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Population Structure, Growth and Production of *Corbicula moltkiana* and Their Relation to Cage Aquaculture Activity in Lake Maninjau, West Sumatra Indonesia.

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Abstract. Cage aquaculture that has been growing enormously in Lake Maninjau, West Sumatera, Indonesia, is supposed to have an impact on benthic fauna including *Corbicula moltkiana*, the species of bivalves. The objective of this study addresses the population structure, growth and production of *C. moltkiana* that describing the impact potential of cage aquaculture activity. The result show that annual 2013-2014 production [P] of *C. moltkiana* were 465-1559 g AFDM m⁻² y⁻¹ and the annual biomass [B] was 183-453 g AFDM m⁻², resulting in P/B ratio of 2.54-3.44 y⁻¹. Even though the P/B ratio was not consistent with the cage density level, as consequently of different L_∞ in determined zones. The increased cage aquaculture activity that marked by adding number of cage from <225 cages km⁻¹ to > 675 cages km⁻¹ impact to decrease of biomass [B] and production [P] of *C. moltkiana*..

1. Introduction

Over recent decade cage aquaculture has developed in several lakes in Indonesia and has given problems to environmental condition. In Lake Maninjau, West Sumatera, Indonesia, cage aquaculture activity has begun since 1997, and in 2013 the number of cage aquaculture reached 18,600 units [1]. Activity of cage aquaculture has impact to deterioration of aquatic environment was especially due to large amount of organic materials wasted and nutrients. Irisarri [2] that rearing of salmon on cages system has discharges large amounts of solid effluents that include fish feed waste (i.e. small feed 'fines' and larger uneaten feed particles) and feces, as well as dissolved nutrients like excretory products. Stocking density of fish and feed type on cage culture influence to degree of organic enrichment and its influence to the structure of benthic fauna [3]. Huang et al. [4] that cage culture in marine area could have negative impact to surrounding benthic environment, although the hydrographic regimes play roles to determining extent and distribution of the impact.

The change of water environment occurred on Lake Rupanco in Chile, since the salmon (*Oncorhynchus mykiss*; *O. salar*) farming activities increased continually in the last two decades. The level of salmon production between August 2008 and July 2009 has reached to 1626 tons, it was estimated that cage aquaculture (unconsumed feed, feces, and urine) contributed annually to the loss of 76.4 tons of TN and 12.1 tons of TP. Total nitrogen concentrations in the sediments varied from 37-18 mg kg⁻¹ in near-pristine sub-watersheds without salmon farming to 6400 - 698 mg kg⁻¹ where the sub-watershed was dominated by crop and pasture lands combined with the presence of salmon farming [5].



Several studies have been done on cage aquaculture effects on the water quality in Lake Maninjau[6-8]. The lake is indeed in the condition of eutrophication. However, the impact of cage aquaculture on benthic ecosystem seems to be a forgotten area and only a little attention has been paid, although most impact is done through the bottom area. Water quality deterioration greatly influenced the abundance and composition of molluscs [9].

Corbicula moltkiana (Prime 1878), is inland water species of molluscs (bivalves) and indigenous inhabitant of Lake Maninjau. The local community commonly exploits *C. moltkiana*, although their fishing activities are relatively small compared to the finfish fishing and cage aquaculture (Fisheries Board of Agam District, West Sumatera, 2009; not published).

Somatic production of macro zoobenthic populations can be an important component for evaluating ecosystem dynamics. As a quantitative measure of population function, somatic production often used to assess environmental stress, rational management of biological resources as economic commodity, energy flow, organic matter cycling and food web interactions[10].

For the interest of *C. moltkiana*, either as benthic fauna or its role for the people, it is important to understand the impact of the cage aquaculture on *C. moltkiana* population. Therefore, this study addresses the population structure, growth and production of *C. moltkiana* that describing the impact potential of cage aquaculture activity.

2. Material and Methods

2.1. Study area and sampling design

Lake Maninjau (0°19'S, 100°11'E) is a volcano-tectonic lake with an area of 97.4 km², it is currently a eutrophic lake. The lake body is approximately 16.5 km long (north to south) and 7.5 km at its widest point, with an average water depth of 105.0 m, a maximum depth of 168.0 m and has water retention time of 24.6-25.1 years [11]. *C. moltkiana* is a species of bivalvia (mollusk) has a distribution from territory of Sumatera to Malaysian peninsular. For instance, they are found in Lake Maninjau, Lake Singkarak, Lake Diatas and Lake Ranau[12].

