 1
	<i>Euvynnus japonica</i>								
Oplegnathidae	<i>Oplegnathus fasciatus</i>		0.1 $\pm$ 0.4						
Siganidae	<i>Siganus fuscescens</i>					26 $\pm$ 26	1 $\pm$ 1		0.2 $\pm$ 0.4
Pomadasyidae	<i>Plectorhinchus cinctus</i>					0.3 $\pm$ 0.8			
Teraponidae	<i>Rhyncopelates oxyrhynchus</i>						1 $\pm$ 2		
Percichthyidae	<i>Lateolabrax japonicus</i>	5 $\pm$ 10	3 $\pm$ 3	1 $\pm$ 3	0.1 $\pm$ 0.4	1 $\pm$ 2	10 $\pm$ 10		
Embiotocidae	<i>Ditrema temminiki</i>	5 $\pm$ 14			3 $\pm$ 7	34 $\pm$ 47	18 $\pm$ 105		34 $\pm$ 59
Pomacentridae	<i>Chromis notatus notatus</i>				2 $\pm$ 5				1 $\pm$ 3
Leiognathidae	<i>Leiognathus nuchalis</i>								10 $\pm$ 25
Labridae	<i>Halichoeres poecilopterus</i>				1 $\pm$ 2			5 $\pm$ 13	82 $\pm$ 117
	<i>Halichoeres tenuispinnis</i>				25 $\pm$ 35				51 $\pm$ 44
	<i>Suezichthys gracilis</i>								0.4 $\pm$ 0.9
	<i>Pseudolabrus</i> sp.								
	<i>Semicossyphus reticulatus</i>								
Scorpaenidae	<i>Sebastes</i> cf. <i>inermis</i>	59 $\pm$ 65	15 $\pm$ 29		1 $\pm$ 2	152 $\pm$ 177	593 $\pm$ 1284		4 $\pm$ 10
Carangidae	<i>Seriola quinqueradiata</i>								
Hexagrammidae	<i>Hexagrammos</i> spp.				0.3 $\pm$ 0.5				
Monacanthidae	<i>Thamnaconus modestus</i>	8 $\pm$ 10	5 $\pm$ 3	0.1 $\pm$ 0.38	1 $\pm$ 1	19 $\pm$ 29	55 $\pm$ 105		
	<i>Stephanolepis cirrifer</i>	0.4 $\pm$ 0.8	1 $\pm$ 1		3 $\pm$ 7	11 $\pm$ 2	3 $\pm$ 4	0.1 $\pm$ 0.4	0.7 $\pm$ 0.8
Tetraodontidae	<i>Takifugu poecilonotus</i>	8 $\pm$ 9	2 $\pm$ 2			10 $\pm$ 8	5 $\pm$ 6	0.4 $\pm$ 0.5	0.2 $\pm$ 0.4
	<i>Takifugu pardalis</i>					1 $\pm$ 2	0.3 $\pm$ 0.5		
	<i>Takifugu niphobles</i>				1 $\pm$ 1				6 $\pm$ 4
	<i>Mugil cephalus cephalus</i>				2 $\pm$ 3				34 $\pm$ 31
Mugilidae	<i>Mugil cephalus cephalus</i>								63 $\pm$ 142
Drosomatidae	<i>Konosirus punctatus</i>								1 $\pm$ 1
Dasyatidae	<i>Dasyatis akajei</i>				0.3 $\pm$ 0.5				0.2 $\pm$ 0.4
Myliobatidae	<i>Aetobatus</i> sp.								

*N represent number of video samples.

**Fig. 3.** Nonmetric multidimensional-scale ordination plot of the fish assemblage in the oyster-farming area (Δ : upper, ∇ : lower, and $\circ$: sea bottom) and the littoral area ($\blacksquare$: littoral area).

the littoral-area-associated fish assemblages (Fig. 3).

