Artificial reef habitat-supported integrated aquaculture

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Abstract. The study was aimed at analyzing the target fish species polyculture, seaweed farming, and pearl oyster culture supported by artificial reef habitat. This study benefits the space around the artificial reefs as an integrated aquaculture location of fish in the floating fish cage (FFC), seaweed *Kappaphycus alvarezii* on the long line system, and pearl oysters *Pinctada maxima* hung under the FFC. Parameters measured were specific growth rate (SGR), daily growth rate (DGR), and survival rate for fish and oysters, while for the seaweed, only SGR and DGR were recorded. There were 5 target fish species cultured, giant trevally *Caranx sexfasciatus*, surgeonfish *Acanthurus blochii*, rabbitfish *Siganus canaliculatus*, grouper *Epinephelus sexfasciatus*, and rainbow runner *Elagatis bipinnulata,* with mean survival rate of 93.66%, absolute length of 4.5-14.6 cm, absolute weigth of 48.7-161.2 g, SGR of 4.52-5.52%, and DGR of 0.41-1.34 g d^{-1}. Seaweed *K. alvarezii* had SGR of 1.16-1.67% and DGR of 1.52-2.48 g d^{-1}. Pearl oyster absolute growth ranged from 5.87 to 19.96 mm, DGR from 0.20 to 0.67 mm d^{-1}, and survival rate above 88.89%. These results confirm that the integrated aquaculture activity is appropriate and applicable to run in the artificial reef habitat, since it could contribute to providing nursery ground for small fishes, commercial mariculture, coral reef protection and rehabilitation, and controlled fishing ground.

Key Words: fish, seaweed, pearl oyster, growth, target species, major species, indicator species.

Introduction. Coral reef ecologically functions as beach protection from wave and abrasion, spawning ground, and nursery ground for most importantly economic fish (Reppie 2006). Nevertheless, coastal development activities and destructive fishing practice have negatively impacted the coral reef existence and quality in Indonesia. There are many efforts done to save the coral reef ecosystem in Indonesia, such as conservation regulations, coral reef ecosystem rehabilitation, and establishment of coral reef ecosystem management programs. However, such a management instrument implementation has been ineffective. Law seems not to be enforced, impact assessment procedure is rarely obeyed, conflict between stakeholders is getting worse, and traditional rights are eroded, so that the impact on coral reef ecosystem destruction is getting bigger (Asri et al 2019).

Artificial reef is one of the usable alternatives to reduce the fishing pressures on the coral reefs through creation of new productive fishing ground. This is supported by Park et al (2018) that integrated multitrophic aquaculture is a solution for intensive aquaculture in Korea to increase the sustainability and reduce the environmental impacts. This system can be implemented as an environmental friendly-mariculture development model (Verdian et al 2020) and to equilibrial environmental system (Chopin & Sawhney 2009).

The deployment of artificial reef in shallow coastal waters is a potential tool for protecting or restoring beaches and marine habitats, and nursery grounds (Kliucininkaite & Ahrendt 2011). This development is a public work project with no direct value for the local people. Therefore, an integratedly appropriate and applicable multi-purpose needs to be technically and economically built to meet the goal of nursery ground, habitat recovery, and commercial aquaculture activities. One of the application in the form of appropriate technology concept is the integration of fish culture in the floating fish cage supported by the presence of artificial reef as source of cultured fish seeds and feed, while seaweed and pearl oyster culture function as an equilibrium penetration on the aquatic environment.

Lembeh Strait, North Sulawesi, geographically has several coral reef areas with moderate and heavy damage conditions. The damaged coral reefs in the protected area are feasible to develop as artificial reef deployment locality and fish culture development in the floating fish cage integrated with sea weed and oyster culture. This study is aimed to analyze the impact of artificial reef habitat on the integrated aquaculture of fish in the floating fish cage, seaweed *Kappaphycus alvarezii*, and pearl oyster *Pinctada maxima*.

Material and Method

Study site and period. This study was carried in Tandurusa coatas waters, Lembeh Strait, Bitung, North Sulawesi (Figure 1), for six months, and divided in two phases.