Research base of *C. moltkiana* population study was considering to the cage aquaculture activity and type of sediment as their substrate. The cage aquaculture activity at each location was determined by the cage density level and the sediment type as referred [1; 13]. Cage density was categorized into three levels (I:<225 units.km⁻¹; II: 225-675 units.km⁻¹; III >675 units. km⁻¹) (Tabel 1). Bottom type in the northern and eastern shore are dominated by soft substrate (sand >50%), while on the southern and western shore are hard substrate (gravel and rocks) [13].The groups of *C. moltkiana* population was determined based on the cage density level and substrate types. Therefore this paper proposes five zone categories of population groups (Tabel 2; Figure 1).

Table 1. Cage density levels at sites of *C. moltkiana* observation

Site	Cage density (units km ⁻¹ *)		
	I (<225)	II (225-675)	III (>675)
S1			V
S2			V
S3		V	
S4		V	
S5	v		
S6	v		
S7	v		
S8	v		
S9		V	
S10		V	

*) parallel distance to coast straight line [1]

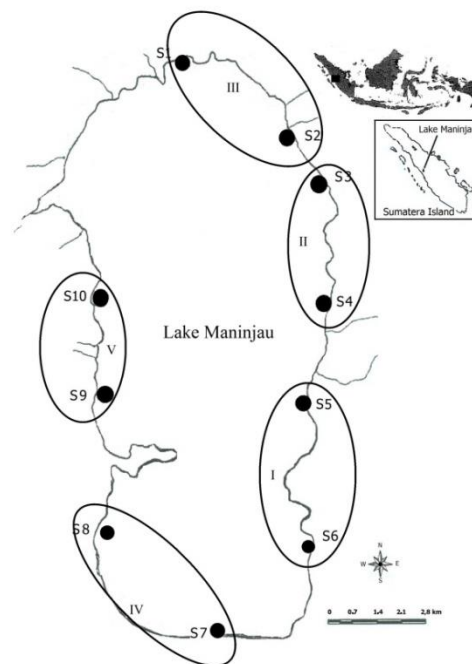


Figure 1. Zone categories for *C.moltkiana* population which refer to cage density and substrate types (See Table 2)

The study was conducted at 10 stations (Figure 1) on the shore of Lake Maninjau, by quantitative sampling of *C. moltkiana* on the substrate at a depth of 1 m, 3 m, and 5 m, conducted from June 2013 to May 2014 on the fourth week of the month. The surber was placed at the appointed depth and then pulled as far as 0.5m toward the coast, respectively. At each sampling site and each sampling depth there were three transects parallel to the coastline, with the distance of 50m between the transects. As a note, due to the difference of cage place which are generally located in waters with a depth more than 10m, while the *C.moltkiana* population is less than 10 m, sampling of *C.moltkiana* were not in precisely on the same place with the presence of cage.

Table 2. Zone categories of *C. moltkiana* population which refer to cage density and substrate types

Zone category	Cage density level	Cage density (units.km ⁻¹) ^{a)}	Sites [% Substrate type] ^{b)}	
			Soft ^{c)}	Hard ^{d)}
I	Low	<225	S(5)[77.8]; S(6)[80.2]	
II	Middle	225-675	S(3)[100]; S(4)[100]	
III	High	>675	S(1)[54.6]; S(2)[60.1]	
IV	Low	<225		S(7)[100]; S(8) [100]
V	Middle	225-675		S(9)[100]; S(10)[100]

^{a)} see table 1; ^{b)} [13]; ^{c)} sand (Ø grain size > 0.026 mm) dominated (>50%); ^{d)} gravel and rock

Biological material was processed through a sieve with a mesh size of 1 mm and the anterior-posterior length of each individual was measured to the lower 0.01 mm with an electronic digital caliper. Length measurements were converted to estimate the individual biomass expressed in grams of ash free dry mass (AFDM), by regression analysis:

$$M = a \times L^b \quad (1)$$

where M is AFDM (g), obtained by ignition of soft tissue at 550°C for 7 hours [14], L is the shell length (mm), a and b are constants. AFDM was determined for 140 specimens of all size classes between June 2013 and May 2014.

2.2. Growth and production estimations

Growth rates were estimated following recognizable cohorts with size-frequency distribution from the successive 12 monthly sample dates. Growth was described by the von Bertalanffy growth function (VBGF) [15] as follows:

$$L_t = L_{\infty} (1 - e^{-K(t-t_0)}) \quad (2)$$

Where L_t is length at age t , L_{∞} is the asymptotic length (mm), t is the age (y) and t_0 is the age at zero length.