Fish abundance and species diversity

Fish abundance, the number of species, and species diversity were compared among

the three sections of the oyster rafts and the control sites (littoral area). Fish abundance (mean $\pm$ SD) near the upper and lower sections of the oyster wires and at the sea bottom was 229.3 ± 205.8 , 255.3 ± 750.6 and 122.0 ± 169.9 , respectively in all cases, greater than in

Autumn				Winter			
UO (n=6)	LO (n=5)	Bottom (n=6)	Littoral (n=5)	UO (n=7)	LO (n=7)	Bottom (n=7)	Littoral (n=4)
119 ± 54 1 ± 1	32 ± 27	34 ± 77 2 ± 2	0.4 ± 0.9 0.8 ± 1.3 1.8 ± 4	37 ± 54	27 ± 33 1 ± 0.3	68 ± 99 1 ± 2	1 ± 3
1 ± 2			0.2 ± 0.4				
9 ± 14 11 ± 23	13 ± 22	3 ± 6 0.2 ± 17	0.2 ± 0.4	1 ± 3 3 ± 7.5	1 ± 1 3 ± 7	3 ± 6 10 ± 17	20 ± 33 10 ± 21
			62 ± 69 4 ± 6				
			1 ± 3				1 ± 3
	0.4 ± 0.9						0.3 ± 0.5
7 ± 9		0.2 ± 1	1 ± 1	1 ± 1 1 ± 2	1 ± 3 1 ± 2	0.3 ± 1	
4 ± 6	1 ± 2	0.5 ± 1					
			22 ± 48 9 ± 9	0.3 ± 1 0.1 ± 0.4	0.1 ± 0.4		2 ± 5 3 ± 4
			2 ± 2.2				
		0.2 ± 0.4					

the littoral area, where fish abundance was 34.7 ± 67.1 . A two-way ANOVA indicated the statistically significant factors (monitoring location and seasons) and their interaction effects on the fish abundance ($p < 0.05$; Table 2). A seasonal comparison of fish abundance showed significantly greater fish abundance in summer near the upper and lower sections of the oyster wires than at the sea bottom beneath the rafts (Scheffé's method, $p < 0.05$; Fig. 4).

The numbers of fish species associated with the upper section, lower section, and sea bottom at the oyster rafts, and in the littoral area were 5.7 ± 2.3 , 4.9 ± 2.6 , 3.1 ± 1.3 , and 5.4 ± 2.8 , respectively. A two-way ANOVA indicated the statistically significant factors (monitoring location and seasons) and their interaction effects on the number of species ($p < 0.05$). The number of species at the sea bottom was significantly lower than at the upper

Table 2. Effect of locations (upper and lower sections of oyster wire, sea bottom beneath oyster rafts, and littoral area) and seasons on fish abundance, number of species, and species diversity index, tested by two-way ANOVA

	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
Fish abundance				
Location	3	6.09	23.26	< 0.01
Season	3	1.20	4.59	< 0.01
Location × Season	9	1.63	6.23	< 0.01
Residuals	86	0.26		
Number of species				
Location	3	0.22	12.50	< 0.01
Season	3	0.27	15.30	< 0.01
Location × Season	9	0.06	3.22	< 0.01
Residuals	86	0.02		
Diversity index				
Location	3	0.17	8.56	< 0.01
Season	3	0.11	5.49	< 0.01
Location × Season	9	0.02	0.88	0.55
Residuals	86	0.02		

section of the oyster wires during summer (Scheffé's method, $p < 0.05$).

