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Sustainable aquaculture to improve productivity and water quality of marginal brackishwater pond

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Abstract—An Integrated Multi Trophic Aquaculture (IMTA) technology by using blacktiger shrimp, tilapia, algae/seaweed (*Gracillaria* sp.) and oyster green mussel (*Pernapiridis* sp.) that are cultivated integrately in one pond has demonstrated high productivity on the biomass and environmental stability of water quality compared to the monoculture and polyculture without algae and benthic organism. The availability of seaweed and benthic organism in an integrated aquaculture system have contributed on the improving water quality by reducing DIN and increasing DO concentration. In the future, developing aquaculture models using the biorecycle system to reduce and minimize the inorganic and organic waste from the remaining feed, faeces and the other sources will be useful to maintain sustainable aquaculture in the coastal area. Particularly when supported by coastal communities involvement as denoted on the Sato Umi-GEMPITA-SPL/SFiCoMS concept, it will be successful.

Key words: sustainable aquaculture, productivity, water quality, marginal brackishwater pond

Introduction

Indonesia has 1.2 million ha of brackishwater pond area, but only 37.5% of them are used for aquaculture activities. The low utilization of brackishwater pond is generally caused by environmental damage due to the excessive exploitation by intensive aquaculture activities during the period of 1980s. It is well known that more than two decades ago, the Northern Coastal Area of Java was to be a center of shrimp production and an important regions for the economic growth of the western Indonesia. However, the rapid development of shrimp farming, industry and housing in the region has caused environmental damage (Ongkosono 1990, Ongkosono 1992, Praseno 1995, Nurdjana 1997). Since 1985, land along the Northern Coastal Area of Java have gradually been converted into shrimp ponds with intensification system. In the early stages, this system has contributed greatly to the production of shrimp for the region with an average productivity of more than 4 tons/ha. However, after a decade until recently, shrimp productivity decreases dramatically to less than 1.5 tons/ha. The rapid development of shrimp farming that was followed by massive mangrove deforestation which actually serves as a buffer zone to degrade an organic waste as well as an intensified used of feed and drugs has caused an excess on the decreasing of water quality, aquatic environmental and the carrying capacity in the region. As a result, various of diseases threatened the lives of shrimp from an early stage of the cultivation to pre-harvest (Phillips et al. 1993). Various environmental damage caused by intensive shrimp farming in some areas have been reported, (Pillay 1992, Chua 1993, Gowen and Rosenthal 1993, Flaherty and Karjanakesorn 1995).

In line with the growing global paradigm in the face of change and good environmental damage caused by excessive exploitation of natural resources and the consequences of climate change and global warming, it is time for Indonesia to implement the concept of management and utilization of natural resources taking into account the balance and stability of the natural resources and the environment, such as in the concept of SATO-UMI as promoted by Yanagi (2008). To support those paradigm, it is necessary to develop a management and utilization concept of fishery, coastal and marine resources wisely, balanced, harmonious, integrated and more productive by actively involving the community as in the concept of GEMPITA-SPL (Gerakkan Masyarakat Peduli Kelestarian Sumberdaya Perikanan, Pesisir dan Laut) or SFiCoMS (Sustainable Utilization of Fisheries, Coastal and Marine Resources for the Society) which is being developed by Agency for the Assessment and Application of Technology (BPPT). To implement the SATO-UMI–GEMPITA-SPL/SFiCoMS concept and to improve the productivity of the marginal brackishwater pond in the coastal area, a sustainable aquaculture model should be developed. An integrated and environmental friendly farming technology model such as the Integrated Multi-Trophic Aquaculture (IMTA), can be applied to improve the productivity of marginal brackishwater