The infinity length (L_{∞}) was used from the longest measured specimen from each zone. Growth coefficient estimated by using ELEFAN (*Electronic frequency analysis*) I from FISAT II package (FAO-ICLARM *Stock Assessment*) [16]. Theoretical age at zero length was estimated partially using Pauly empiric equation [17] as follows:

$$\log(-t_0) = -0.392 - 0.275(\log L_{\infty}) - 1.038(\log K) \quad (3)$$

Total annual production of *C. moltkiana* (June 2013 – May 2014) was calculated for the littoral zone of Lake Maninjau by the mass specific growth rate method [18, 19] from the size–mass relation and the size–frequency distribution obtained from all pooled samples and the VBGF, as follows:

$$P = \sum N_i M_i G_i \quad (\text{g AFDM m}^{-2} \text{ yr}^{-1}) \quad (4)$$

where N_i and M_i are the average number of animals (numbers per m^2) and mean individual AFDM in length class i , respectively, and G_i is the mass-specific growth rate.

$$G_i = bK ((L_{\infty}/L_i) - 1) \quad (\text{yr}^{-1}) \quad (5)$$

where b is the exponent of the size–mass relation, K and L_i are VBGF parameters and L_i is the mean size in class i .

The mean annual biomass was computed by

$$B = \sum N_i M_i \quad (\text{g AFDM m}^{-2}) \quad (6)$$

and the annual P/B ratios of the *C. moltkiana* populations were calculated from annual total production P and annual biomass B .

3. Result and Discussion

3.1. Population structure

The observed relationship between length (mm) and AFDM (g) of *C. moltkiana* $y = 0.0001 x^{2.869}$ ($r^2 = 0.87$, $n = 140$) was used for production estimation. Average of abundance and biomass of *C. moltkiana* for all observation sites fluctuated monthly and ranged 550 – 2,919 ind. m^{-2} and 10.5 – 49.0 g AFDM m^{-2} , respectively, and highly varied among sites (Figure 2).

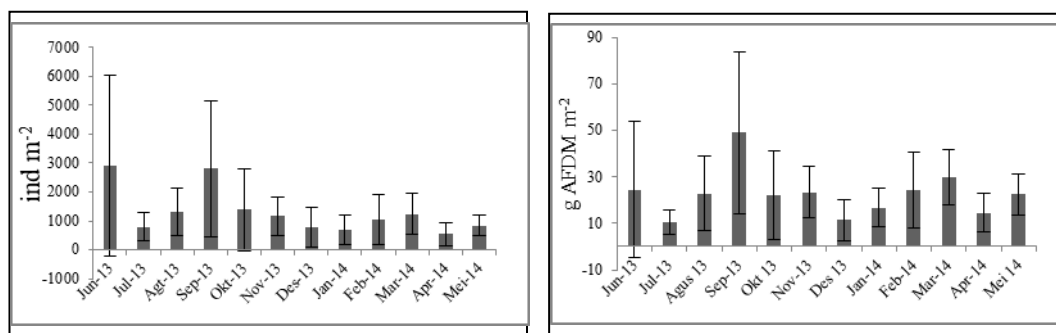


Figure 2. Monthly average abundance and biomass distribution of *C. moltkiana* for all observation sites

By comparing the abundance and biomass of *C. moltkiana* in different zone category, it was shown that the highest biomass was found in zone III. A high cage density had implications to *C. moltkiana*

abundance and biomass, as shown for the Zone III which was lower than Zones II and I. On the other hand, a sand type of substrate was more suitable than gravel and rock which was indicated by lower biomass in Zones IV and V (Figure 3).