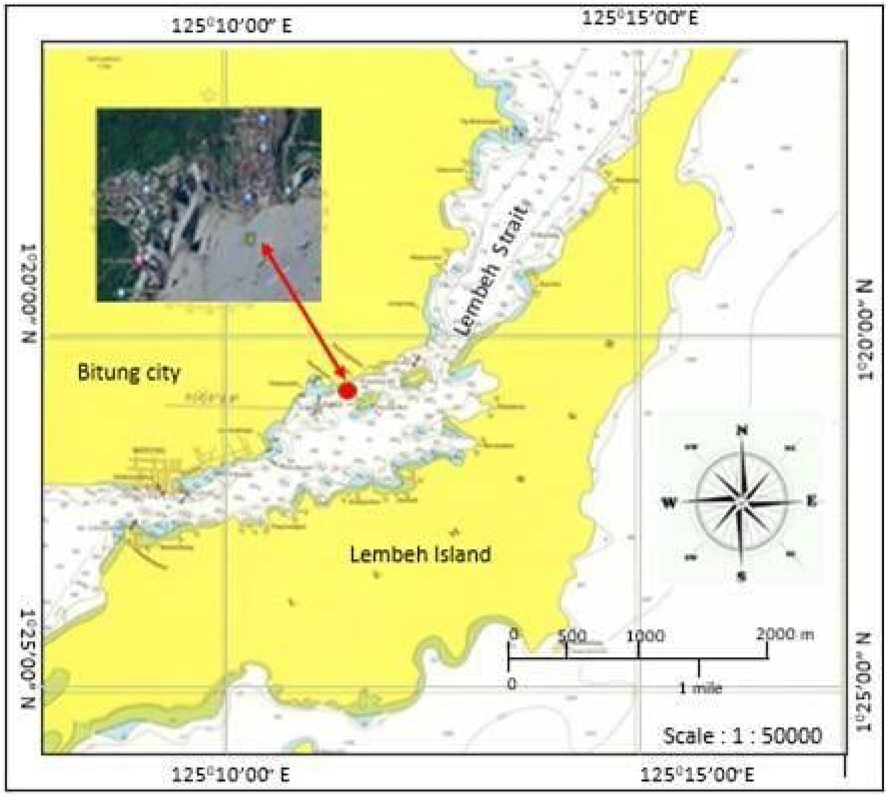

Figure 1. Study site.

Phase 1 was done to prepare facilities and instrument placement in the study site, in September to October 2013, while phase 2 was focused on data collection from November 2013 to February 2014. After seven years of the integrated culture activities, the artificial reef deployment site was revisited to monitor the success of the artificial reef deployment and the fish condition. Two dives were done in this survey for fish community observation.

Research facility design. The integrated aquaculture facilities were set as presented in Figure 2.

Research facility construction. This study was supported by the following elements:

Artificial reef. The artificial reef substrate was made as 75 cm x 25 cm x 25 cm concrete block construction. Each unit of artificial reef consists of 6 blocks piled in 3 levels of pyramid. Twenty-four (24) units of the constructions were placed at 5 m depth parallel to the floating fish cage at 5 m distance interval. Nine 8-10 cm coral fragments of *Acropora* sp. were tied on the 4 inches-stainless steal nailed on the artificial reef substrate.

Floating fish cage. An 8 x 8 m floating fish cage of 1" mesh-polyethylene (PE) net was facilitated with 6 blocks of 3 m x 3 m x 3 m area and 4 blocks of 3 m x 1.5 m x 1.5 m fish cages as temporary fish holding. The cultured fish were target economic species associated with artificial reefs and collected around the artificial reef.

Seaweed Kappaphycus alvarezii culture. The culture media of seaweed were prepared in the form of 10 m x 5 m rectangular frame consisting of main 12-sized polyethylene line as frame and 6-sized polyethylene line as branch line to tie the seaweed seed. The seaweed culture frame was hung at the depth of 10-15 cm below water surface using plastic floats. Three units of line frames were set parallel to the floating fish cage about 5 m distance, and each unit consisted of 8 lines with 15 planting points with 50 cm interval.

Pearl oyster (Pinctada maxima) culture. The culture media of the pearl oyster used 40 cm x 30 cm plastic bucket to place 3-4 cm long oyster seeds. The bucket was hung under the floating fish cage at the depth of 2.5 m, and this study used 12 buckets.

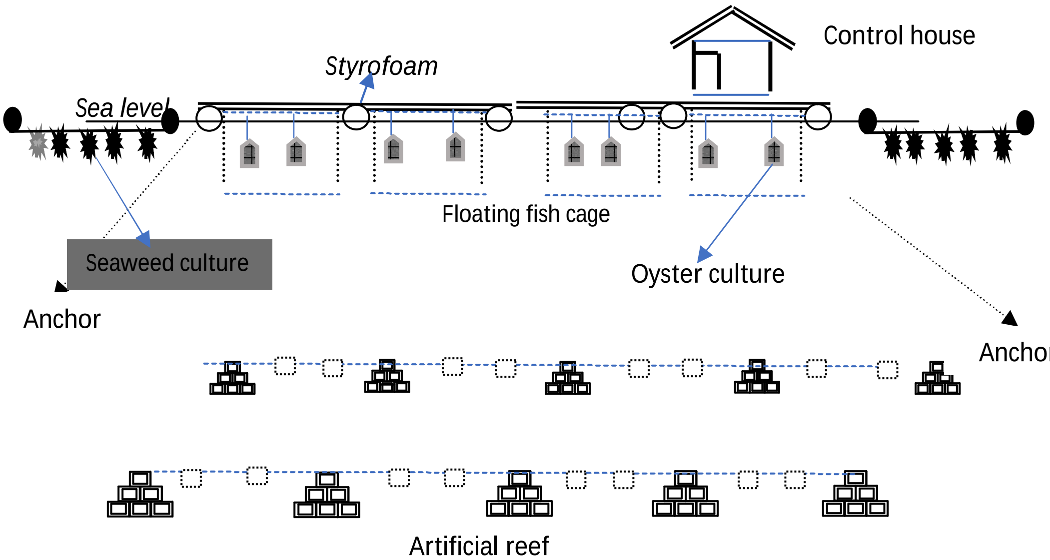

Figure 2. Research facility design.

