Feasibility study of combined *Gracilaria verrucosa* seaweed with giant tiger prawn *Penaeus monodon* farming

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Abstract. *Gracilaria verrucosa* seaweed is one of the leading fishing commodities which can be cultured in ponds, in connection with the government's program for the development of seaweed aquaculture, in order to overcome the disease and failure issues in the cultivation of giant tiger prawn (*Penaeus monodon*). The waste resulting from the feed unused by *P. monodon* is one of the main causes of disease and failure in aquaculture, while it could provide the nutrients required for the seaweed cultivation in a polyculture system. This study aimed at evaluating the density of aquaculture which would be suitable for combining tiger prawn with seaweed cultures (polyculture). The method of observing and taking water samples at each observation location and the method of analysis refer to the American Public Health Association (APHA). In order to determine the prospects for developing tiger prawn and seaweed farming, a business profitability analysis was carried out. The results showed that among the relevant water quality parameters, the total suspended solids (TSS) and chemical oxygen demand (COD) have exceeded the thresholds of quality standard requirements for the aquaculture feasibility. The results of the economic valuation of shrimp farming in ponds can be applied to develop profitable businesses, as it can be seen from the R/C ratio>1 for tiger prawn farming densities of 8, 11 and 13 ind m^{-2}. The seaweed cultivation area was 50% planted with seaweed, respectively R/C ratio 2.11, 1.83, 1.37. The combination of tiger prawn cultivation with seaweed at each density level of 8, 11 and 13 ind m^{-2} generates a profit of 6,039.831, 5,182,726, and 5,639.662 USD $year^{-1}$, respectively.
Key Words: cultivation, seaweed, tiger shrimp, business profitability.

Introduction. Seaweed, *Gracilaria verrucosa*, is one of the leading fisheries commodities with a great potential to be developed in ponds (Widiastuti 2011; Irsan 2021) in connection with the government's program for the development of seaweed aquaculture in order to overcome disease and failure issues in the cultivation of giant tiger prawn (*Penaeus monodon*), due to the waste resulted from the unused feed. By recycling the waste to nutrients seaweed cultivation becomes an alternative for combined cultivation (Serdiati & Irawati 2010). The combination of seaweed cultivation with tiger prawn cultivation will create an environmentally friendly and sustainable aquaculture business, with an efficient use of cultivated coastal waters area and an increased tiger prawn and seaweed production (Nurjannah 2007; Abeson & Taku 2006). So far, tiger prawn farmers often experience crop failures and losses so that the combination of seaweed and tiger prawn cultivation is expected to improve this context.

Rearing tiger prawns takes longer (4 months), while the maintenance time for seaweed is shorter (45 days), therefore 3 seaweed production cycles occur during one tiger prawns production cycle. From both ecological and economic points of view, the circular economy design of the operations is beneficial: shrimp farming will produce waste/leftover feed that is not used by tiger prawn, but which is a source of nutrients for seaweed. Beyond its sustainability, this polyculture business will also increase the income of pond farmers. Not only this business can be considered as a profitable alternative for the fish farming, but it also adds to the knowledge capital of the aquaculture science and technology.

The objectives of this study were: (1) to determine the physical and chemical parameters defining the suitability of the waters for tiger prawn cultivation; (2) to determine the priority scale of the aquatic environment suitability for both tiger prawns, and seaweed; (3) to test the aquatic environment suitability through the combined tiger prawn and seaweed cultivation at the locations deemed appropriate; (4) to evaluate the profitability of an integrated tiger shrimp and seaweed cultivation.

Material and Method

Data collection*.* This research was conducted in the aquaculture area of Barru Regency, South Sulawesi. Geographically this area is located at 4°5'49"-4°47'35" south latitude and 119°49'16" east longitude (Figure 1).

