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Carrying Capacity for *Pinctada maxima* (Jameson 1901) Farming in Sathean Bay, Southeast Maluku Based on Nitrogen and Phosphate Balance

Usman Madubun, Ario Damar, Kadarwan Soewardi, Niken Tunjung Murti Pratiwi

Abstract— *Sathean Bay is a small, semi-enclosed waters which have been utilized as an area for pearl oyster farming using floating long line method. The growth of pearl oysters are affected by the availability of food (phytoplankton) in the waters. The phytoplankton own self is highly affected by N and P in the waters. This study aims to assess the carrying capacity of the Sathean Bay for pearl oysters farming for three different size group pearl oyster based on the nutrient balance which was the ratio between N and P are available in the waters and in the pearl oyster tissue. The study was conducted from April to September 2016 in nine sampling sites of Sathean Bay, Southeast Maluku. The result showed the smallest group size of pearl oyster(5 ± 2 cm) had the highest carrying capacity among the other two size group (13 ± 2 cm, 18 ± 2 cm). The carrying capacity of pearl oyster based nitrogen level(DIN) in the waters was always greater than the carrying capacity based on DIP level for all size groups of pearl oyster.*

Keywords— Pinctada maxima, Sathean Bay, Nitrogen, Phosphate.

I. INTRODUCTION

Sathean bay is a small, semi-enclosed waters with an average depth of 22 m and an average area of 382 ha. The bay have been utilized as an area of fisheries, pearl oyster culture, and seaweeds culture (Tomatala 2011; Erbabley & Kelabora 2014; Ngamel 2012; Renjaan 2011). Pearl oyster culture activities in the bay was carried out using single rope floating (floating long line). Types of cultivated pearl oyster is *Pinctada maxima* (Jameson 1901) or commercially known as white south sea pearls (Southgate 2007). Oyster culture using floating long line method is usually built in waters with a depth of 10-30 m (Sutaman 1993; Kangkan 2006). Based on observations, the current long line number are 36 pieces, but can vary according to the needs and availability of seed pearl oysters.

Pearl oyster cultured using a single rope system floating (floating long line) have an impact on the dynamics and processes of aquatic ecosystems. Some of them are, controlling the dynamics of suspended particles, including phytoplankton (Zhou et al., 2006; Tweddle et al., 2005), to divert material suspended from the water column to the food webs benthic through biodeposit feces and pseudofeces (Newell et al., 2005; Newell 2004; Chapelle et al. 2000), and change the dynamics of nutrient waters (Cranford et al. 2003; Newell, 2004; Newell et al. 2005; Nizzoli et al., 2005; Metzger et al. 2007).

A low concentration of nutrients in the water column has negative effect on the growth and development of phytoplankton (Damar 2003). On the other hand, the growth of oyster including pearl oysters are affected by the availability of food in the waters, i.e phytoplankton (Anwar et al., 2005; Pouvreau et al. 2000; Yukihira et al. 1999; Rice, 2008; Newell et al. 2005; Loret et al., 2000; Winanto 2009; Syda Rao et al., 2009; Hashimoto et al. 2007). Thus, the loss of N and P from the water column have a negative impact on the growth of the pearl oysters, as well as excessive amounts of pearl oysters cause a reduction of N and P of waters through phytoplankton.

The negative impact of the decline of N and P through phytoplankton can be prevented by limiting the loss of N and P of waters by limiting and controlling the number of long line oyster pearls used. Restriction and control is conducted by determining the carrying capacity of the waters. Kaiser & Beadman (2002) defined carrying capacity as the maximum production potential of a species or population that can be supported by related resource availability. Estimation of the carrying capacity of oyster based on resource availability is generally approximated using the availability of phytoplankton or particulate organic matter (POM) in the waters which then compared with the needs of oysters (Carver & Mallet 1990; Karayùcel & Karayùcel 1998; Penney et al. 2001).

This study aims to assess the carrying capacity of the Sathean Bay on determining the number of long line and pearl oysters that can be accommodated in a sustainable manner. Carrying capacity was estimated based on the nutrient balance which is the ratio between N and P are available in the waters and in the pearl oyster tissue.