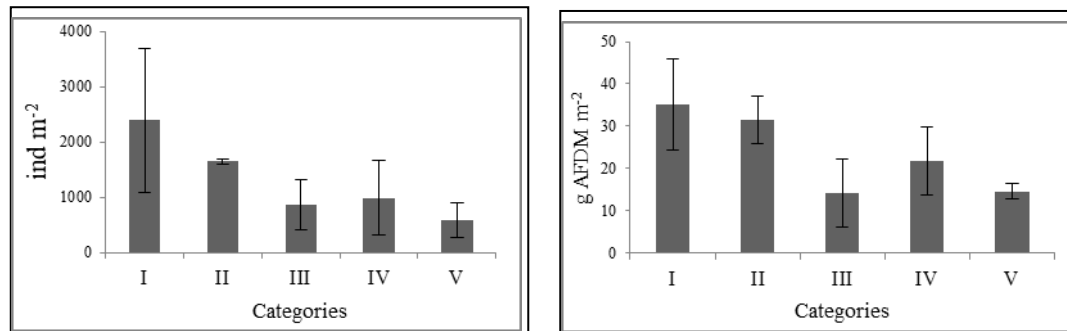


Figure 3. Abundance and biomass average of *C. moltkiana* from different zone categories (I: Low cage density, soft substrate; II: Middle cage density, soft substrate; III: High Cage density, soft substrate; IV: Low cage density, hard substrate; II: Middle cage density, hard substrate).

The monthly abundance of *C. moltkiana* in Lake Maninjau ranged 550 – 2,919 ind. m⁻², relatively high compared to other lake in Indonesia. As a comparison, abundance of bivalvia group in Lake Singkarak, West Sumatera Indonesia, not far from Lake Maninjau, was 355 ind. m⁻² [20]. The variance of *C. moltkiana* abundance was low show that the lake condition was more stable compared to marine. In sandy-beach on the coast of southeastern Brazil, the trigonal clam (*Tivela mactroides*) (Bivalvia, Veneridae) has wide range abundance, namely between 8.87 . 10² ind per transect (7 x 0.5 m x 0.5 m = 1.75 m²) or 507 ind .m⁻² in 2003 until 1.25 . 10⁵ ind. per transect (71428 ind m⁻²) in 2004. The higher abundance in the second period was related to successful recruitment events [21]. Abundance of *C. moltkiana* was higher, relatively than abundance of *Diplodon chilensis* (33 – 176 ind m⁻²), the bivalvia species in glacial lake of North Patagonia [22].

A great difference of individual number can be registered between zones, but rather the bivalves in Zone III reached a much higher anterior-posterior shell length (*apSL*) (Figure 4). Only one individual with *apSL* of >30 mm in the entire study period was found in Zone II. Population structure of biotic influenced both by natural or anthropogenic condition. Population structure of *Mesodesma matroides*, bivalve in beach of northern Argentina, diversified between beaches, that was assumed it could be corresponding to contrasting of beach morpho dynamics [23]. In glacial lake of North Patagonia, the increase of allochthonous organic material in the sediments and water enhances the growth of *D. chilensis*. However, increased allochthonous organic matter leads to a drastic reduction in population density through lowering longevity, increasing mortality and, probably, through disturbing of juveniles recruitment [22].

Implication of substrate type on *C. moltkiana* population was shown by difference of its biomass [B] and production [P]. Value of [B] and [P] in rocky and gravelly area (Zone categories IV, V) was lower than those in sandy (Zone category I, II, III). As mentioned before, northern and eastern shore of the lake dominated by sand and southern and western shore dominated by gravel and rocks [13]. Suitability of substrate as a habitat depends on the physical properties of sediment as keep up the burrowing behavior and life habits of benthic species. Effect of sediment grain size on metabolic activity and growth rates of *Donax trunculus* (26–28 mm shell length) has studied in different sediment grades. The metabolic activity and growth rate were highest in the medium and coarse grades of sand, whereas in gravels and very coarse sand were lower by as much as 43% [24]. In coast of Southeastern Brazil, the high production of trigonal clam (*T. mactroides*) on a periods suppose related to successful recruitment events [21]. Continuity of recruitment depend on successful of settlement of larva. Adult abundance of bivalves determined by fundamental factor that is spatial and temporal variation in the amount of larval settlement in soft sediments [25]. Confirmed [25] that fine sand (0.125 and 0.063 mm) may be unsuitable for larva settlement and very low without substrate. Settlement was abundant in dishes with substrate grain size of 1 mm and 2 mm. Sand (Ø

grain size > 0.026 mm) dominated in substrate of Zone categories I, II, III supposed to influence on higher biomass and production than Zone categories IV and V.