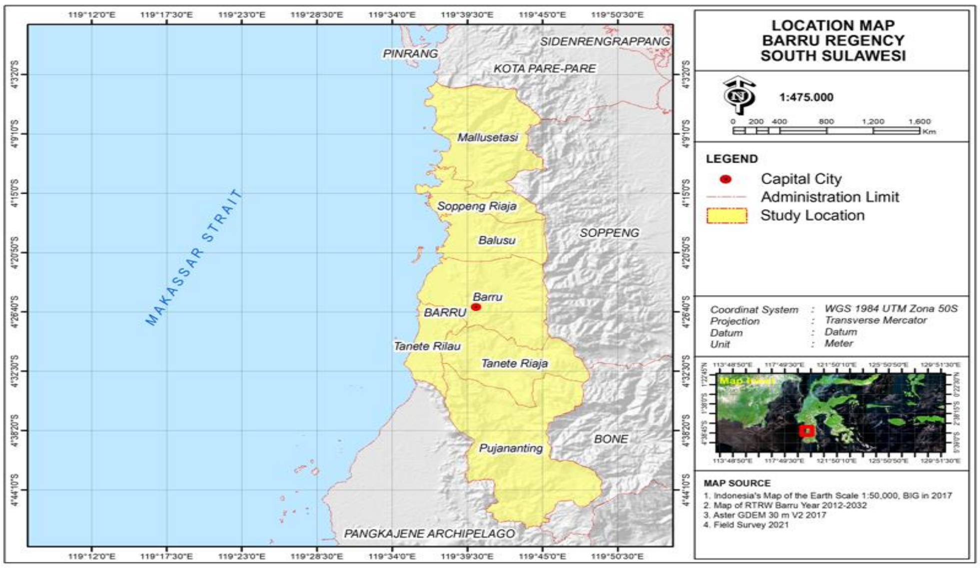

Figure 1. Research location.

Implementation of research activities

Water chemical physical parameter. In-situ data were collected at 24 observation points determined by using a GPS tool (Raufet al 2020). The method of observation and sampling at each observation location refers to the American Public Health Association (APHA) (1992).

P. monodon and G. verrucosa production farming methods in pond. Pond areas of ±0.25 ha were used for rearing seaweed and tiger prawns. The rearing system consisted of pond plots 50% planted with seaweed and 50% stocked with tiger prawns at different densities, namely 8, 11 and 13 ind m^{-2}. Seaweed area and tiger prawn rearing area are limited by waring to allow water to flow from and to the tiger prawn rearing area with the assumption that there is a mutually beneficial relationship between seaweed and tiger prawns. In this study, the maintenance was carried out in 2 cycles and was replicated. To determine the production of tiger prawns, the conditions and outcomes of the *G. verrucosa* cultivation and of the combined seaweed and tiger prawns cultivation in shrimp ponds were examined by maintaining seaweed and shrimp for a period of 120 days. Tiger prawns were weighed every 2 weeks and seaweed plants were weighed every week, in order to determine their growth performance. The observed variables were the survival rate for tiger prawns and growth rates for tiger prawns and seaweed.

Feasibility of P. monodon and G. verrucosa integrated cultivation business. Environmental suitability for tiger shrimp cultivation is a supporting ecosystem service to the cultivators' benefit (Kasmir 2012). In addition, the success of cultivation will ultimately be evaluated trough the amount of income (profit) generated (Irsan 2021).

After analyzing the suitability of the aquatic environment in accordance with the aquaculture requirements, a profitability analysis was carried out. To identify the prospects for developing tiger prawn and seaweed farming, a business profitability analysis was carried out. For assessing the profitability of a business, it is necessary to carry out a profits and costs analysis, intended to offer the entrepreneurs/farmers an overview of the profitability of the business being carried out. Thus, the entrepreneurs/farmers (cultivators) can evaluate the profit and loss of the developed business and the capital return. The R/C ratio analysis was used to assess the profitability of tiger shrimp and seaweed cultivation, profitability by comparing the revenue and production costs for 1 year. When the R/C ratio <1, the business is not profitable. An R/C ratio equal to 1 defines the break even point. For an R/C ratio>1, the business can be developed with profits (Kasmir 2012).

Results

Quality of coastal waters (physical and chemical parameters of waters). The average value of the results of measuring the quality of coastal waters in Barru Regency taken from each observation station (sea and ponds) is presented in Table 1.