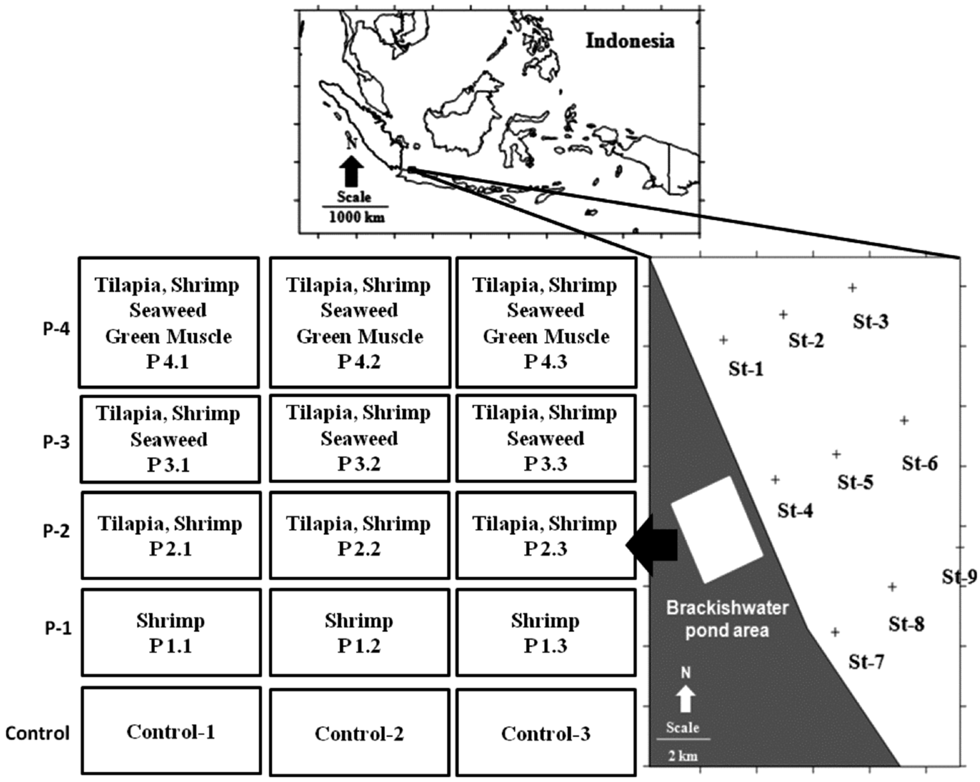

Fig 1. Site location, experimental design of the "*Integrated Multi Trophical Aquaculture (IMTA)*" and sampling station of the water qualities in the northern coastal area of Karawang.

pond by increasing the diversity product through biorecycle system to ensure the sustainable utilization of brackishwater pond in the coastal area.

The IMTA technology is a clean technology (green technology) and Zero Waste Emission (Troell et al. 2003, Neori et al. 2004, Chopin 2006). The aquaculture productivity can be improved through the development of an integrated and intensive aquaculture system by using multi product, i.e. tilapia, tiger prawns, sea grass and oyster that are maintained in a pond for inclusion. Furthermore, the water quality will be stable because the remaining organic waste of fish or shrimp feed will be utilized by oyster and an inorganic waste in the water pond as fertilizer will be used by seaweed for their growth. These conditions will create the balance of the ecosystem (Goldman et al. 1974, Ryther et al. 1975, Huguenin 1976, Neori et al. 1989, Shpigel et al. 1993a, 1993b, Neori and Shpigel 1999, Neori et al. 2001, Chopin et al. 2004). If this technology is successfully implemented in a national level, in which a whole Indonesian marginal brackishwater pond area is utilized optimally, the income of the community in a local, regional and national level will increase.

The occurrences of water quality degradation due to the expansion of an intensive shrimp culture in the several areas have been reported (Pillay 1992, Chua 1993, Gowen and Rosenthal 1993, Flaherty and Karnjanakesorn 1995), but for the northern coastal area of Karawang, it is still very limited. Since the performance of shrimp culture yield is considered to be a problem within this region, a systematic understanding of water quality status in the coastal area in different seasons as well as in the brackishwater pond during the cultivation are important to be clarified in order to provide a better and proper management of aquaculture in the future. In this study, we introduce four (4) systems of the aquaculture experiments i.e. pond containing black tiger shrimp (*Penaeus monodon*), pond contains black tiger shrimp and tilapia (*Oreochromis niloticus*), pond contains black tiger shrimp, tilapia and seaweed (*Gracillaria* sp.) and pond contains black tiger shrimp, tilapia, seaweed and oyster green mussel (*Pernapiridis* sp.) as well as the water quality of the coastal area in the wet and dry seasons and in the brackishwater pond during the cultivation were monitored to understand the water quality status and performance of the model to improve the productivity of marginal brackishwater pond in the coastal area.

