Ecofriendly land-based spiny lobster (*Panulirus* sp.) rearing with biofilter application in recirculating aquaculture system

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Abstract. The aim of the study was to create water treatment units for ecofriendly land-based spiny lobster rearing. Recirculating aquaculture system (RAS) is widely used because it is more environmentally friendly. Water quality requirement for spiny lobster cultivation are DO>4 mg/L and ammonia (NH\(_3\)) less than 0.1/mgL. Attachment growth biofilter with sponge media used for reducing ammonia. Hydraulic loading rate 200 m\(^3\) m\(^{-2}\) day\(^{-1}\) was used to evaluate biofilter TAN removal. Ammonia (NH\(_3\)) concentration during the study range between 0.006-0.02 mg/L, total ammonia nitrogen 0.0-0.26 mg/L and DO concentrations at 6.29-6.54 mg/L. Volumetric TAN removal average value during the 24-hour observation was 23.33 g TANm\(^3\)/day and lobster survival rate reach 91.89\%. This water treatment unit complied water quality requirements for lobster cultivation, and also can be used for other fishery commodities by adjusting their capacity to meet specific water quality standard.

Keywords: attachment growth biofilter, hydraulic loading rate, recirculating aquaculture

1. Introduction

Goals of sustainable aquaculture are establishing food production system while maintaining conservation of natural resources, both of these can be achieved if applied aquaculture system has a low ecological impact (Martins et al 2010). Recirculating aquaculture system offer opportunity to refine waste management by nutrient recycling and eliminate water usage, this system makes intensive fish farming become more environmentally friendly and budget effective (Martins et al 2010). The advantage of using recirculation systems is the ability to control water quality in the system controlled daily to alleviate loss by diseases outbreak, lessen animal stress, increase growth rate and can be applied for high density aquaculture (Kamermans et al 2016). RAS usually equipped with few water treatment unit to eliminate ammonia (biofilter), solid particle removal (drum filter or protein skimmer), aeration and carbon dioxide degassing in order to provide optimum water quality for fish growth (Diaz et al 2012).
Therefore to meet water quality standard for aquaculture, a RAS require water treatment units to eliminate water pollutants (mostly biota metabolites) to maintain water quality for optimum growth performance in the system. Metabolites which generated in RAS include ammonia, nitrite, nitrate and suspended solid accumulation was found to be directly related to feeding rates (Liao and Mayo 1974). Biofilter and protein skimmers were used in this research as water treatment units, biofilter eliminates ammonia level in water, while a protein skimmers is on duty for CO₂ degassing and solid removal. Sponges used for biofilter media because they have a large specific surface area than other materials, which suitable for nitrifying bacteria attachment. Zhang et al (2016) examined three biofilter materials (sponges, SSA 20,000 m²/m³; zeolite, SSA 300 m²/m³ and ceramsite, SSA 600 m²/m³) ability on ammonia conversion and the result showed that sponge media capable to reduce ammonia concentration higher than the other material.

The accumulation of particulate organic material on biofilms will increase BOD loading and it will reduce TAN removal rates (Anderson et al 1994). Build up of feed residue, feces and bacterial floc are an important issue in aquaculture using recirculation systems, because their presence will reduce water quality and increasing stress of the maintained biota (Cripps and Bergheim 2002). Although the recirculation system is environmentally friendly, this system requires large operational costs, so to make it more commercially viable this system only can be used for cultivation with a very high biota densities, high-value commodity or a large scale production (Anh Ngoc et al 2016).

Lobster price in world trade increase every year because of lobster supply scarcity, lobster global trade is decreasing, with quantity almost 2000-2500 metric tons per year (Drengstig and Bergheim 2013), mean while the demand is increasing (Jones 2015). Due to lobster expensive price and their susceptibility from environmental changes, lobster is suitable to be reared using RAS. This research was conducted to test hydraulic loading rate 200 m³/m².day⁻¹ on RAS biofilter to produce suitable water quality for lobster panulirus rearing.