II. METHODS

Study site

The study took place in the Sathean Bay, Southeast Maluku, and the study was conducted from April to September 2016 (**Figure 1**). Water quality parameters measurement and water sampling for nutrient analysis was performed on nine stations. Stations were selected by considering the depth, broad of the bay, and the pearl oysters farming locations. Water quality parameters measured include temperature, salinity, current velocity, pH, and dissolved oxygen. Data obtained by measuring the depth of the bay using a fish finder, while the extents area of the bay was obtained through GIS analysis using Arc GIS software version 10.1. Data of the waters depth and extents of the bay were intended to obtain the waters volume of the bay. Dissolved inorganic nutrients analyzed including nitrate-nitrogen (NO3-N, □□gL^{-1}), nitrite-nitrogen (NO2-N, □gL^{-1}), ammonium-nitrogen (NH4-N, □gL^{-1}), and orthophosphate (PO4-P, □gL^{-1}). Water sampling, preservation, transportation, and sample analysis were performed by standard methods from Standard Methods for the Examination of Water and Wastewater (APHA 2005).

Pearl oyster used in the study were grouped into three size classes of shell length (Dorso Ventral, DV), i. e 5 ± 2 cm, 13 ± 2 cm, and 18 ± 2 cm. The oysters were obtained from Sathean Bay. All of the pearl oyster shell used were cleaned from the tacks organisms, the pearl oyster weight (BW, g) was measured using digital scaleto the nearest 0.1 g, then the total shell length (mm), total shell width (mm), and the shell thickness (mm) was measured using caliper and ruler. Thirteen pearl oysters with size range 3 cm to 18 cm of a shell height were collected for the meat (BKD, g)and shell (BKC, g)dry weight analysis which was dried at 105° C for 24 hours. In addition, others supporting data were also collected such as the total number of pearl oyster and number of pearl oyster per basket in the current culture, the number of baskets per longlne, long line length, the distance between long line, and the growth of pearl oysters.

Data Analysis

Estimation of the DIN and DIP needs of pearl oyster

Prediction of TN and TP levels in pearl oysters using a value which was defined by Gifford et al. (2005), namely, the nitrogen content in meat and shells of pearl oyster were g^{-1}BK 9.82% and 0.39% g^{-1}BK. Phosphorus levels in meat and shells of pearl oyster are g^{-1}BK 0.74% and 0.03% g^{-1}BK, respectively. Referring to these values, the levels of N and P per individual of each group size of pearl oyster is calculated as follows:

$TN_{tm} = (A \bullet 9{,}82\%) + (B \bullet 0{,}39\%)$ ..... (1)

$TP_{tm} = (A \bullet 0{,}74\%) + (B \bullet 0{,}03\%)$ .... (2)

Where:

TN_{tm}&TP_{tm}	=	N and P needs of pearl oyster according to group sizes (g)
A& B	=	dry weight of the meat and shell pearl oyster of one individual of each class sizes (g)
9,82%& 0,74%	=	fraction of N and P content per GBK pearl oyster meat
0,39%& 0,03%	=	fraction of N and P content per GBK pearl oyster shell

Forms of nutrients that were used in this analysis were DIN and DIP. Pearl oyster nutrient levels in the form of TN and TP (gg-1BK) need to be converted to the form of DIN and DIP. To convert TN and TP to DIN and DIP we used Diego-McGlone et al. (2000) approach, where DIN = 0.38 x TN and DIP = 0.5 x TP. DIN is the summation of nitrogen form NH4, NO_2 and NO_3. Whereas DIP consisting only of PO_4. DIP_{tm} and DIN_{tm} value were pearl oyster parameter nutrient needs which was used in assessing the carrying capacity of the waters for the development of pearl oyster culture in this approach.