Materials and Methods

An experiment to clarify the sustainable model of Integrated Multi Trophical Aquaculture model was conducted during 4 months from June to September 2010 in the marginal brackishwater pond area of the northern coastal area of Karawang, West Java, Indonesia (Fig. 1). This experiment is a part of the SATOUMI (Yanagi 2012) and GEMPITA-SPL/

Table 1. Water qualities of the northern coastal area of Karawang in the wet and dry seasons.

	Temperature (°C)	Salinity (PSU)	Transparency (m)	Turbidity (NTU)	DO (mg/l)	pH	TSS (mg/l)	DIN (mg/l)	DIP (mg/l)	Chl-*a* (µg/l)
Wet season	30.28	25.21	0.58	96.11	6.69	7.98	39.00	2.29	2.00	3.67
Dry season	31.28	31.02	1.41	26.17	5.74	8.02	8.33	1.36	0.08	2.62

SFiCoMS concept application to sustain and improve aquaculture productivity with environmental stability, high biodiversity and involving community intervention to create the aquaculture sustainable model.

The experiment used four (4) aquaculture models using 500 m^2 pond of each with three (3) replications (Fig. 1). The model-1 (P-1) contains seed of black tiger shrimp fry with density 5 shrimp/m^2. Model-2 (P-2) contains seed of tilapia and black tiger shrimp fry with density of each, 5 fish and shrimp/m^2. Model-3 (P-3) contains the same density with P-2 of tilapia and blacktiger shrimp, with additional algae/seaweed (*Gracillari* sp.) in the longline system with density of 0.1 kg/m^2 per point. Model-4 (P-4) contains the same composition and density with P-3 of tilapia, blacktiger shrimp and algae/seaweed (*Gracillaria* sp.) with additional benthic organism of oyster green mussel (*Pernapiridis* sp.) in the longline system with density 100 g per point, and as a control we used pond without organism.

To understand the growth performance of the cultivated organism and the water quality status of each brackishwater pond model, the monitoring was carried out during the observation. The growth performance data was collected by weighing of the sample organism of each brackishwater pond model and water quality of temperature, salinity, turbidity, pH and Dissolved Oxygent (DO) were measured directly in the field by using Horiba Model U-10 and Total Suspended Solid (TSS) by gravimetric method. For nutrient analysis of Dissolved Inorganic Nitrogent (DIN), Dissolved Inorganic Phosphate (DIP) and Biological Oxygent Demand (BOD_5), water sample of each brackishwater pond model was analyzed in the laboratory using spectrophotometers (Spectronic 21D Milton and Spectro 2000 RS, Labomed). DIN and DIP were analyzed according to APHA (1979) standard method and BOD_5 was analyzed by titrimetric Winkler method.

To support this study, the similar water quality parameters as the experimental brackishwater pond, with additional chlorophyll-*a* parameter of sea surface water quality of the northern coastal area of Karawang was also collected from 9 stations (St-1–St-9) in the wet (April 10, 2010) and dry seasons (August 10, 2010) using small boat as shown in Fig. 1, while soil quality (pH and redox potential) of the experimental pond was sampled and analyzed in the laboratory and chlorophyll-*a* was measured by spectrophotometric method (Parsons et al. 1984). Statistical analysis of the ANOVA (Sokal and Rohlf 1981) was applied to understand the differences in water quality among treatments with focusing on the DIN, DIP and DO as key parameters.

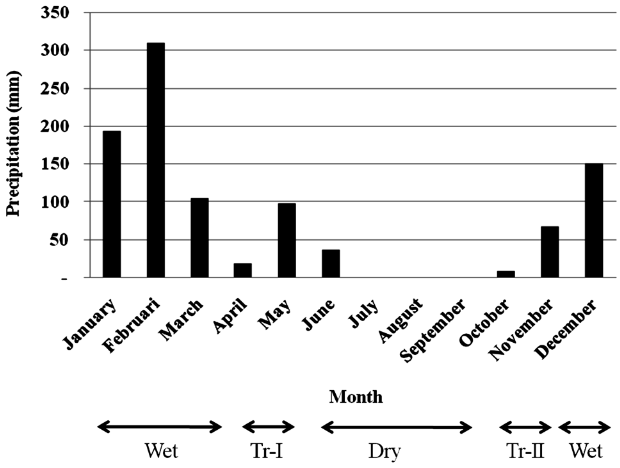

Fig. 2. Precipitation in the northern coastal area of Karawang, West Java (Perum Jasa Tirta, 2010).