Table 1
Value of water quality measurement results at marine stations and ponds in coastal waters, Barru Regency

Parameters	*Station*		*Quality standards*
	Sea	*Pond*	
Temperature (°C)	28.9±1.5	28.5±0.80	21-32
Brightness (%)	72.10±7.40	65.90±15.20	>5
Salinity (ppt)	30.8±1.25	30.12±1.18	5-35
Current (ms^{-1})	0.178±0.035	-	-
DO (mg L^{-1})	5.86±2.26	3.75±01.05	≥3
pH	7.90±0.08	7.60±0.19	6.5-8.5
TSS (mg L^{-1})	68,5±18.5	130.5±39.6*	25-80
BOD_5 (mg L^{-1})	5.64±2.14	6.54±1.70	<25
COD (mg L^{-1})	74.05±14.37	81.20±21.40*	40-80
BOT (mg L^{-1})	7.40±2.12	17.50±12.20	-
Turbidity (NTU)	5.02±3.86	29.4±14.8	≤30
Ammonia (mg L^{-1})	0.081±0.110	0.308±0.136	≤1.0
Nitrate (mg L^{-1})	0.054 ±0.114	0.174±0.104	-
Nitrite (mg L^{-1})	0.054±0.09	0.154±0.124	0.25
Total phosphate (mg L^{-1})	0.100±0.034	0.0176±0.124	0.05-0.50

*) Exceeded the permissible limits for cultivation activities based on the criteria of Boyd (1990), Wedmeyer (1996), MENKLH (1988), Poernomo (1991), Widigdo (2000) and Ramanujam (2008).

Development of P. monodon cultivation with G. verrucosa. The development of the tested tiger shrimp culture is carried out by direct rearing of shrimp in ponds measuring 2,500 m^2. The treatments concerned the variation of the tiger prawn specimens' density levels, namely: treatment A (8 fish m^{-2}), treatment B 11 (tail m^{-2}) and treatment C 13 (tail m^{-2}), and aimed at testing the productivity and revenue variation for different conditions of maintenance of polyculture with seaweed (50% of the pond area planted with seaweed).

P. monodon cultivation business performance. The performance of *P. monodon* culture at various density levels is presented in Table 2.

Table 2

Characteristics of *Penaeus monodon* cultivation at various density levels

Parameters	*Stocking density (ind m^{-2})*		
	8	*11*	*13*
Maintenance period (days)	120	120	120
Survival rate (%)	38.98	37.59	27.77
Size (kg)	42	40	49
Average harvest weight (g)	23.83	24.56	20,36
Production (kg/0.25 ha)	185.78	253.88	183.29
Growth rate (%)	0.246	0.270	0.208

The survival rate of *P. monodon*, reared at various density levels, at the end of the study is presented in Table 3.

Table 3

Survival rate (%) at the end of the research period, at various density levels

Treatment/ Repeat	*Survival rate (%) at various densities (ind m^{-2})*		
	8	*11*	*13*
1	38.54	34.09	32.69
2	36.45	40.90	25.00
3	41.96	37.80	25.64
Average	38.98	37.59	27.77

G. verrucosa cultivation. Seaweed growth during rearing in ponds can be seen in Table 4.

Table 4

Seaweed growth during the pond maintenance

Description	*Maintenance of time (days)*			
	0	*15*	*30*	*45*
Average weight (g)	50	76.3	156.0	245.2
Growth rate	0	1.75	3.53	4.33

Economic valuation of P. monodon cultivation. The results of the economic analysis of *P. monodon* culture with various densities are presented in Table 5.