Estimation of availability of DIN and DIP in Waters

To determine the availability of dissolved inorganic N and P in the waters of the bay, we need the data of the concentration of N (NH_4-N, NO_3-N, NO_2-N) and P (PO_4-P) in water (N-water and P-water) and the volume of waters bay (Vo). N-water and P-water value were obtained from the analysis of water samples in the laboratory, which produce unit mgl^{-1}. This unit needs to be converted to gL^{-1} to facilitate further calculations. By applying the precautionary principle in order to avoid over-estimation, the value N-water and P-water used in the calculation were the lowest one that measured during the study. Then N-water and P-water value were then converted to DIN-water and DIP-water (Diego-McGlone et al. 2000). Value of DIN-water and DIP-water in total over the whole bay waters were calculated by the equation:

$DIN_{water\text{-}tot}$ (g) $= N_{air} \bullet Vo$ .... (3)

$DIP_{water\text{-}tot}$ (g) $= P_{air} \bullet Vo$ .... (4)

Where:

$DIN_{water\text{-}tot}$ dan $DIP_{water\text{-}tot}$ = the total amount of N and P in the waters of the bay (g)

DIN_{water}dan DIP_{water}= N and P concentrations in water samples (gL^{-1})

Vo = total volume waters of the bay (L)

The volume of water in the bay (Vo, m^3) was calculated according to the formula Beveridge (2004):

$$Vo = A \cdot D \quad \ldots\ldots\ldots\ldots \quad (5)$$

Where:

Vo = waters volume of the bay (m^3)
A = the surface area of the bay (m^2)
D = The average depth of the bay (m)

Vo unit converted to liters by multiplying 10^{-3}. The surface area of the bay was calculated using GIS. The average depth of the bay waters known through bathymetric measurements.

However, not all $DIN_{water\text{-}tot}$ and $DIP_{water\text{-}tot}$ taken by pearl oysters. Based on research Gifford et al. (2005), the amount of nutrients flowing into the body of the pearl oyster is only approximately 2.0% N and 0.2% P of N and P in the waters. This figures were used as a correction factor retrieval capability of N and P by pearl oyster of N and P which are available in the waters. Thus, DIN and DIP which are available in total over the bay waters that can be used by the oyster was:

$$DIN_{available}\ (g) = DIN_{water\text{-}tot} \cdot 2{,}0\% \quad \ldots\ldots\ldots \quad (6)$$

$$DIP_{available}(g) = DIP_{water\text{-}tot} \cdot 0{,}2\% \quad \ldots\ldots\ldots \quad (7)$$

Where:

$DIN_{available}$ and $DIP_{available}$ = DIN and DIP which available for oysters (g)
$DIN_{water\text{-}tot}$ and $DIP_{water\text{-}tot}$ = total availability of DIN and DIP in the waters of the bay (g)
2,0% & 0,2% = retrieval capability of N and P by pearl oyster from the waters.

$DIN_{available}$ and $DIP_{available}$ are the value of nutrient availability parameter that will be used in the estimation of the carrying capacity of the nutrient balance approach developed in this study.

Analysis of Carrying Capacity for pearl oysters culture

Estimation of the carrying capacity of sustainable oyster pearl culture based on nutrient (N and P) balance was performed separately for each group size as follows:

$$DD_{L\text{-}tm}DIN = DIN_{available} / DIN_{tm} \quad \ldots\ldots\ldots \quad (8)$$

$$DD_{L\text{-}tm}DIP = DIP_{available} / DIP_{tm} \quad \ldots\ldots\ldots \quad (9)$$

Where:

$DD_{L\text{-}tm}DIN$ & $DD_{L\text{-}tm}DIP$ =sustainable carrying capacity of pearl oysters based on DIN and DIP according to the size (number of individual)
$DIN_{available}$&$DIP_{available}$ =DIN and DIP which are available for oysters (g)
DIN_{tm}&DIP_{tm} = DIN and DIP oysters needs according to the size (g)

Then, if each one long line consisting of E (individual) pearl oyster according group sizes, the numbers of long line possible are:

$$nL = DD_{L\text{-}tm} / E \quad \ldots\ldots\ldots \quad (10)$$

and the effective broad water area (ha) that can be used as a pearl oyster farming using long line method is:

$$\text{waters area (ha)} = nL \cdot 1 \text{ unit size} / 10.000 \quad \ldots\ldots\ldots \quad (11)$$

by nL is the number of long line permitted, and 10,000 are convertion value into hectares (ha).