Observations and data analysis

Artificial reef-associated fish. This observation utilized underwater visual census (UVC) following coral reef and fish monitoring guide of Cormep-CTI LIPI (Suharsono & Sumadiharga 2014). It was done from the outside artificial reef at the radius of 3-5 m. The monitoring was accomplished in the morning (09.00 am) and the afternoon (15.00 pm) in four different periods, period 1 (P1) in November 2013, period 2 (P2) in December 2013, period 3 (P3) in January 2014, and period 4 (P4) in February 2014. Fish identification employed Pictorial Guide to Indonesia Reef Fishes part 1, 2, 3 (Kuiter & Takamaza 2004a, b, c). Fish associating in the artificial reef consisted of target species, major species, and indicator species.

Fish fingerling capture. The fish species used for culture belonged to economically important fish group associating with the artificial reef. The fish were collected 3 times a week using hand line and 3" mesh-sized gill net of 37.8 m long and 4.2 m wide. The fish were selected at even minimum size of 5-13 cm long ind^{-1}. The fish feed was taken from major species and anchovy *Stolephorus indicus.*

Fish rearing in the floating fish cage. Fish rearing utilized a polyculture system by combining several species groups based on the fish total length individual weight. The fish density was set as many as 5-7 ind m^{-3}. The fish were grouped with species and reared separately. Feeding was conducted ad libitum 3 times a day. Number of fish and growth were recorded weekly. In this study, the fish survivorship and growth were measured (Ricker 1979). These measurements are intended to describe the condition of the culture system.

$$\text{Survival rate (SR)} = Nt/N0 \times 100$$

where: SR is survival rate (%), No is initial number of fish, and Nt is final number of fish.

Fish growth estimation used specific growth rate (SGR) and daily growth rate (DGR) (Ricker 1979) as follows:

$$\text{Specific growth rate (SGR)} = (\ln wt - \ln wo)/t \times (100)$$

where: SGR is specific growth rate, Wo is initial fish weight (g), Wt is final fish weight (g), and t is time (day).

$$\text{Daily growth rate (DGR)} = (Wt - W0) / t$$

where: DGR = daily growth rate, Wo is initial fish weight, Wt is final fish weight, and t is time (day).

Length increment was assessed as absolute length using the following equation:

$$L = Lt - Lo$$

where: L is absolute length, Lo is initial fish length, Lt is final fish length.

Seaweed Kappaphycus alvarezii culture. Seaweed seed *K. alvarezii* was obtained from Arakan, Minahasa regency, and the cultivation was carried out in 3 planting periods, in September to October 2013, October to November 2013, and January to February 2014. The seeds were tied along the horizontal line as much as 100 g point^{-1}, so that there were 120 seeds tied on the branch line of 360 planting points or a total of 36,000 g seed planted. Parameters measured were growth performance in 20 planting points. These measurements were carried out every 15 days, at day-0, day-5, day-30, and day-45. Seaweed growth was also measured in weight as SGR and DGR.

Pearl oyster (Pinctada maxima) culture. This study used 36 spats in which each bucket held 3 individuals. The oysters *P. maxima* were obtained from PT. Artha Samudera, Bitung. Shell and bucket cleaning was periodically conducted every week, while shell measurements were done every month. Growth was recorded as dorso-ventral shell measurements (DVM) and expressed as DGR. Survival rate was estimated as well. Growth calculation followed Ricker (1979):

$$L = Lt - Lo$$

where: L is absolute growth, Lo is mean shell length at the beginning of the study, and Lt is mean shell length at the end of study.

Water quality measurements. Water temperature, visibility, and salinity were recorded *in situ* once in two weeks using Horiba U 50 Multiparameter Water Quality Checker. Water current measurements were determined by calculating the length of time spent by ball drifted at certain distance.

Results and Discussion

Fish association in the artificial reef. Tables 1-3 show the occurrence of fish around the artificial reef set in this study, consisting of target species, major species, and indicator species. Target species are economically important species; major species is the fish group of ecologically important species; indicator species is the fish group of Chaetodontidae that is usually present in healthy corals.

Fish colonization in the artificial reef increases with time. With species, P4 exhibited the highest number, followed by P3, P2, and P1 even though the fish appearance was relatively not stable and the fish was still short-time visitors.