Table 5

The results of the economic analysis of *Penaeus monodon* culture with various densities

Description	*Density (ind m^{-2})*		
	8	*11*	*13*
Volume (kg)	743.12	1.015.52	733.16
Total production volume (kg)	743.12	1.015.52	733.16
Price (USD kg^{-1})	4.919	4.919	4.919
Total revenue (USD)	3,955.544	3,606.549	3,803.316
Expenditure (USD)			
a. Fixed cost			
1. Rent pond	175.685	175.685	175.685
2. Pond construction	84.328	84.328	84.328
3. Labor wages per capita	224.877	224.877	224.877
5. Bank interest	620.000	620.000	620.000
Total cost	43.56	443.56	43.56
b. Variable cost			
1. 80,000 fry USD. 0,002	168.657	231.904	274.068

Description	Density (ind m^{-2})		
	8	11	13
2. Improvement of pond land	35.137	35.137	35.137
3. Feed	126.493	245.959	245.959
4. Fertilizer	35.137	105.411	105.411
5. Lime	14.054	70.274	35.137
6. Drugs	14.054	70.274	35.137
7. Harvest	42.164	70.274	52.705
Total variable cost	435.699	829.234	783.555
Total expenditure (TC)	964.160	1,357.695	1,312.016
Profit	6,039.831	5,182.726	5,639.662
R/C ratio	2.11	1.83	1.37

Discussion. Based on Table 1, it can be observed that there are several parameters of the quality of coastal waters in Barru Regency that have exceeded the permissible quality standard values for marine biota, namely the TSS (80 mg L^{-1}) and COD (80 mg L^{-1}). At pond stations, the water quality parameters that exceed the allowable standard values for marine biota are TSS=130.5±39.6 mg L^{-1} and COD=81.20±21.40 mg L^{-1}. The high TSS and COD in tiger shrimp aquaculture areas are a consequence of unused artificial feed (leftover feed) and metabolic waste (faeces) dissolved into the waters (Johnsen et al 1993; Primavera 1994). Furthermore, the shrimp farming technologies for covering the nutritional needs depend entirely on feed (Cheng-Nan 2007). When artificial feed exceeds the requirements, it becomes the main cause of high organic matter, TSS and COD in pond waters.

Based on the weight gain of tiger prawns during the maintenance at each density level, it was found that the cultivation with densities of 8, 11 and 13 tails m^{-2} generated survival rates of 38.98, 37.59 and 27.77%, with an average weight of 29.6 g, 26.0 g and 23.0 g, and average growth rates at the end of rearing of 0.246, 0.270 and 0.208, respectively. Based on these results, tiger shrimp culture with a density of 11 fish m^{-2} is more productive than shrimp culture with a density of 8 and 13 fish m^{-2}. The analysis of variance (α=0.05) showed that the growth rate of tiger prawns for densities of 11 and 13 fish m^{-2} had significant differences. Protein is a nutrient needed for growth (Rustam et al 2013), growth will occur when the energy needed for metabolism and tissue maintenance has been met according to the needs of the shrimp (Rachmawati 2016; Yuvaraj et al 2015).

***G. verrucosa* cultivation**. Seaweed requires nutrients for growth and survival (Kasniret al 2021). The absolute growth rate of the seaweed reared in ponds reached a total of 12 nodes every 15 days. At 15 days of maintenance, the average weight was 76.3 g, with a growth of 1.75 g day^{-1} $node^{-1}$. At 30 days of maintenance, the average weight was 156.0 g, with a growth of 3.53 g day^{-1} $node^{-1}$. At 45 days of maintenance, the average weight was 245.2 g, with a growth of 4.33 g day^{-1} $node^{-1}$. The seaweed per node productivity obtained in this study was of 215–306 g (average 245.2 g $node^{-1}$), meaning 4.3–6.1 (average 5.6) times the initial weight, which was±50 g.

Economic valuation of P. monodon cultivation. To find out the economic benefits obtained by *P. monodon* farming business actors in the ponds of Barru Regency and the profitability of the business, it is necessary to conduct a financial analysis of the shrimp farming business. Input prices and shrimp selling prices are obtained through the price observation at the location, when the activity takes place. The production obtained is based on the results of research, by converting into 1 ha of ponds.