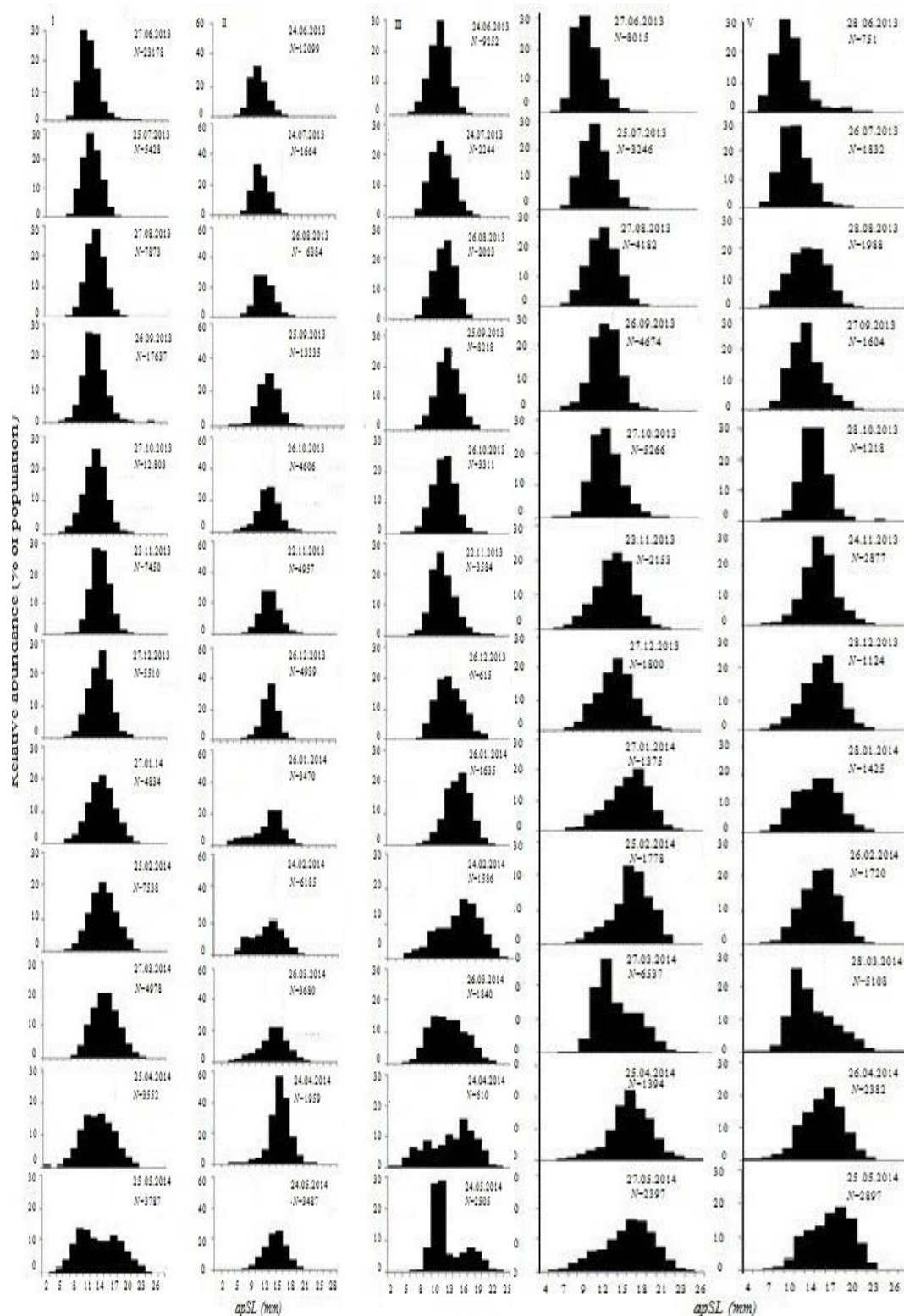


Figure 4. Monthly length-frequency distribution of *C. moltkiana* collected between June 2013 and May 2014 in Zones I - V.

3.2. Growth and Production

Size-frequency distributions were analyzed for recognizable cohorts. During the 12 months of sampling it was observed 4-5 different cohorts from five zone categories I – V (Figure 5), and the biggest specimen had length varied between 25.4 – 30.3 mm.