Fish association data (Table 4) show that there are 469 fish recorded in P1, 649 individuals in P2, 938 individuals in P3, 1941 individuals in P4. It could be related with the artificial reef placement near the natural coral reef and the time length of the deployment. Coral fishes in the artificial reef will be more stable with time. This finding is in agreement with Fadli et al (2012) and Manembu et al (2014) that the deployment of artificial reef and coral transplantation in some Indonesian waters could increase the reef fish condition and composition.

Target species group was represented by 15 species of 5 families (Table 1). Total occurrence of target species group showed that P4 had the highest ability to gather the target fish group, 1,113 individuals, followed by P3, 527 individuals, P2, 378 individuals, and P1, 324 individuals, respectively. Major species are the most often fishes seen in the study site. Number of individuals demonstrates that the highest is recorded in P4, 801 individuals, followed by that in P3, 399 individuals, P2, 267 individuals, and P1, 142 individuals, respectively.

Major species comprised 49 species of 13 families, and their occurrence varied with time period (Table 2). Species occurrence was dominated by family Pomacentridae*,* 15 species, and Apogonidae*,* 10 species, while other families were only represented by 1-5 species. The presence of major species, according to Chase & Hoogenboom (2019), is highly determined by the reef type and or coral reef-composing hard coral morphology. Mujianto & Sugiyanti (2008) also added that coral fish community structure in the artificial reef is highly affected by the design, shape, and locality of the artificial reef.

The occurrence of the indicator species (Chaetodontidae) in the study periods is represented by 9 species of genus *Chaetodon* and one species of genus *Coradion* (Table 3). This fish group occurred in very low number. According to Nybakken (1992), Chaetodontidae are usually present in the branching and flat coral life forms, where the fish group searches for food and stays in the reef waters. This condition is influenced by several factors, such as substrate complexity, food availability, water quality, currents, waves, shelters, coral cover, etc. Family Chaetodontidae can quickly associate with branching coral colony, such as *Acropora* sp. (Madduppa et al 2014). The highest total occurrence was found in the P4, 27 individuals, followed by P3, 12 individuals, P2, 4 individuals, and P1, 3 individuals, respectively. Similar condition was also recorded in each study period that number of fish occurrence increases with the artificial reef deployment time length.

The fish number rank was recorded in giant trevally *Caranx sexfasciatus*, surgeonfish *Achanthurus blochii*, grouper *Epinephelus sexfasciatus*, rainbow runner *Elagatis bipinnulata*, yellowtail scad *Selaroides leptolepis,* rabbitfish *Siganus canaliculatus*, and Indian mackerel *Rastrelliger kanagurta*. According to Yuliana et al (2017), the fish occurrence could be highly determined by environmental conditions, especially coral reef rehabilitation of artificial reef deployment.

Table 4

Total fish occurrence per week during the study

Observation (week)	*Period 1*			*Period 2*			*Period 3*			*Period 4*		
	Ts	*Ms*	*Is*	*Ts*	*Ms*	*Is*	*Ts*	*Ms*	*Is*	*Ts*	*Ms*	*Is*
1	69	25	0	87	51	1	125	76	3	262	152	6
2	85	31	1	96	62	0	94	93	2	208	186	7
3	85	35	1	100	69	2	145	100	4	281	205	7
4	85	51	1	95	85	1	163	130	3	362	258	7
Total ind/ week	324	142	3	378	267	4	527	399	12	1,113	801	27
Total/ period	469			649			938			1941		

Note: Ts – target species; Ms – major species; Is – indicator species.

Table 1

Target fish species

No	Species	*Period 1*					*Period 2*					*Period 3*					*Period 4*				
		November					*December*					*January*					*February*				
		1	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*
1	Acanthuridae																				
	Acanthurus blochii	13	6	24	27	70	13	15	11	7	46	10	6	25	24	65	28	27	29	38	122
	A. nigrofuscus	0				0		16	0		16	9		26	13	48	28	17	37	43	125
2	Carangidae																				
	Caranx sexfasciatus	18	52	19	52	141	15	46	31	36	128	57	30	49	40	176	69	65	77	118	329
	Elagatis bipinnulata		2	1	4	7	5	1	1		7	3	2	5		10	6	4	2		12
	Selaroides leptolepis					0		11	22	24	57	20	18	30	30	98	85	69	78	89	321
3	Scombridae																				
	Rastrelliger kanagurta																10	-	19	22	51
4	Serranidae																				
	Epinephelus coioides	7	7			14	12		0		12				10	10	6				6
	E. corallicola			3		3	6	5			11	2				2	3				3
	E. fuscoguttatus		4			4					0					0			2		2
	E. quoyanus		1	7		8				6	6	5		5		10	9				9
	E. sexfasciatus	15	3	2		20	6		18	4	28	2		2	12	16	13	10	5	4	32
5	Siganidae																				
	Siganus canaliculatus	10		12	2	24	9	2	6	6	23	8	25		12	45	5	10	25	42	82
	S. fuscescens	6	3	6		15	12		11		23	5	3		22	30			7	6	13
	S. guttatus		7	11		18	9			12	21	4	10			14		5			5
	S. vulpinus													3		3		1			1
	No. individuals	69	85	85	85	324	87	96	100	95	378	125	94	145	163	527	262	208	281	362	1113
	No. families	4	4	4	3	4	4	4	4	4	4	4	3	4	4	4	5	4	5	5	5
	No. species	6	9	9	4	11	9	7	7	7	12	11	7	8	8	13	11	9	10	8	15

Note: T - total; 1, 2, 3, 4 - week.