The production of *P. monodon* cultivation with a density of 8 ind m^{-2} in 1 ha of pond will be stocked with 80,000 ind ha^{-1} and every year has 2 production/planting seasons (cycles). The assumption used in production, based on research results, is that survival reaches 38.98%, so that if 80,000 shrimp are stocked, the harvested number of live shrimp is of 30,400 ind. If 1 kg consists of 42 shrimps, then the total shrimp harvested is of 743.12 kg. If the selling price of shrimp is USD 4.919 kg^{-1}, then the total revenue for one season (6 months) is USD 3,655.544. The total expenditure is of USD 964.160, so the amount of profit in one season is USD 2,691.384. Since shrimp can be produced 2 times a year, the annual revenue is of USD 5,382.768. Based on the results of the economic valuation analysis, the R/C ratio value obtained was 2.11.

The production of *P.monodon* cultivation with a density of 11 ind m^{-2} in 1 ha of pond will be stocked with 110,000 ind ha^{-1} and every year has 2 production cycles. The assumption used in production, based on research results, is that survival reaches 37.59%, so that if 110,000 shrimp are stocked, the harvested number of live shrimps is of 41,349 tails. If the selling price of shrimp is USD 4.919 kg^{-1}, then the total revenue for one season (6 months) is USD 3,606.549. The total expenditure is of USD 1,357.695, so the amount of profit in one season is USD 2,248.854. Since shrimp can be produced 2 times a year, the annual revenue is of USD 4,497.709 $year^{-1}$. Based on the results of the economic valuation analysis, the R/C ratio value obtained was 1.83.

The production of *P. monodon* cultivation with a density of 13 ind m^{-2} in one hectare of pond will be stocked with 130,000 ind ha^{-1} and every year has 2 production cycles. The assumption used in production, based on research results, is that survival reaches 27.77%, so if 130,000 shrimp are stocked, then the harvested number of live shrimps is of 36,101 tails. If 1 kg consists of 42 shrimp, then the total shrimp harvested is of 773.16 kg. If the selling price of shrimp is USD 4.919 kg^{-1}, then the total revenue for one season (6 months) is USD 3,803.316. The total expenditure is of USD 1,312.016, so the amount of profit in one season is USD 2,491.300. Since shrimp can be produced 2 times a year, the annual revenue is of USD 4,982.600. Based on the results of the economic valuation analysis, the R/C ratio value obtained was 1.37.

Production of G. verrucosa cultivation business revenue in pond. The production results of seaweed cultivation in ponds are relatively constant every year. The assumption used in production is that the production obtained is 5 times the number of seeds planted. 12.5% of this production can be sold, after a number of treatments (drying). If 300 kg of seaweed seeds are stocked, the amount of seaweed harvested is 1,500 kg. Of this amount, only 187 kg are sold to collectors, at a price of USD 0.702 kg^{-1} of seaweed. In a year (for 5 harvests) farmers can receive USD 657.062.

Production revenue of the combination of P. monodon and G. verrucosa cultivation in ponds. Shrimp and seaweed farming (in ponds) per year will generate an additional profit of USD 328.531 $year^{-1}$. Thus, if the pond farmers apply shrimp and seaweed cultivation, the economic valuation analysis will show per year revenues at each density level of: USD 5,382.768 + USD 657.062 = USD 6,039.831 for 8 ind m^{-2}, USD 4,525.664 + USD 657.062 = USD 5,182.726 ind m^{-2} and USD 4,982.600 + USD 657.062 = USD 5,639.662 ind m^{-2}.

Conclusions. The study concluded that the activities of *P. monodon* cultivation on the quality of pond waters, total suspended solids (TSS) and COD have exceeded the threshold of quality standard requirements allowed for marine aquaculture and aquaculture. Based on the economic valuation of *P. monodon* cultivation in ponds, it can be applied and developed as a profitable business for pond farmers, this can be seen from the calculation of the R/C ratio of more than 1, namely each *P. monodon* cultivation business with a density of 8, 11 and 13 ind m^{-2} in seaweed cultivation area, respectively 2.11, 1.83, 1.37. The combination of shrimp farming with seaweed at each density level of 8, 11 and 13 ind m^{-2} gets a profit of USD 6,039.831 $year^{-1}$, USD 5,182.726 and USD 5,639.662 $year^{-1}$.

Conflict of interest. The authors declare no conflict of interest.

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