III. RESULT

Waters volume of Sathean Bay

Tides Type in the Sathean Bay was semi diurnal with the maximum daily tidal differences was 2.6 m (**Figure 2**). The surface area and volume of the bay waters at various water level was shown in **Table 1**.

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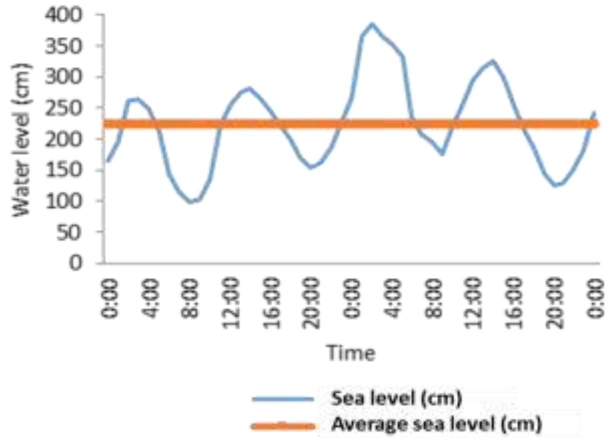

Fig.2: Type and duration of the tides in the Sathean bay measured at spring tide

Table.1: Volume of Sathean Bay waters at different water level

Tides	Tidal range (m)	MSL water level (m)	Surface area of the bay (m^3)	Waters volume of the bay (L)
MHWS	2.6	1.3	3,758,132	84.951.099,41
MLWS		-1.3	3,470,249	75,179,956.21
Volume mean			80.051.165	80.051.164.940

MHWS: Mean High Water Spring
MLWS: Mean Low Water Spring

N and P Needs of pearl oyster

Dry weight of the meat and shell of pearl oyster from the three size groups were listed in **Table 2**, while the levels of DIN and DIP were shown in **Table 3**.

Table.2: The mean and percentage of dry weight of the pearl oyster according to group sizes

No	Size groups	height	wide	Total wet weight	Meat wet weight		Meat dry weight		Shell wet weight		Shell dry weight	
	cm	cm	cm	g	g	%	g	%	g	%	g	%
1	5±2	4,3	4,5	9,1	1,6	18,0	0,3	19,1	7,5	82,0	8,0	92,9
2	13±2	13,8	13,0	253,5	46,0	18,1	10,7	23,2	207,5	81,9	192,4	92,7
3	18±2	17,4	15,4	657,0	86,0	13,1	19,9	23,1	571,0	86,9	560,9	98,2

Table.3: The mean levels of DIN and DIP (gg^{-1}BK) of meat and shell of pearl oysters in the Sathean Bay in various group sizes

No	Size groups (cm)	Meat (g)		Shell (g)		Total	
		DIN	DIP	DIN	DIP	DIN	DIP
1	5±2	0,013	0,001	0,011	0,001	0,023	0,002
2	13±2	0,400	0,040	0,263	0,029	0,663	0,069
3	18±2	0,743	0,074	0,766	0,084	1,509	0,158

Availability of DIN and DIP in Water

Minimal concentration of DIN and DIP in the waters was presented in**Table 4**, while **Table 5** contained the maximum number of DIN and DIP which were available for pearl oysters.

Table.4: Minimal concentration of DIN and DIP in the Sathean Bay

No	Parameter	Unit	Value
1	NH_4	mgL^{-1}	0,048
2	NO_2	mgL^{-1}	0,003
3	NO_3	mgL^{-1}	0,023
4	PO_4	mgL^{-1}	0,003
5	DIN	mgL^{-1}	0,074
6	DIP	mgL^{-1}	0,003

Table.5: The concentration of DIN and DIP available in the waters which can be utilized by oysters in the Sathean Bay

No	Nutrient type	Minimal concentration (mg/L)	Waters volume (L)	Total nutrient in water (g)	Available nutrient(g)
1	DIN	0,074	80.128.050.840	5.934.216	118.684
2	DIP	0,003	80.128.050.840	240.384	481

Carrying capacity of pearl oysters farming

Number of pearl oysters that can be accommodated in Sathean Bay waters according to group sizes and types of nutrients was shown in **Table 6**. Number of long line of pearl oyster and effective waters area for pearl oysters farming were presented in **Table 7** and **Table 8**.

