EFFECTS OF RAINFALL ON THE POPULATION OF SHRIMPS *Penaeus monodon* Fabricius IN SEGARA ANAKAN LAGOON, CENTRAL JAVA, INDONESIA

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ABSTRACT

Segara Anakan Lagoon (SAL) widely recognised as traditional fishing ground for many fisheries organism and is located at a area with high rainfall. The objectives of the present study are to determine the effects of rainfall on the distribution of *Penaeus monodon* Fabricius in the SAL and/or mangroves waters and to explain the cause of the yearly fluctuations in the shrimp catch in this area during 13 years period (1998 - 2011). The effects of rainfall on the local distribution and abundance of the shrimp in the SAL, Cilacap, Central Java, Indonesia, were examined for three periods by Anco method: first period (of commercial catch production, 1998 – 2011), second period (December 2010-November 2011) and third period (December 2011 – April 2012), as part of shrimp fishery and eco-biology study in this region. The marked increase in the rainfall from 557 mm in East Monsoon (June-August) to 1,225 mm in second transition season (September-November) and West Monsoon (December-February) in the Segara Anakan region enhanced the seasonal movement of shrimp into the fishing ground zone IV and produced an initial increase in the abundance of adults (CL > 25 mm) in the region (312 to 2,630 individuals). This initial increase in adult abundance enhances the shrimp reproductive potential and the heavy rainfall indirectly assists the recruitment of young shrimp to the estuary and their growth and survival to increase shrimp abundance in the following year. Lower rainfalls (July-August-September) adversely affect shrimp population and usually result in smaller size of the population (312 individuals). Statistical analysis on relationship between shrimp catch with annual rainfall showed highly significant at 1% level.

Keywords: distribution, abundance, Segara Anakan Lagoon (SAL), *Penaeus monodon*, rainfall.

INTRODUCTION

Segara Anakan Lagoon (SAL) is a habitat for the variety of aquatic and terrestrial organisms, including various species of shrimp. Major shrimp species found in SAL are fine shrimp (*Metapenaeus elegans*, *M. ensis*, *M. affinis* and *M. dobsoni*), White shrimp (*Penaeus merguiensis* and *P. indicus*), Krosok shrimp (*Parapenaeopsis* sp.) and Tiger shrimp (*P. semisulcatus* and *P. monodon*), which are involved in the family Penaeidae (Sukardjo, 2004, Saputra, 2008). Mangrove areas of SAL function as nursery areas for shrimps and fish, such as certain species of penaeids that are dependent on mangrove forests during their juvenile stages (Sukardjo, 2004). The shrimp (in Indonesia and local area known as udang windu), *Penaeus monodon* Fabricius inhibits in estuaries with silty clay and sandy clay substrates in the SAL (Toro & Sukardjo, 1987), and in inshore oceanic water of Hindian Oceans at Nusawere (Toro & Sukardjo, 1988a, Naamin, 1991). Though the shrimps has an extensive habitat or distribution specifically in estuarine habitat, large juvenile population of the shrimp are usually abundance in a few estuarine. Salinity decrease gradiently such as in large estuaine of Citanduy, Cibereum and Kawunganten (Toro & Sukardjo, 1988a).

In Indonesia, the relationship between the annual fluctuations in rainfall and the catch of Penaeid shrimps has not been examined. We have merely insufficient knowledge of the effects of rainfall on the behavior and abundance of the shrimp. The objectives of the present study are to determine the effects of rainfall on the distribution of *Penaeus monodon* Fabricius in the...
SAL and/or mangroves waters, and to clear the cause of the yearly fluctuations in the shrimp catch in this area during 13 years period (1998 - 2011).

**MATERIALS AND METHODS**

**The area of study**

The Segara Anakan area is located approximately at 7°40'00" – 7°45'00" N and 108°46'00" – 109°00'00" E in the southern coast of Java province (Figure 1). The Segara Anakan has many rivers and estuarine which carry the freshwater and sediments run-off from the high land (Napitupulu & Ramu, 1982, Sukardjo, 2004, Sutrisno & Prayitno, 2013). At this time SAL is facing some ecological problems. One of them is high sedimentation rate along the lagoon, which causes the narrowing the SAL which is coming from Citanduy, Cibeureum, and Cikonde Rivers (Sutrisno & Prayitno, 2013). In the past, Segara Anakan had around 4603 ha of mangrove areas. However, illegal logging had caused the decrease the area of mangrove forest. It was around 1454 ha between 1974 and 1987. In 1989, about 16.5 ha of mangrove forest in the Segara Anakan areas had been converted into shrimp ponds (Nuryanto & Susanto, 2010). According to Sutrisno & Prayitno (2013) calculation of mangrove extent resulted in 2002 the mangrove extent in SAL was 9.163,19 ha decreased respectively to 8.433 ha in 2003, 7.764 Ha in 2004, 7.252,72 Ha in 2005 and 6.213,80 Ha in 2006. Further decrease occured in 2007 to 5.575,16 ha, 4.987 ha in 2008 and finally to 4.267,13 in 2009. Mangrove coverage in SAL decreased approximately 677 ha each year. The decreased of mangrove coverage in SAL followed by the decrease of lagoon extent. According to Suryawati et al., (2011), the extent of SAL, in the year 2001 was 1.178 ha decreased to 800 ha in the year 2007, which means that average decrease rate was 63 ha/year. This decrease was caused by the high sedimentation rate and caused to the decrease of mangrove extent in SAL (Dudley, 2000). Rohmat (2005) mentioned that sediment supply to SAL was estimated about 6 million cubic meters per year where a million cubic meter was settled down. The sediment accumulated in SAL was then filled the lagoon area and soon would turn into land (Sutrisno & Prayitno, 2013).