Results and Discussion

Water quality of the coastal area

The performance of water quality in the northern coastal area of Karawang is shown in Table 1. In the wet season, water temperature and salinity were lower than those in the dry season as response to high precipitation during the wet season. Low salinity is mainly caused by the existence of the run off from the coast and rivers. High precipitation in the rainy season shown in Fig. 2 (Perum Jasa Tirta 2010) has also caused decreasing water transparency, increasing water turbidity, TSS, DIN, DIP and DO, and on the contrary in the dry season. High concentration of DIN and DIP in the wet season has stimulated phytoplankton bloom as shown by high concentration of chlorophyll-*a*.

The brightness level (transparency) was lower and turbidity (turbidity) was higher in the wet season compared to the dry season. This evidence was also seen from the total suspended solids (TSS) level that was higher four times than that in the dry season. High concentration of DIN and DIP in the wet season indicated that the load of the organic nitrogen and phosphorus from the terrestrial environment brought by the river and coastal land surface discharge to the coastal waters was high as response to high precipitation during the wet season. The concentration of dissolved oxygent (DO) is also quite high during the wet season due to high rate of photo-

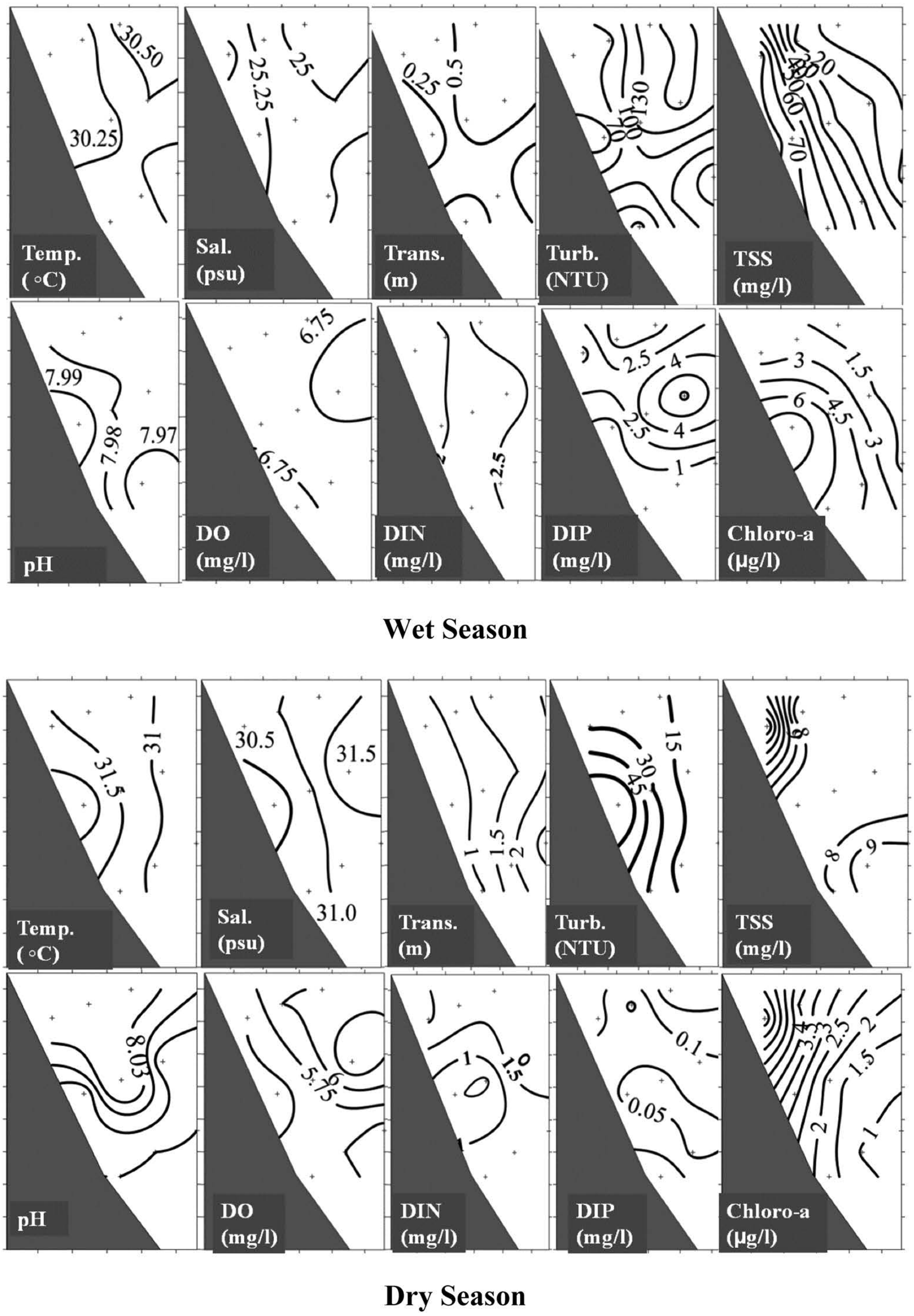

Fig. 3. Horizontal distribution of water qualities of the northern coastal area of Karawang in the wet and dry seasons.

synthesis and high chlorophyll-*a* concentration.

Horizontal distribution of water quality in the northern coastal area of Karawang are shown in Figure 3. In approaching shore, water temperature, salinity, turbidity and suspended solids were higher in the wet and dry seasons. This occurence was generated due to the strong turbulence of the water mass near the shore as response to the strong current. The heat transfer from the bottom of the shallow waters near the