Table.6: Carrying capacity of the Sathean Bay waters for pearl oyster farming based on nutrient availability approach

No	Size group (cm)	Available nutrient (g)		Nutrient needs of oyster(g)		DDL_TM	
		DIN	DIP	DIN	DIP	DIN	DIP
1	5±2	118.684,3	6.410,2	0,023	0,002	5.060.838	2.624.541
2	13±2	118.684,3	6.410,2	0,663	0,069	179.127	7.017
3	18±2	118.684,3	6.410,2	1,509	0,158	78.651	3.046

DDL_TM = Carrying capacity for pearl oyster

Table.7: Number of long line for pearl oyster farming according to group sizes

No	Size group	DDL_TM		Number of oyster/long line	Number of long line	
		DIN	DIP		DIN	DIP
1	5±2	5.060.838	2.624.541	4.800	1.054	41
2	13±2	179.127	93.558	2.000	90	4
3	18±2	78.651	40.612	1.600	49	2

Table.8: Water area effective for pearl oysters in the bay Sathean

No	Size group	Number of long line		Broad of 1 unit BDT	Total area (ha)	
		DIN	DIP		DIN	DIP
1	5±2	1.014	547	0,5	507	21
2	13±2	87	47		43	2
3	18±2	47	25		24	1

IV. DISCUSSION

Hidromorphology bay and Water Quality Parameters

Sathean bay is a small bay, semi-enclosed, yet deep enough. Waters inside the bay is connected with the waters outside the bay through two doors, the first located in the northern part of the bay, and on the eastern side another. At low tide, the second door is completely dry. Thus the exchange of water is much more smoothly on the first door. Type ebb tide mix is similar to double daily, occurs twice ups and downs in 24 hours a day. Stables water or the difference between the highest highs and the lows is 2.60. Average depth of the bay is 21.66 m, the surface area of 347.02 ha bay at low tide, while when the tide is 375.81 ha. At high tide the water volume amounted to 84,936,736,540 L and the bay at low tide approximately 75,165,593,340 L (Table 1).

Water quality parameter is not fluctuate between stations and moon observation (Table 2). This happens allegedly caused by the time to observed were only conducted in the transition of the East and only that of seasonal changes in these parameters are not detected, despite extensive bay waters are relatively small, and the absence of input of fresh water mainly through the river that may cause significant changes in the parameters of the water environment. This condition causes relatively homogeneous of Sathean Gulf. All the parameters of the water quality does not vary much with the results of research from elsewhere (Hamzah & Nababan 2011; Gervis and Sims 1992; Anwar 2005; Winanto et al. 2009). Overall the quality parameter Sathean Gulf are still suitable for the life and growth of pearl oysters (Winanto 2009).

Levels of N and P in pearl oysters and Bodies

The percentage of wet and dry weight of meat and pearl oyster shell from third group size does not vary much (Table 4). Wet weight percentage of meat from total weight body group size of 18 ± 2 cm smaller (13.1%) compared two groups of other sizes (18.0 and 18.1%). Percentage of dry weight of the meat on a group size of 5 ± 2 cm relatively smaller of the two sizes larger. The percentage weight of the wet shell was greater in group size of 18 ± 2 cm from the two groups of other sizes. Percentage of dry weight of the shell are relatively similar between the two smaller groups and smaller of the group size of 18 ± 2 cm.

Both levels of DIN and DIP higher in meat than a shell. In the pearl oyster meat, DIN and DIP highest levels found in oysters (size of 18 ± 2 cm) and the smallest class size of 5 ± 2 cm (Table 5). The same pattern also applies to DIN and DIP in pearl oyster shells. This is reasonable considering the percentage of N and P per gram dry weight relatively constant, but the weight of individuals increases with increasing height dimension. Thus the real value will depend on the dry weight of the pearl oyster.