Fish species diversity in the upper section,

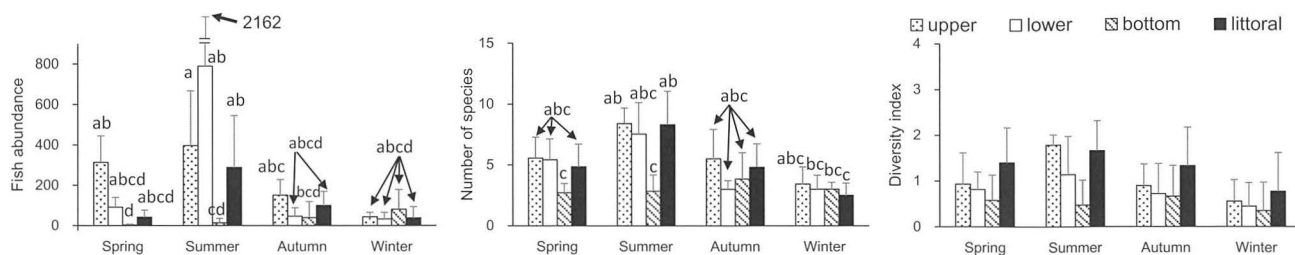


Fig. 4. Fish abundance, number of species, and species diversity at the four locations (upper and lower sections of the oyster wires, sea bottom beneath the oyster rafts, and the littoral zone). Error bars represent standard deviations. The same letter (above bars) indicates no significant difference ($p < 0.05$).

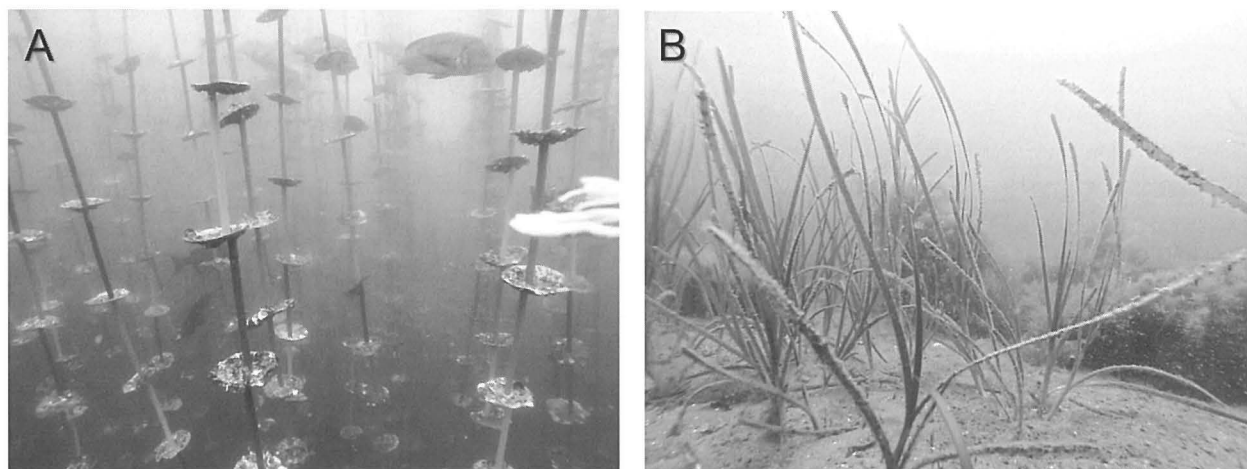


Fig. 5. Underwater photographs showing the spatial arrangement of the oyster wires (A) and the sea floor in the littoral area (B).

lower section, and sea bottom at the oyster rafts and in the littoral area was 1.0 ± 0.7 , 0.8 ± 0.6 , 0.5 ± 0.5 and 1.3 ± 0.7 , respectively. A two-way ANOVA indicated effects of the statistically significant factors (monitoring location and season) on the species diversity ($p < 0.05$).

Discussion

In the present study, a total of 18 fish species were observed around the oyster rafts in Hiroshima Bay. We had first observed *Pagrus major*, *Oplegnathus fasciatus*, *Plectorhinchus cinctus*, *Rhyncopelates oxyrhynechus*, and *Aetobatus narutobiei* at the oyster farms during previous research (Sakai et al. 2013); in the current study, the abundance of *Acanthopagrus schlegelii* was greater than that described previously during the visual survey. Though it is difficult to estimate fish abundance based on relatively few counts, these results suggest that deploying underwater video cameras can improve the accuracy of counts of larger-sized

fishes during the daytime.