shoreline affected the temperature of the surface water, while it was also influenced on the increasing salinity as denoted by Sachoemar and Yanagi (1999, 2000). Increasing turbidity and suspended solids level in the near shoreline area decreased the brightness, which seems due to the existence of the turbulent water mass due to the circulation of currents around the coast. In this area, coastal erosion was high due to unavailable mangrove forest, and mud from the

Table 2. Water qualities of each brackishwater pond model.

Brackishwater pond model	Temperature (°C)	Salinity (ppt)	pH	DO (ppm)	Turbidity (NTU)	TSS (mg/l)	BOD_5 (mg/l)
P-1	30.81	24.94	7.92	6.28	121.83	36.50	1.66
P-2	30.77	23.11	7.87	6.27	127.46	22.33	0.71
P-3	30.92	22.48	7.90	6.74	157.08	22.83	0.24
P-4	30.94	22.91	7.91	7.11	177.67	18.00	1.18
Control	30.60	20.30	8.05	6.65	197.00	38.00	0.71

bottom waters were upwelled and it caused the water to be turbid. The process of mixing water near the coast seems to have lifted of nutrients from bottom waters into the surface waters and resulted in the enrichment process of inorganic nutrient that stimulated phytoplankton bloom. This is indicated by the high concentration of chlorophyll-*a* near coastline.

Based on the observations of the water quality in the northern coastal area of Karawang, the water quality is still feasible to support the aquaculture activity. However, to capture better sea water quality and to reduce the turbidity level, longer channel should be constructed to the offshore, especially during the wet season. Moreover, to reduce water quality deterioration and prevent erosion in the northern coastal area of Karawang, reforestration program of the mangrove should be established to protect the coastal environment within this region. The mangrove forest is well known has multifunction that is physically capable to protect the coastal environment from the erosion, and also has function as a buffer to neutralize the organic waste as well as a nursery ground for various marine biota.