Table 2

Major fish species

No	Species	Period 1					Period 2					Period 3					Period 4				
		November					December					January					February				
		1	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*
1	Apogonidae																				
	Apogon albimaculosus											1				1				1	1
	A. punctulatus			1		1							1			1					
	Jaydia poecilopterus			1	2	3												4	2	6	12
	Ostorhinchus cavitensis						1	1	1	1	4				3	3			1		1
	O. hartzfeldii		1			1		2			2						3	3	3	3	12
	O. moluccensis		1			1		2			2			4		4	4	6	4	6	20
	Pristiapogon kallopterus													5		5	3	3	2	6	14
	Pristicon trimaculatus		1		3	4	6	6	6	6	24	3	5			8	3	2	4	4	13
	Sphaeramia orbicularis		1			1						1				1			2		2
	Taeniamia fucata		1			1															
2	Balistidae																				
	Balistapus undulatus	6		3		9	6	6	8	5	25	1	2		3	6	6	8	9	11	34
	B. viridescens		2		1	3	3				3			4	2	6		7	8	11	26
3	Fistulariidae																				
	Fistularia commersonii														3	3	3	3	3	6	15
4	Holocentridae																				
	Sargocentron cornutum		2			2	1	6	1	1	9							3	3	6	12
5	Monacanthidae																				
	Aluterus scriptus	1		2		3	3				3		2		5	7		3		4	7
	Amanses scopas		1		1	2	1	5	3	4	13	1	3	5	6	15	12	8	9	8	37
	Pervagor aspricaudus	1				1												4	5	7	16
6	Muraenidae																				
	Gymnothorax isingteena			1		1												2		2	4
	G. eurostus			1	1	2		1			1							2		1	3
7	Ostraciidae																				
	Lactoria cornuta																		2	2	4
	Ostracion cubicum		1			1											2				2
8	Pomacanthidae																				
	Centropyge vrolikii																2		2	2	6
	Chaetodontoplus melanosoma																			1	1
	Chaetodontoplus mesoleucus											2				2	6	7	6	6	25

	Dischistodus prosopotaenia																	2	6	7	15
	Paracentropyge multifasciata												2			2		2	4	3	9
9	Pomacentridae																				
	Abudefduf septemfasciatus																	4		1	5
	A. vaigiensis													3		3	8				8
	Amblyglyphidodon curacao	2	3	2	3	10	5	4	4	6	19	5	9	6	12	32	12	14	15	18	59
	Chromis scotochiloptera																			2	2
	C. viridis	3	5	2	3	13	5	5	5	8	23	7	10	8	14	39	12	18	16	16	62
	Dascyllus aruanus			1	12	13			15	12	27	5	5	4	8	22	9		7	15	31
	D. melanurus																		8	8	16
	D. trimaculatus			5		5			10	12	22	10	10	8	11	39		13	12	3	28
	Hemiglyphidodon plagiometopon		2	2		4				3	3	3		4		7	12			14	26
	Neoglyphidodon crossi													4	4	8		8	8	11	27
	N. melas	4	4	1	5	14	4	6	5	8	23	6	12	7	13	38	15	16	14	7	52
	Pomacentrus brachialis			1	6	7						6	6	7	8	27	6		6	8	20
	P. burroughi																	4	6	6	16
	P. grammorhinchus													9		9			8	7	15
	P. pavo	7	5	5	13	30	15	10	7	14	46	19	16	10	16	61	22	15	9	8	54
10	Soleidae																				
	Liachirus melonospilos																			1	1
11	Synodontidae																				
	Synodus macrops	1		2		3		3			3		1	2	2	5		4	4	5	13
12	Tetraodontidae																				
	Arothron hispidus											1			4	5		7			7
	A. mappa													2		2	4		5	5	14
	A. nigropunctatus			2		2									4	4			4	4	8
	A. reticularis		1	2		3		3						2		2					
	Canthigaster solandri												2			2		5		6	11
13	Zanclidae																				
	Zanclus cornutus			1	1	2	1	2	4	5	12	5	7	6	12	30	8	9	8	10	35
	No. individuals	25	31	35	51	142	51	62	69	85	267	76	93	100	130	399	152	186	205	258	801
	No. families	4	7	8	6	10	6	8	6	6	9	7	8	7	8	9	9	11	11	12	13
	No. species	8	15	18	12	28	12	15	12	13	20	16	16	20	14	32	30	22	33	41	46

Note: T - total; 1, 2, 3, 4 - week.