The data show that fish species composition differed between the area of the oyster rafts and the littoral area, though these study sites were located within 2 km of each other in Hiroshima Bay. Previous studies have demonstrated that habitat provided by artificial structures intrinsically influenced fish assemblages in estuaries (Clynick et al. 2008; Folpp et al. 2013). The sea bottom in the littoral area at Etajima Bay is mainly composed of sand and some revetments covered by seaweeds, while oyster-raft habitat consists of spatially arranged oyster wires (see Fig.5). Not surprisingly, the resident wrasses *Halichoeres tenuispinis* and *H. poecilopterus* and pufferfish *Takifugu niphobles* were dominant in the sandflats or seaweed beds of the littoral area but were less frequent around the oyster rafts; additionally, the stingray *Dasyatis akajei*, which typically sits on sandy bottom (Masuda et al. 1988), was not observed under the oyster rafts, where the sea bottom is covered with fallen oyster shells.

Food availability in the oyster wires likely influences the degree to which different fish species aggregate near the structures. We observed that the omnivorous and herbivorous fishes (e.g. *A. schlegelii*, *Siganus fuscescens*, *T. poecilonotus*, and *Thamnaconus modestus*) preyed on sessile organisms on the oyster wires. The main food resources of these fishes consists of mollusks, macroalgae and crustaceans, which are commonly abundant on oyster wires (Saito et al. 2008; Satuito et al. 2013; Tsuyuki 2018). A possible explanation for high densities of the carnivorous *Lateolabrax japonicus* around the oyster rafts is the accompanying abundance of small-sized fishes, such as the goby *Tridentiger trionocephalus* and pygmy filefish *Rudarius ercodes* (Sakai et al. 2013). Furthermore, the spatially complex structure of oyster rafts may act as resting sites for aggregations of *L. japonicus*. We observed a large aggregation of the *Sebastes* cf. *inermis* and noted their foraging behavior at the oyster rafts during spring and summer. *Sebastes* cf. *inermis* in the Seto Inland Sea generally inhabit rocky reefs and seaweed beds (Shoji 2009), although our findings imply that this fish is also reliant on the resources created by the oyster rafts in Hiroshima Bay.

We confirmed significant differences in both fish abundance and numbers of species between the study areas and seasons. The most notable difference occurred in summer. A decline in fish abundance and species number at the sea bottom under the oyster rafts in the summer may be attributed to the formation of hypoxic water. A previous study showed that sites with bottom dissolved oxygen concentrations less than 3 mg/L generally supported fewer numbers of fish and species than sites with concentrations above 3 mg/L (Howell and Simpson 1994). Low numbers of species and individuals were observed in the megabenthos of Osaka Bay, eastern Seto Inland Sea, due to intense hypoxia in summer (Ariyama et al. 1997). In the oyster-farming areas of Hiroshima Bay, dissolved-oxygen stratification generally occurs from July to October in zones deeper than 10 m (Kimura 1999). Thus, declines in

fish abundance and numbers of species under the oyster rafts in the summer may be because of fish avoiding the hypoxic waters. Further studies are needed to monitor the relationship between decreasing dissolved-oxygen stratification and fish abundance at the sea bottom in the bay, testing their tolerance to hypoxic-water conditions.

In conclusion, the fish community at oyster rafts in Hiroshima Bay comprised some unique species, and displayed obvious dissimilarities with the fishes observed in the littoral areas. Oyster rafts can provide feeding and resting habitats for fish. Thus, we propose that hanging-raft oyster culture in the bay also efficiently functions as an artificial reef in the regional ecosystem.

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水中ビデオカメラにより記録した広島湾におけるカキ筏の魚類相

津行篤士・海野徹也

広島湾のマガキ養殖場は魚類の生息場所となっているが、魚類群集に関する知見は乏しい。そこで、広島湾のマガキ養殖場の魚類相を水中ビデオカメラにより調査した。カキ筏では18種の魚類が確認されたが、出現種組成は、比較対象として観察した沿岸域とは異なった。カキ筏には水産有用種のクロダイ、ウマヅラハギ、ウミタナゴが全ての季節において出現した。特に、カキ筏におけるクロダイの出現割合は高く、春季、秋季、冬季の出現割合は68-85%に達した。ビデオ観察によって優占種であるクロダイ、ウマヅラハギ、ウミタナゴが垂下連上の付着生物を採餌する行動も確認された。本研究によって、広島湾のカキ筏には多くの水産有用種が唼集しており、カキ筏は同湾における漁礁として機能している可能性が示唆された。