2. Materials and methods

2.1. Designing a biofilter for a recirculating aquaculture system

Biofilter design for recirculating aquaculture mainly based on the highest waste yield during the culture system, the highest waste production which usually produced during harvest period was the basis for designing water treatment units (biofilter) in recirculation systems. This filter system is an improvement of the filter system for spiny lobster made previously by Supriyono et al (2017). The assumptions used to build biofilter for this research are: lobster harvest weight 40 kg, water temperature 28°C, organic loading (daily feed 10% from total lobster mass), lobster density 5.7 kg/m³, half complete water turnovers per hour, sponge filter media with void fraction 0.92 and specific surface area (SSA) 1600 m²/m³.

Eding et al (2006) showed that estimation of total ammonia nitrogen (TAN) generated each day in a common aquaculture system can be calculated based feeding rate, by using equation (1) and ammonia generated in seawater shrimp culture can be calculated with equation (2). Equation (3) until equation (9) used to calculate the biofilter dimensions, the equations adopted from Hochheimer and Wheaton (1998) research.

\[ P_{\text{TAN Load}} \left( \frac{\text{kg}}{\text{day}} \right) = F \text{Feeding rate} \left( \frac{\text{kg}}{\text{day}} \right) \times \text{PC Feed's protein concentration} \times 0.092 \]  \hspace{1cm} (1)

\[ P_{\text{TAN Load}} \left( \frac{\text{kg}}{\text{day}} \right) = F \text{Feeding rate} \left( \frac{\text{kg}}{\text{day}} \right) \times \text{PC Feed's protein concentration} \times 0.144 \]  \hspace{1cm} (2)
W_{\text{feed weight}} (kg) = \text{total harvest weight (kg)} \times \text{Feeding rate (\%)} \quad (3)

\text{Oxygen demand (kg)} = 0.25 \times W_{\text{feed weight}} \quad (4)

V_{\text{total water volume}} (m^3) = \frac{\text{total harvest weight (kg)}}{\text{lobster density (kg/m}^3)} \quad (5)

A_{\text{biofilter}} (m^2) = \frac{P_{\text{TAN load}} \times \frac{f}{\text{day}}}{r_{\text{TAN}} \times \frac{m^2}{\text{day}}} \quad (6)

V_{\text{biofilter}} (m^3) = \frac{A_{\text{biofilter}} \times (m^2)}{a \times \text{biofilter media}} \quad (7)

S_{\text{cross sectional area}} (m^2) = \frac{Q_{\text{biofilter}} \times \frac{m^3}{\text{day}}}{HLR_{\text{Hydraulic loading rate}} \times \frac{m^2}{\text{day}}} \quad (8)

H_{\text{biofilter height}} (m) = \frac{V_{\text{biofilter}} (m^3)}{S_{\text{Cross sectional area}} (m^2)} \quad (9)

2.2. Experimental set up
The research was conducted in an 8 m$^3$ recirculated system, according results of calculations with equations (5). The system has 8 rearing tanks (each 1 m$^3$ in volume), a set of biofilters, a waste water holding tank and a clean water holding tank. Two submerged water pumps (PG-12000, Resun, China) use for water cycle and an aerator (LP-100, Resun, China) for aeration. Following the method of Supriyono et al (2016) the aeration system used rubber micro porous line as an aeration agitator. Rearing tanks were stocked with 148 lobster juvenile with total weight 20 kg. Lobster were fed once a day at 17:00 with fish trash, feeding rate was 3% of total weight and lobster reared for 70 days.

2.3. Sampling procedures.
Temperature, DO, Salinity, pH were recorded everyday in each tank for 70 days with multi parameter tester (YSI 556, Ohio, USA). TAN, ammonia, alkalinity and biometry sampling in each tank was carried out every 10 days. Water sampling to analyze biofilter volumetric TAN removal, used grab sampling method on biofilter inlet and outlet over 24 hours period (table 1).