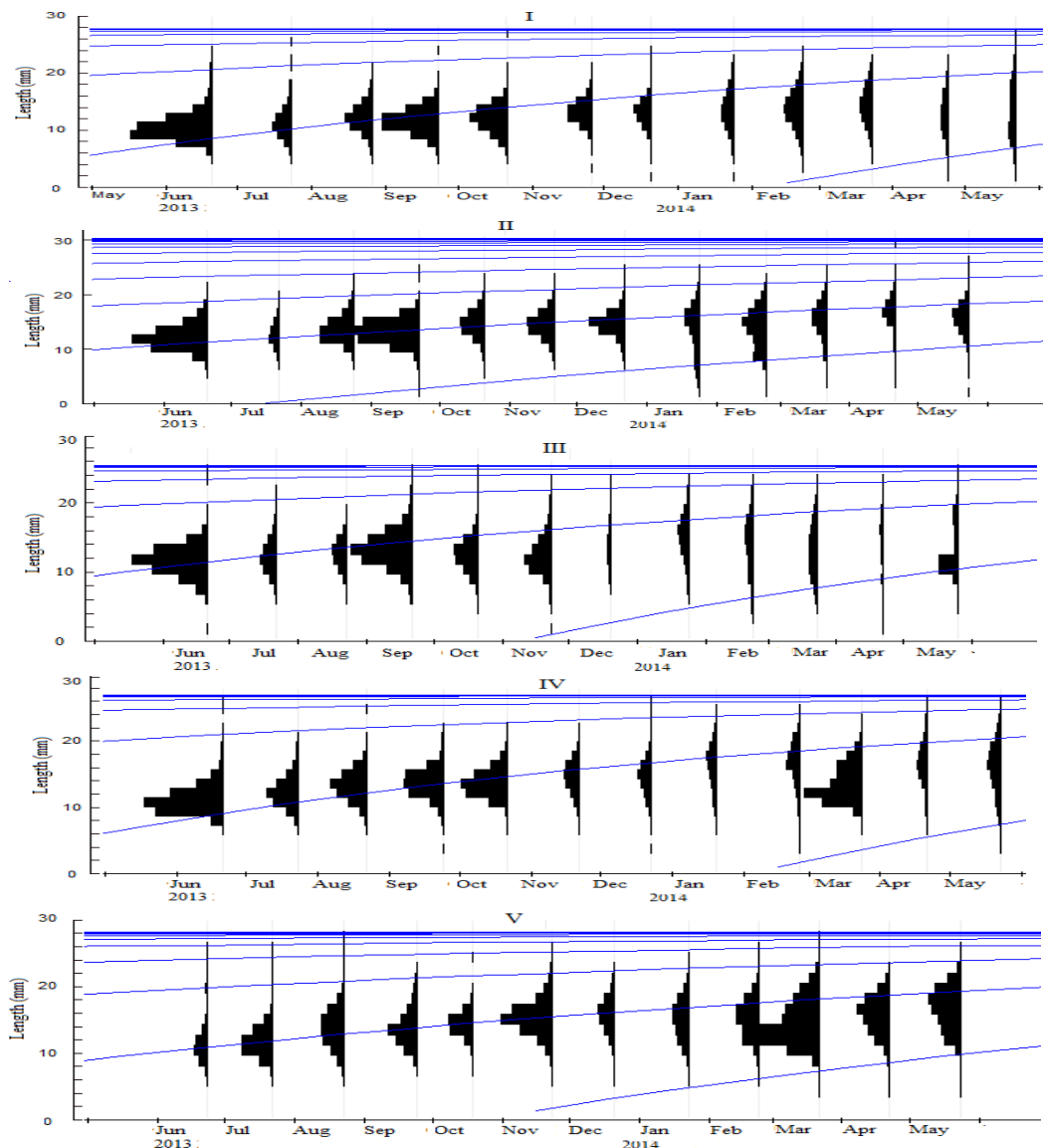
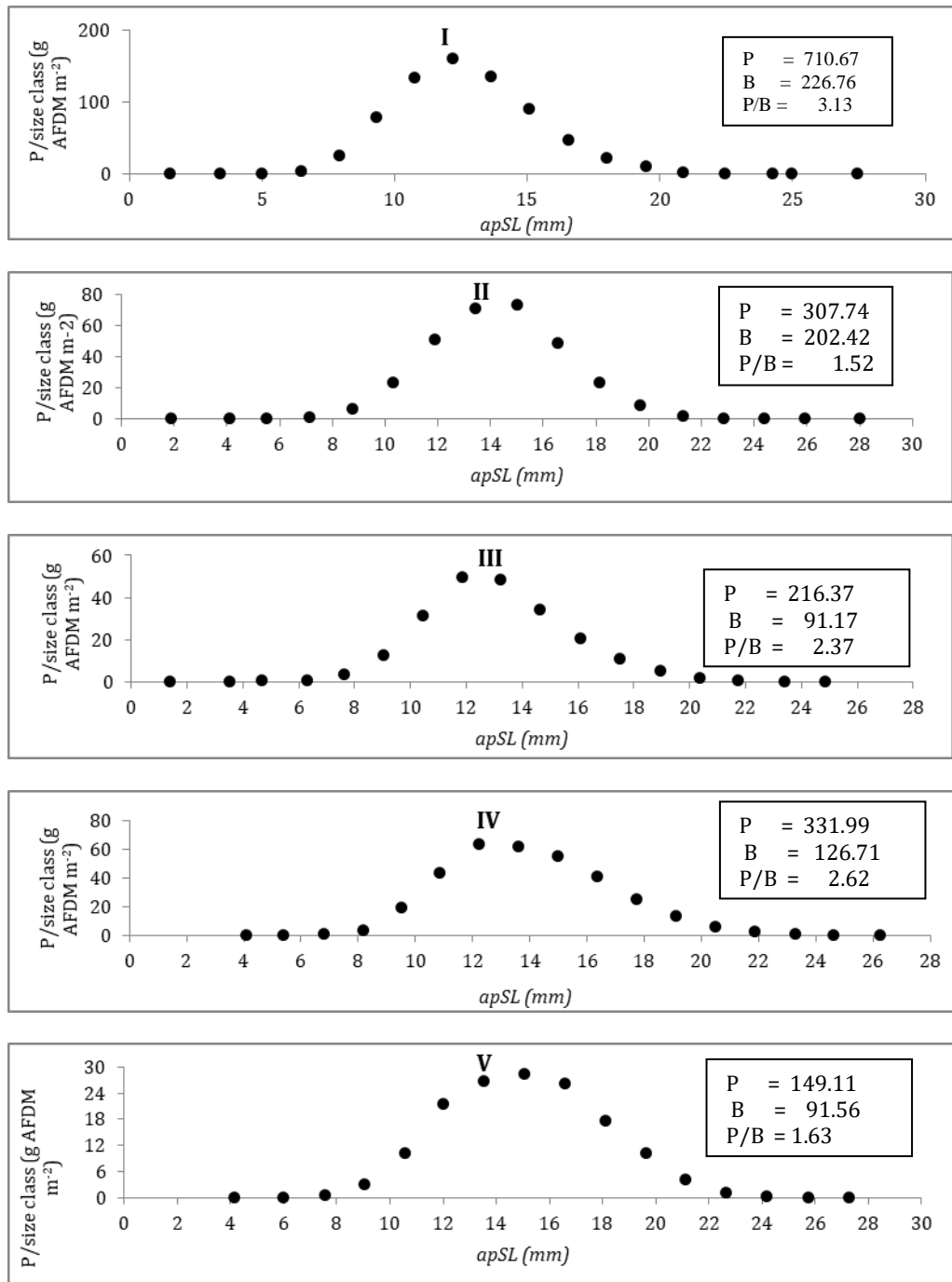