Table 3

Indicator species

No	Species	*Period 1*					*Period 2*					*Period 3*					*Period 4*				
		November					*December*					*January*					*February*				
		1	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*	*1*	*2*	*3*	*4*	*T*
1	Chaetodontidae																				
	Chaetodon bennetti		1	-	-	1	-	-	-	-	0	-	-	-	-	0	-	-	1	-	1
	C. guentheri		-	-	-		-	-	-	-		-	-	-	-			1	-	-	1
	C. guttatissimus	-	-	-	-		-	-	-	-		-	-	-	-		1	1	-	-	2
	C. kleinii		-	1	-	1	1		1	1	3	1	-	2	2	5	2	-	3	2	7
	C. lineolatus	-	-	-	-		-	-	-	-		-	1	-	-	1	1	-	-	1	2
	C. melannotus	-	-	-	-		-	-	-	-		-	-	-	1	1		1	1		2
	C. ocellicaudus	-	-	-	1	1	-	-	-	-		1	1	-	-	2	1	-	1	1	3
	C. trifasciatus	-	-	-	-		-	-	-	-		1	-	-	-	1		1	1		2
	C. trifascialis	-	-	-	-		-	-	-	-		-	-	1	-	1	1	1	-	2	4
	Coradion chrysozonus	-	-	0		0	-	-	1		1	-	-	1	-	1	-	2	-	1	3
	No. individuals	0	1	1	1	3	1	0	2	1	4	3	2	4	3	12	6	7	7	7	27
	No. families	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
	No. species	0	1	1	1	3	1	0	2	1	3	3	2	3	2	10	5	6	5	5	21

Note: T - total; 1, 2, 3, 4 - week.

Fish community condition. In general, fishes associating with artificial reef in the study site were transient, in which the floating fish cage facility, seaweed culture, and artificial reef were used only as temporary shelter from predators.

This area also functions as fish feeding ground, especially at the feeding time of the cultured fish. In the periods 3 and 4, this site has already become new habitat for the fish. In spite of that, several schooling good swimmer fishes were hard to identify using simple taxonomic technique, since they could not be approached at 5 m distance and went away from the diver.

Water temperature, salinity, and brightness were also in good range to support marine life around the study site (Table 5), so that the environmental conditions could support the fish occurrence in the study site. During the study, water brightness was very good so that photosynthesis could optimally occur. Decline in water quality condition, particularly in the study site, occurs in rainy season due to much run-off with garbage from the terrestrial area. South wind could result in waves and shake the bottom particles in the coastal area, and could increase turbidity and sedimentation.

Table 5

Oceanographic parameters in the study site

Parameter	*Period 1*	*Period 2*	*Period 3*	*Period 4*
Temperature (^{o}C)	27.2-28.7	26.2-28.7	27.2-27.7	27-28
Salinity (‰)	29-30.5	29-30.5	29-31.5	29.5-32.5
Current (cm sec^{-1})	0-15.4	0-5.4	0-45.5	0-57
Visibility	7-20	5-9	15-20	20-30

High growth of sessile benthos (fouling organisms) occurred on the surface opened to the laminar current and relatively vertical substrates. High density of sessile organisms tended to be more effective to attract fish.

Fish caught for culture in the floating fish cage. Fish capture was done for target species as cultured fish seed candidates and major species as natural food using 3 inch-mesh-sized gill net and handline. Table 6 demonstrates that total number of economically important fish caught was 1,069 individuals consisting of *C. sexfasciatus*, S. *leptolepis*, *R. kanagurta*, *E. bipinnulata*, *E. sexfasciatus*, *S. canaliculatus*, and *A. blochii.*

Table 6

Number of target species for polyculture

		No. fish catches per period				
No	*Species*	*Period 1*	*Period 2*	*Period 3*	*Period 4*	*Total catch*
1	*Caranx sexfasciatus*	83	57	104	203	447
2	*Achanturus blochii*	55	24	42	85	206
3	*Epinephelus sexfasciatus*	12	10	9	17	48
4	*Siganus canaliculatus*	24	10	38	70	142
5	*Elagatis bipinnulata*	3	4	5	6	18
6	*Selaroides leptolepis*	0	31	84	60	175
7	*Rastrelliger kanagurta*	0	18	0	0	18
8	Total	177	154	282	441	1,054

Polyculture. The integrated aquaculture included economically important species, seaweed *K. alvarezii,* and pearl oyster *P. maxima.* Only 5 of 7 caught target species can be cultured with a total number of 861 individuals consisting of 447 *C. sexfasciatus,* 206 *A. blochii*, 48 *E. sexfasciatus*, 142 *S. canaliculatus*, and 18 *E. bipinnulata*. Mean survival rate was 93.66% with the range of 90.01 to 100% reflecting that the cultured target fish have high possibility to live in the floating fish cage supported with artificial reef (Table 7).