Water quality of brackishwater pond model

Based on the analysis and evaluation of water quality (temperature, salinity, pH, DO, turbidity, TSS, BOD_5, DIN and DIP) of 4 models brackishwater pond and control as shown in Table 2, indicated that water quality for all models is normal to support the aquaculture organism life. Though the pond in the land is located a few hundred meters away from the coastline and there is a channel between the pond and the sea, but no significant water exchange occur between the pond and the sea because the water from the channel was filled manually to the pond using a pump. The interesting situation is seen on the model of P-4 where temperature and DO are relatively high, while salinity and pH are low. High DO concentration of P-4 model exposed the enrichment of DO as response to the availability of algae/seaweed (*Gracillaria* sp.) that produced DO through high intensity of photosynthesis and it is stimulated by high temperature. The almost similar situation was seen on P-3 in which the DO concentration was higher than that in P-1 and P-2. High turbidity in P-4 model seems due to high chlorophyll-*a* because TSS is low. From this situation it can be concluded that the presence

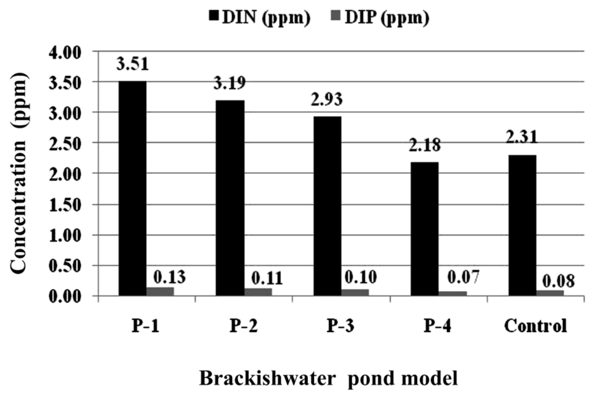

Fig. 4. Mean average of DIN (*Dissolve Inorganic Nitrogen*) and DIP (*Dissolve Inorganic Phosphorus*) of each brackishwater pond model.

of seaweed in P-4 and P-3 model has improved the water quality.

Moreover, based on the data shown in Fig. 4, the DIN concentration of P-4 is the lowest even compared to the control. This situation indicates that P-4 containing green muscle as the organic consumer organism and seaweed as an inorganic consumer has contributed on the reduction of DIN concentration through the biorecycle system. In this system, organic material derived from residual feed, fish waste and other sources will be used for the growth of seaweed and green muscle. As the result, water quality and ecosystem of P-4 to be more stable compare to the other models. Statistical analysis shown in Table 3, strengthened the situation that P-4 model is significantly different with the other models on the DIN concentration, but no significant with control. It means that the biorecycle system in the integrated multi trophic aquaculture model worked well in the reduction of DIN concentration of P-4 model. The similar situation was seen on the DO concentration in which P-4 model is significantly different with the other models and control. High DO concentration of P-4 model is stimulated by availability of seaweed and high temperature that contributed on the intense of photosynthesis. High DO concentration was also shown by P-3 model compared with P-1, P-2 and control. The availability of seaweed in P-3 model has also contributed on the enrichment of DO concentration. The different situation was seen on the DIP that is no significant different among the models

Table 3. Statistical analysis of the ANOVA and mean average of DIN, DIP and DO of each brackishwater pond model.

Parameters	Control	Brackishwater pond model			
		P-1	P-2	P-3	P-4
DIN (mg/l)	2.31±0.33	3.51±0.38*	3.19±0.61*	2.93±0.34*	2.18±0.28
* Significantly different with control and P-4 (P<0.05)					
DIP (mg/l)	0.08±0.03	0.13±0.10	0.11±0.11	0.10±0.08	0.07±0.04
Non significantly different among treatments (P>0.05)					
DO (mg/l)	6.65±0.34	6.28±0.22*	6.27±0.12*	6.74±0.34*	7.11±0.57 **
*Significantly different with control (P<0.05)					
**Significantly different with control, P1, P2 and P3 (P<0.05)					

even with the control as shown on the Table 3 and Fig. 4. It is indicated that DIP was not a major element that affects the aquaculture system in the northern coastal area of Karawang compare to the DIN.

Growth performance of cultivated organism

Green Technology in the field of aquaculture was developed to overcome the problem of environmental degradation. By developing a model of environmentally friendly aquaculture as an integrated multi-trophic aquaculture, the productivity of marginal brackishwater pond in the coastal area is expected can be increased and the quality of the environment can be well maintained and sustained. In the integrated multi-trophic aquaculture with biorecycle system, the organic material from remaing feed, fish waste and the other sources can be reused for growing out of oyster and in unorganic material for seaweed.