Figure 5. Growth cohorts estimation (mean shell length) from June 2013 to May 2014 for zones I, II, III, IV, and V

A mathematical model to estimate the growth pattern was used from the recognizable cohorts. The equation used to generate this cohort is shown in Table 3. The distribution of total annual production [P] and the abundance [B] among the size classes are illustrated in Figure 6. Annual production ranges between 149 and 711 g AFDM m⁻² y⁻¹ and P/B ratios are between 1.52 and 3.13. The condition of *C. moltkiana* production is similar to their biomass. It means that Zone III is lower than Zones II and I. Production and biomass of *C. moltkiana* in Zones IV and V are lower than in Zones I, II and III. This is an implication of substrate characteristic in which Zones IV and V are dominated by gravels and rocks (Table 2).

Table 3. Application of a growth mathematical model to recognizable cohort

Zone category	L_{∞} (mm)	K (y^{-1})	t_0
I	27.72	1.00	-0.16
II	30.32	0.50	-0.32
III	25.43	0.97	-0.17
IV	26.91	1.10	-0.15
V	28.15	0.73	-0.22

**Figure 6.** Distribution of population production for zones I, II, III, IV, and V

Annual production of *C. moltkiana* in Lake Maninjau ranged 216-711 g AFDM m⁻² yr⁻¹. This value is equal to the production of *Donax serra* (Donacidae) inhabiting the highly exposed sandy beaches of Namibia which ranged between 167 g and 637 g AFDM m⁻² yr⁻¹ at Paaltjies IV and between 273 g and 357 g AFDM m⁻² yr⁻¹ at Langstrand [14]. The higher bivalvia production than *C. moltkiana* showed by trigonal clam (*Tivela mactroides*) from coast of southeastern Brazil were between 0.18 - 7.89 kg AFDM m (transect; 7 x 0.5 m x 0.5 m)⁻¹ yr⁻¹ or between 0.103 – 4.51 kg m⁻² yr⁻¹ [21].