Table 7

Survival rate with fish species

No	Fish species	Initial number	Final number	Mortality	SR (%)	MR (%)
1	*Caranx sexfasciatus*	447	411	36	91.9	8.1
2	*Acanthurus blochii*	206	195	11	94.7	5.3
3	*Epinephelus sexfasciatus*	48	44	4	91.7	8.3
4	*Siganus canaliculatus*	142	128	14	90.01	9.9
5	*Elagatis bipinnulata*	18	18	0	100.0	0.0
	Total	861	796	65	-	31.6
	Mean				93.66	6.32

Note: SR – Survival rate, MR – mortality rate.

Length growth indicates that the fish absolute growth is very good. *C. sexfasciatus* grew as much as 14.6 cm from 8.1 cm long at the beginning of the study to 22.7 at the end of study, followed by *Elagatis bipinnulata*, 13.6 cm, from 13.7 cm to 27.3 cm, E. *sexfasciatus*, 7.4 cm, from 9.2 cm to 16.6 cm, *S. canaliculatus*, 5.5 cm, from 12.3 cm to 17.8 cm, and the lowest was recorded in *A. blochii*, 4.5 cm, from 13.5 cm to 18 cm long (Table 8).

Table 8

Mean total length growth during the study

No	Fish species	Initial length (cm)	Final length (cm)	Length growth (cm)
1	*Caranx sexfasciatus*	8.1	22.7	14.6
2	*Acanthurus blochii*	13.5	18	4.5
3	*Epinephelus sexfasciatus*	9.2	16.6	7.4
4	*Siganus canaliculatus*	12.3	17.8	5.5
5	*Elagatis bipinnulata*	13.7	27.3	13.6

Furthermore, Table 9 shows that the fish weight increment is also good. Several previous findings (Philipose et al 2013; Mojjada et al 2012; Paruntu 2015; Lutfiyah et al 2019) confirm that the cultured fish growth is influenced by the environmental conditions and the sustainable food availability. Fish growth condition in the floating fish cage (FFC) is affected by fish stocking density, food quantity, and food quality. The present study used a density of 4.9 ind m^{-3}. It is also supported by small fish occurrence as natural food, such as *Stolephorus indicus*, as visitor in the artificial reef habitat at night. This visit could be related to the fish attraction to the night light of the integrated aquaculture facilities.

Based on the fish survival rate and growth, the present study indicates that the cultured fish can live and grow well under this aquaculture system. It is supported by good water quality conditions in this area. Besides, stocking density, feeding, and the availability of live food, such as *Stolephorus indicus*, visiting the area at night, highly contribute to their growth.

Table 9

Mean individual weight growth during the study

No	Fish species	Initial weight (g)	Final weight (g)	Weight growth (g)	SGR (%)	DGR (g)
1	*Caranx sexfasciatus*	61.3	222.5	161.2	5.37	1.34
2	*Acanthurus blochii*	106.5	155.2	48.7	5.01	0.41
3	*Epinephelus sexfasciatus*	31	94.3	63.3	4.52	0.53
4	*Siganus canaliculatus*	46.7	123.5	76.8	4.78	0.64
5	*Elagatis bipinnulata*	150	259	109	5.52	0.91

Seaweed culture. Seaweed growth is presented in Table 10. The highest growth was found in the seaweed of the eastern frame, and the lowest in the southern frame. It reflects that the seaweed growth condition is good enough. Similar finding was also recorded by Kasim et al (2016) that seaweed culture under long line method around the FFC has high growth rate. It is supported by fish culture activity in the FFC at the same period, in which food wastes and metabolic products give positive impact on the seaweed growth. This finding is in line with Neori et al (2000) and Yu et al (2016) that multitrophic mariculture activity highly contributes to seaweed growth rate. The cultured fish secrete ammonia to the aquatic environment, and seaweed can filter ammonia from the water. Yu et al (2019) found that seaweed and oyster culture combination can reduce eutrophication and heavy metals, and increase water quality and nutrition in the water column, so that seaweed culture development could be done. However, culture period and locality highly influence the seaweed productivity (Hurtado et al 2001; Radiarta et al 2014).

Table 10

Mean growth of the seaweed *Kappaphycus alvarezii* in three harvest periods

No	*Planting position*	*Mean weight growth (g)*				*SGR*	*DGR*
		Day 0	*Day 15*	*Day 30*	*Day 45*	*(%)*	*(g)*
1	East frame	100	116.00	133.58	211.72	1.67	2.48
2	South frame	100	116.67	137.67	168.60	1.16	1.52
3	West frame	100	117.00	144.68	200.51	1.55	2.23

Pearl oyster culture. The pearl oysters reach higher and higher survival rate. Low mortality occurred at the beginning indicating that the oyster could be reared together with other animals and seaweed under the integrated aquaculture system. There were 36 individuals of larvae cultured in period-1 with mean length of 43.9 mm. The survival rate was 88.89% and increased with time up to period 4. Similar situation also occurred in shell growth of the oyster with total length increment of 19.96 mm during the study and daily growth rate from 0.2 mm d^{-1} in the second period to 0.67 mm d^{-1} in period-4 (Table 11). In the beginning of the experiment, the pearl oysters had some mortality and low growth.