The integrated multi trophic aquaculture is expected to solve the problems in maintaining the stability of aquatic ecosystems and improve productivity of marginal brackishwater ponds within Indonesian coastal waters. It is already evident in the pond of P-4, where algae/seaweed (*Gracillaria* sp.) and oyster green mussel (*Pernapiridis* sp.) that were cultivated with blacktiger shrimp and tilapia was growing well as well as maintenance of water quality. In this system, the inorganic and organic wastes from remaining feed and faeces of tilapia and shrimp are reused for seaweed and oyster growth. The existence of seaweed has also enriched the dissolved oxygen and made the aquatic ecosystem more health and stable to maintain the cultivated organism. The performance of the biomass productivity of each experiment model in Fig. 5 shows that model of P-4 is the most productive followed by P-3 model, while the water quality stability as shown on Tabel 2 and Fig. 4 indicated the excellent condition for P-4 model with the lowest concentration of DIN compared to the other models. This condition shows that the biorecycle system worked well on the P-4 model containing multi trophic organism to reduce and minimize the organic and inorganic waste from the remaining feed, faeces and the other sources on the aquaculture system. The model also was

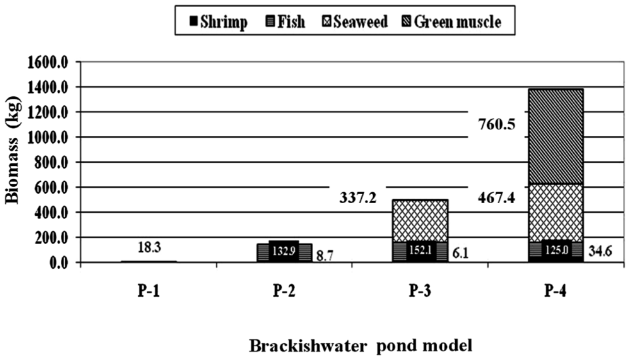

Fig. 5. Productivity profile of each brackishwater pond model.

more productive on the biomass production compared to the mono culture or polyculture system as shown on the P-1 and P-2 models with no algae and benthic organism.

In the view point of the quantity of cultivated organism, by applying the integrated multi trophic aquaculture model using tilapia, shrimp, algae/seaweed (*Gracillaria* sp.) and oyster green mussel (*Pernapiridis* sp.) as a polyculture system, the utilization of marginal brackishwater pond can be optimized and more productive. Moreover, water quality and aquatic ecosystem health can also be naturally well maintained compared to monoculture and polyculture non integrated multi trophic aquaculture system. The similar models using different organisms of the integrated multi trophic aquaculture model, is expected to be developed to improve and increase the productivity of marginal brackishwater pond in a sustainable manner. The result of experiment has shown that P-4 containing 4 cultivated organism as an integrated multi trophic aquaculture model was the most productive aquaculture system with the most stable water quality compared to monoculture and polyculture non integrated multi trophic aquaculture system. This result indicates that the aquaculture system with integrated multi trophic polyculture will be more benefit to sustain the aquaculture system in the coastal area and more productive to provide financial benefits for the society compared to monoculture and polyculture non integrated multi trophic aquaculture system without algae and benthic organism as shown in P-1, P-2 and P-3. With integrated multi trophic aquaculture models, the risk of failure aquaculture business is expected to be reduced, because at least one or more cultivation organisms are still expected to be harvested. The farmer can also reduce the risk of capital farming and maintain the coastal area to sustain aquaculture activities with the natural balance.

Conclusion

The integrated multi trophic aquaculture (IMTA) technology using tilapia, blacktiger shrimp, algae/seaweed (*Gracillaria* sp.) and oyster green mussel (*Pernapiridis* sp.) in a pond has demonstrated high productivity on the biomass and environmental stability with the lowest of the DIN concentration through biorecycle system, compared to the monoculture and polyculture without algae and benthic organism. In the future, developing aquaculture models using the biorecycle system to reduce and minimize the inorganic and organic waste from the remaining feed, faeces and the other sources will be usefull to maintain sustainable aquaculture in the coastal area. Particularly when supported by coastal communities involvement as denoted on the Sato Umi-GEM-PITA-SPL/SFiCoMS concept, it will be successful.

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