Production/biomass (P/B) ratio of *C. moltkiana* in Lake Maninjau ranged 1.52-3.13 yr⁻¹ (Figure 5), with the pattern of P and B ratio can be seen on Figure 7. The P/B ratio value of *C. moltkiana* is higher than that of Namibian sandy beach clam *Donax serra* (1.18 yr⁻¹ and 1.59 yr⁻¹) [14] and trigonal clam (*T. mactroides*) from Southeastern Brazil coast (1.00 – 1.45 yr⁻¹) [21]. Ratio of P/B is the “turnover rate” or the ‘renewed’ population entirely within period. The consequences of those P/B ratios, the renewed population in one year in Zone II was only 1.5 times, while in Zone I it was 3.1 times.

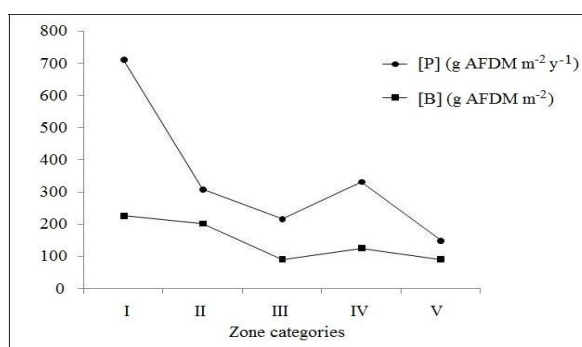


Figure 7. Production [P] and biomass [B] of *C. moltkiana* for zones I, II, III, IV, and V

A high density of cage aquaculture gave implications to population of *C. moltkiana*, as well as its biomass and production, seen it was Zone III lower than Zone II, and Zone II lower than Zone I. Attention to cage aquaculture effects, especially the sedimentation of particulate matters that cause the organic enrichment of sediments. The high level of organic matters in the sediment underneath the aquaculture cages has been commonly detected [26]. In worst situation, anoxic condition and virtually azoic (no animal life present) occurred immediately beneath the stocked cages [27].

Impact the cage aquaculture activity on water quality condition in Lake Maninjau, indicated spatial pattern base the water quality were similar condition, although the increase of cage density tends to influence the anthropogenic characteristics of water quality condition [1]. From statistical analysis (*Test T*, for variant analysis) showed Chemical Oxygen Demand (COD) on low to middle level cage density and ammonium on middle to highest level cage density were significantly different ($P < 0.5$). Cage aquaculture activity has an impact to lower the dissolved oxygen in the bottom area. Dissolved oxygen in cage area was secure levels (2 mg. L⁻¹) relatively only up to 5 meters depth, and dissolved oxygen daily fluctuations strongly related to photosynthetic activity [8].

Effect of organic effluent from a salmon farm has increased the benthic secondary production, but at locations that received the bulks of waste matters was mainly due to the polychaete *Heteromatus filiformis*, meanwhile bivalve species *Abranitida* can grow in periods with moderate loading of organic matter [26]. In the cage culture areas in Penghu Islands, Taiwan, found that sedimentation and organic loading levels are significantly higher [4]. Total organic matters in the sediment, total nitrogen and total organic carbon actually positively correlated to the densities of stress-tolerant polychaetes. In marine cage zone at Magong Bay benthic macrofaunal assemblages were dominated by polychaetes (85.42%) and bivalves only contributed in a small part (4.5%).

In general, this work clearly show that cage aquaculture activity in lake give negative impact to biological population. The increasing of cage aquaculture activity as represented of increasing cage density impact to decrease of biomass and production of *C. moltkiana*. We believe that our study can

contribute to the readers in related field of the need in precautionary principle in the development of cage aquaculture in lake ecosystem.

4. Conclusion

We conclude that *C. moltkiana* is essential benthic organism in Lake Maninjau and its existence threatened by the growing of cage aquaculture. The increased cage aquaculture activity that marked by adding number of cage from <225 cages km^{-1} to > 675 cages km^{-1} significantly decrease the biomass [B] and production of [P] of *C. moltkiana*.

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