Volumetric TAN removal rate calculated with equation (10) or (11) according Eding et al (2006)

\[ VTR = \frac{[\text{TAN}]_{\text{input}} - [\text{TAN}]_{\text{output}} \times Q_{\text{filter flow rate}} (m^3/\text{d})}{V_{\text{media}} (m^3)} \] \quad (10)

biofilter used in this study was plug-flow model which developed by Nijhof (1995), equation (11) can be applied to calculate TAN removal rate.

\[ r_{\text{TAN}} = a \times [\text{TAN}]^{n} + b \] \quad (11)

[TAN] is TAN concentration in influent solution, $r_{\text{TAN}}$ is a VTR value (TAN removal rate), $a$ is the coefficient rate of TAN removal reaction, $b$ is an intercept and $n$ is order of TAN removal rate reaction. According Eding et al (2006), $a$ and $b$ values are influenced by internal factors as biofilm
thickness, abundance of nitrifying bacteria and external factor are temperature, salinity, pH, oxygen concentration.

| Parameter                        | Instruments                        |
|----------------------------------|------------------------------------|
| Temperature                      | YSI 556, Ohio, USA                 |
| Dissolved Oxygen (DO)            | YSI 556, Ohio, USA                 |
| Salinity                         | YSI 556, Ohio, USA                 |
| Total Ammonia Nitrogen (TAN)     | HACH DR1900-01H, Loveland, USA     |
| Ammonia (NH₃-N)                  | HACH DR1900-01H, Loveland, USA     |
| Alkalinity                       | HACH DR1900-01H, Loveland, USA     |
| pH                               | YSI 556, Ohio, USA                 |

3. Results and discussion

3.1. Recirculating aquaculture system design

The result from calculating the assumptions using equation (1) until (9) we build biofilter with this specification showed in table 2. Recirculated aquaculture design can be seen in figure 1.

![Recirculated aquaculture design](image)

**Table 1.** Water quality analysis measuring instrument used in the study.

| Parameter                        | Instruments                        |
|----------------------------------|------------------------------------|
| Temperature                      | YSI 556, Ohio, USA                 |
| Dissolved Oxygen (DO)            | YSI 556, Ohio, USA                 |
| Salinity                         | YSI 556, Ohio, USA                 |
| Total Ammonia Nitrogen (TAN)     | HACH DR1900-01H, Loveland, USA     |
| Ammonia (NH₃-N)                  | HACH DR1900-01H, Loveland, USA     |
| Alkalinity                       | HACH DR1900-01H, Loveland, USA     |
| pH                               | YSI 556, Ohio, USA                 |

**Table 2.** Biofilter Specification.

| Specification                | Value   |
|-----------------------------|---------|
| Sponge SSA (m² m⁻³)         | 1600    |
| Water Turn Over (day⁻¹)     | 0.5     |
| Hydraulic Loading Rate/HLR (200 m³ m⁻² day⁻¹) | 200  |
| P TAN Load (kg day⁻¹)       | 4       |
| Oxygen Demand (kg)          | 1       |
| V total water volume (m³)   | 7       |
| V biofilter volume (m³)     | 0.1     |
| S cross sectional area (m²) | 0.2     |
| H biofilter height (m)      | 0.24    |
| Biofilter (units)           | 2       |
3.2. Water quality
Average value of water parameter during the study can be seen in table 3 and the result of VTR test during 24 hours observation showed in table 4.

**Table 3. Water quality in recirculation system during the study.**

| Parameter                  | Value     | Standard   | References                    |
|----------------------------|-----------|------------|-------------------------------|
| Temperature (°C)           | 27.6-27.9 | 25-30      | Phillips dan Kittaka 2000     |
| Salinity (ppt)             | 34.6-35.6 | 32-36      | Wickins dan Lee 2002          |
| pH                         | 7.91-7.95 | 7.8-8.5    | Wickins dan Lee, 2002         |
| Alkalinity (mg/L)          | 94.0-101.9| 40-200     | Chen et al 2006, Biesterfeldet et al 2003 |
| Dissolved Oxygen (mg/L)    | 6.2-6.5   | 2.7-5.4    | Phillips dan Kittaka 2000     |
| Ammonia (mg/L)             | 0.001-0.016| <1         | Wickins dan Lee 2002          |
| Nitrite (mg/L)             | 0.02-0.49 | <5         | Drenstig dan Bergheim 2013    |
| Nitrate (mg/L)             | 0.019-6.82| <100       | Wickins dan Lee 2002          |
| Organic loading (gr)       | 579.9-799.0|           |                               |