Table 11

Growth and survival rate of pearl oyster *Pinctada maxima*

No	*Period*	*Survival*	*Mortality*	*SR (%)*	*Mean shell length (mm)*	*DGR (mm)*	*(L) (mm)*
9	Period 1 (t-0)	36	4	88.89	43.94	-	-
2	Period 2 (t=1)	32	2	93.75	49.81	0.20	5.87
3	Period 3 (t=3)	30	1	96.67	55.24	0.38	11.3
4	Period 4 (t=4)	29	0	100	63.90	0.67	19.96

This finding indicates that the pearl oysters cultured in the integrated culture can grow well. It is in line with Haws & Ellis (2000) that pearl oyster seed culture in the bucket can yield good growth, because the oyster can freely get food supply from surrounding waters. Mortality occurred in nearly all planting periods, but the highest happened at the first month of the culture period. The oyster seeds were taken from outside the research location, and they need time to adapt to the new environment despite supported with good water quality and natural food abundance conditions. Such a condition could also happen due to the effect of water temperature change and depth (Le Moullac et al 2016; Sanz-Lazaro et al 2018; Syachruddin et al 2018). Therefore, the placement of culture cage should be done at the appropriate depth to avoid high temperature fluctuations.

Site revisit showed that the artificial reefs have grown well with various lifeforms that form new reef habitats and shelters. Fish observation using the same sampling method found nearly all species previously recorded with a total number of 442 individuals, meaning that the study site has stable ecosystem conditions to support the marine life in the area. These comprised 14 species of target group of 5 families, and 184 individuals, 48 species of major group of 13 families and 220 individuals, and 9 species of indicator group of 1 family, and 38 individuals, respectively. Target species is represented by Acanthuridae, *Acanthurus blochii* and *A. nigrofuscus*, Carangidae, *Caranx sexfasciatus, Elagatis bipinnulata*, and *Selaroides leptolepis*, Scombridae, *Rastrelliger kanagurta*, Serranidae, *Epinephelus coioides*, *E. corallicola*, *E. fuscoguttatus*, and *E. sexfasciatus,* and Siganidae, *Siganus canaliculatus*, *S. fuscescens*, *S. guttatus*, and *S. vulpinus*. Major species is dominated by members of Apogonidae (10 species) and Pomacentridae (15 species). Other families are only represented by 1-5 species, such as Balistidae, *Balistapus undulates* and *B. viridescens*, Fistulariidae, *Fistularia commersonii,* Holocentridae*, Sargocentron cornutum*, Monacanthidae, *Aluterus soriptus,* and *Amanses scopas*, Muraenidae, *Gymnothorax isingteena* and *G. eurostus*, Ostraciidae, *Lactoria cornuta* and *Ostracion cubicum*, Pomacanthidae, *Centropyge vrolikii, Chaetodontoplus melanosome, C. mesoleucus, Dischistodus prosopotaenia*, and *Paracentropyge multifasciata*, Soleidae, *Liachirus melonospilus*, Synodontidae, *Synodus macrops*, Tetraodontidae, *Arothron hispidus, A. mappa, A. nigropunctatus, A. reticularis*, and *Canthigaster solandri*, and Zanclidae, *Zanclus cornutus*. Indicator species group was represented by 9 species of Chaetodontidae, *Chaetodon bennetti, C. guentheri, C. guttatissimus, C. kleinii, C. lineolatus, C. melannotus, C. ocellicaudus, C. trifasciatus*, and *C. trifascialis*. In this revisit, *Epinephelus quoyanus*, *Pervagor aspricaudus,* and *Coradion chrysozonus* were not found in this observation. Lower number of individuals than that found in the artificial reef-supported integrated aquaculture activity may be caused by limited carrying capacity of the artificial reef ecosystem in the area. The artificial reef deployment site covers only 500 sq.M. Besides, there is high a number of temporary residents coming for food around the floating fish-cage when the integrated aquaculture activities were run. Nevertheless, this study has shown that artificial reef-supported integrated aquaculture could be adopted as an appropriate approach to coral reef rehabilitation program and economic development.

Conclusions. Integrated aquaculture supported with an artificial reef has attracted many fish stay around. It is reflected from high fish species composition recorded, so that this locality could become both source of target fish cultured and natural food, such as small fish. Fish species diversity analysis in the artificial reef habitat and the growth analysis revealed that the integrated aquaculture supported with the artificial reef could economically and ecologically yield multiple benefits.

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