Minimal concentration of NH_4, NO_3, NO_2 and PO_4 respectively measured at the station and at different times (Table 6). Minimal concentration of NH_4 (0,048 mgl^{-1}) measured at 4 station in September. The concentration of NO_3 minimal (0,023 mgl^{-1}) detected at station 7 September, NO_2 minimal (0,003 mgl^{-1}) measured at station 3 in April, and PO_4 minimal (0,040 mgl^{-1}) at almost all stations in May and June, Based on the sum of all forms of nitrogen, obtained DIN amounted to 0,074 mgl^{-1}, whereas DIP is only represented by PO_4 0.04 mgl^{-1}. The ratio DIN / DIP is 2.

The surface area of the bay to decrease and increase in water level are varied, it causes to use the average of the volume to countthe total number of DIN and DIP in the waters of the bay. DIN number in the overall volume of the bay's waters and provided utilized by pearl oyster is almost 2 times more than DIP. DIN number on the overall volume of the bay water is 5,928,522 g, while DIP 3202 only 047 g (Table 7). Of these maximum capacity by taking each oyster is DIN amounted to 118 570 g and 6404 g of DIP.

Carrying Capacity of Pearl Oysters

The amount of pearl oyster in Sathean Gulf based on the type of nutrients (DIN and DIP) and among groups of different sizes (Table 8). Based on the types of nutrients, the amount of DIN (5,055,982 people) is almost twice more than that based DIP (2,622,023 people). Based on the size, the larger group in succession around 4% and 2% of the number of individual groups of the smallest size.

In general, the number of long line based on DIN level that can be accommodated by Sathean Bay was almost twice higher than DIP-based long line for all group sizes of pearl oysters (Table 9). The number of long line of the smallest group size oysters based on DIN level was 1053 units, both the size of a maximum of 89 longline, and the largest size group up to 49 longline. The total area (ha) needed to accommodate the maximum number of long line was different nearly quadrupled between the calculation based on DIN and DIP (Table 10). Based on DIN level, total area to maintain pearl oyster farming were 507, 43, and 24 ha respectively for the smallest group size oysters to the largest. While based on DIP, total area required for smallest to the largest class sizes of pearl oyster were 273, 23, and 13 ha., respectively.

Compared with the existing condition (Table 3), the size of the oysters are reared currently only measuring 11-15 cm with a total of about 72 000 individuals (77.4% carrying size 13 ± 2 cm), 36 longline (77.0% carrying capacity) and

18 ha (78.3%) of land maintenance. Thus, both the number of individuals oysters, the number of longline units, and land that used not exceed the carrying capacity although it has been approached by the calculation of the balance of N and P.

Carrying Capacity of Maintenance Unit Accordance Carrying Capacity of Sathean Bay

There are differences calculated between the carrying capacity based on DIN and DIP almost twice. To avoid over-estimation, it used the results that gives the smallest value. Thus as the basis for determining the carrying capacity in the Sathean bay for maintenance pearl oyster is calculated based on the results-based DIP.

Results of counting the carrying capacity (Table 8, 9, 10) may be conducted on a group size of oysters separately, in other words, not a group the size of which is maintained continuously. This carrying capacity is a reference that should not be skipped number. For maintenance continuously until it reaches the desired size with the greatest number of oyster appropriate carrying capacity, the number of initial stocking needs to be calculated by taking into account mortality rates.

V. CONCLUSION

Sustainable carrying capacity for pearl oyster farming in the Sathean Bay waters based on DIN and DIP nutrient concentration was different for each size group of pearl oyster. The smallest group size of pearl oyster(5 ± 2 cm) had the highest carrying capacity among the other two size group. Carrying capacity based on level of Nitrogen (DIN) was always greater than the carrying capacity based on DIP level for all size classes of pearl oyster.

Maintenance pearl oyster in Sathean Bay until now

Pemeliharaan tiram mutiara di Teluk Sathean saat ini belum melampaui daya dukung perairan berdasarkan perhitungan daya dukung berbasis pendekatan keseimbangan nutrien N dan P. Namun demikian, memperhatikan persen kondisi eksisting baik jumlah tiram, longline, maupun lahan yang rata-rata sudah di atas 77%, ekstensifikasi pemeliharaan harus diperhitungkan secara hati-hati dan cermat.

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