**Table 4. Volumetric TAN removal (VTR) values with HLR 200 m³/m²/day during 24 hours period observation.**

| Hours | 0  | 2  | 4  | 6  | 8  | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|
| VTR  (gTAN m⁻³ day⁻¹) | 23.52 | 26.8 | 26.8 | 26.04 | 25.2 | 24.36 | 24.36 | 23.52 | 22.68 | 21.84 | 21.84 | 20.16 | 15.96 |
| Average | 23.33 gTAN m⁻³ day⁻¹ |     |    |    |    |    |    |    |    |    |    |    |    |

**Table 5. Dissolved Oxygen (mg/L) on biofilter inlet and outlet for 70 days.**

| Sampling Location | Days | 0   | 10  | 20  | 30  | 40  | 50  | 60  | 70  |
|-------------------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| Inlet (mg/L)      |      | 7.7 | 7.0 | 7.0 | 7.3 | 6.9 | 7.0 | 7.1 | 7.0 |
| Outlet (mg/L)     |      | 7.7 | 6.5 | 6.4 | 6.6 | 6.6 | 6.4 | 6.5 | 6.5 |

Table 3 showed that all water quality parameter in recirculating system during the study compatible with water quality standard for spiny lobster rearing. Biofilter application in recirculating system has proven to be able to control water quality during lobster rearing in optimum condition. Average value of volumetric TAN removal rate during 24 hour observation on HLR 200 m³/m²/day⁻¹ can reach 23.33 gTAN m⁻³ day⁻¹. According Zhang et al (2016) application of sponges filter media on natural ventilation trickling filter reach volumetric TAN removal as 22.50 gTAN m⁻³ day⁻¹. Based on these data, biofilter performance in this study is better, when compared with previous studies.

Percentage of ammonia removal rates influenced by performance of ammonia and nitrite oxidation bacteria in seawater, seawater nitrification bacteria such as nitrosococcus, nitrospira and nitrosolobus, they can live optimally at temperature 25°C-35°C and nitrification process will stop at 50°C (Ebeling et al 2006). The average growth of nitrifying microorganisms will increase every additional temperature of 10°C, and will continue to reach its optimal growth temperature (Metcalf and Eddy 2003).
The nitrification in biofilter was aerobic process resulting low oxygen level in the filtrate which shown in table 5. According Ebeling et al (2006) nitrification was second stage ammonia conversion to nitrate by autotrophic bacteria in aerobic condition. DO greater than 2.3 mg/L will be very useful in preventing the dominance of nitrite formation, since nitrite has harmful affects for biota growth (Chen et al 2006). DO level during the study range between 6.4-7.7 mg/L hence sufficient to complete ammonia conversion, this lead to keep nitrite concentration in water quite low at 0.02-0.49 mg/L.

3.3. Lobster survival rate

Lobster survival rate during study can be seen in figure 2. Based on figure 2, average of lobster survival rate can reach 97.8 % and lobster daily growth rate 0.37%. Survival is an indicator of the success of the aquaculture production process. In this system the survival of lobsters that is reared is higher than that which was done by Pratiwi et al (2016), Supriyono et al (2017) and Djai et al (2017) who use trickling filters as the main component of filtration systems.

![Figure 2. Percentage of spiny lobster survival rate during the study (■ = survival rate%).](image)

4. Conclusion

Biofilter design criteria with hydraulic loading rate 200 m$^3$m$^{-2}$day$^{-1}$ in recirculating system can maintain optimal water quality for spiny lobster rearing. Biofilter ammonia removal rate reach 23.33 gTAN m$^3$day$^{-1}$, average of lobster survival rate can reach 97.8% and lobster daily growth rate 0.37%.

Acknowledgements

This work was funded by Ministry of Fisheries and Marine Affairs Republic of Indonesia.

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