The high rate of exploitation and declining of the Segara Anakan areas are presumed to have direct impact on its animal communities, including fish assemblages and the ecological role of SAL (Setijanto & Rukayah, 2016). Moreover, due to fasted sedimentation and illegal occupation the mangroves area estimated to be 7.500 ha (Sukardjo (In preparation).

Segara Anakan has the largest single block of mangroves in Java. Moreover, the Segara Anakan mangroves are the richest in term of true mangrove species (Sukardjo, 1984a,b, Hardjosuwarno et al., 1982, Sunaryo, 1982) with both primary and secondary succession actively occurred (Djohan, 2007), and are fishing ground for artisanal fishery (Amin & Hariati, 1991, Suwarso & and Wasilun, 1991). During the study periods we have listed 25 species of plants, 25 species of gastropods, 20 species of mollusks and 12 species of crustaceans.

Mangroves of Segara Anakan are inestimable economic value to Cilacap district and the Central Java province, notably as source of firewood (Sukardjo, 1984a) (illegal cuttings recorded as much as 12-18 m3/day was reported by BPKSA 2006), and as a recruitment ground for important fisheries (Naamin, 1991): an amount of shrimp export has been reported over US $ 1,13 million annually (BPS 2016).

The climate in this area is defined as humid tropical within the climatic type A and B (Schmidt & Ferguson, 1951). The intensity of rainfall occurrence is in high along years. Rainfall data for 1998 -2011, December 2010- November 2011, and December 2011- April 2012 at both Candi and Cilacap meteorological stations were collected from the Meteorological and Geophysical Serial Report, Ministry of Transportation (1998-2012). Four locations in the SAL were used for the study area, namely, Zone I (mesotroph): representing the area significantly affected by two main rivers i.e. Cibereum and Citanduy, where low salinity and relatively high sedimentation are expected (sampling stations: approximately 0.6-0.9 km from Nusawere). Zone II (eutroph): representing the area located in the north-eastern part of the lagoon affected by the western channel, where highest sedimentation and low salinity is expected due to freshwater inflow from two rivers i.e. Kawunganten and Muara Dua (sampling stations: approximately 0.9-1.2 km from Nusawere). Zone III (eutroph):
Representing the area located in the south-eastern part of the lagoon, which is mainly affected by the eastern channel, inflow from the western channel might be having a minor effect from both channel. High sedimentation is expected (sampling stations: approximately 1.2-1.5 km from Nusawere). Zone IV (mesotroph): Representing the area near the western channel, where highest salinity is 33 ‰ and relatively low sedimentation are expected due to prevailing strong tidal currents (sampling stations: approximately 0.4-0.7 km from Nusawere) (Figure 1).

Shrimps taken at the Zone I-IV study areas are arbitrarily referred to as adults, carapace length (CL) more than 25 mm, immature CL 18-25 mm, and post-larvae and juvenile CL: 3-18 mm (Toro, 1996, Staples, 1989). The shrimp population referred as recruit population if they have CL ≤ 30 mm (Toro & Sukardjo, 1988). The distribution and relative abundance of adult, immature and post-larvae and juvenile shrimp *P. monodon* were investigated using *Anco* (a traditional stationed lift-net method) (Figure 2) sampling at selected 53 stations (Zone I: 15 stations, Zone II: 9 stations, Zone III: 16 stations and Zone IV: 13 stations) (Figure 1) during daylight hours in the SAL and its estuarine rivers at monthly intervals in December 2002-November 2003 and in August to November 2006. The description of *Anco* (a traditional stationed lift-net) was given in Subani (1980). The net with 18 mm mesh-size collected effectively shrimps over 3 mm of carapace length (CL). The CL of all shrimps caught by *Anco* methods was measured by dial calipers and read to the millimeter unit below, and counted. Additional information was obtained from local fishermen directly in the fields.
The commercial shrimp-catch figures for 13 years (1998-2011) was used as an information (secondary data). Anco methods were permanently used elsewhere in SAL. Salinity was measured in situ by using a refracto salinometer and portable Electronic Switchgear S-T bridge type MC-5 in every station with 5 replications.

RESULTS AND DISCUSSION

Size distribution and seasonal abundance

Throughout the 16 months of sampling periods, a total of 6,854 shrimps *P. monodon* were caught by Anco at all stations in the 4 zones at SAL, and female shrimp (3,384 or 49.37%) dominated the population. The carapace length (CL, mm) of the population ranged from 17.1 to 59.0 mm, for male the ranged was from 20.00-42.50 mm and for female it was 17.1 to 59.0 mm (Table 1).

Table 1 showed also the different CL sizes of shrimp between two substrates in the 4 zones, based on statistical test with significantly at 1% (Toro & Sukardjo, 1987, Toro & Sukardjo, 1988a, Toro & Sukardjo, 1995a). The CL size distribution of the population is presented in Figure 3, and it was shown that during the Transition Period I: March to May (Musim Peralihan I) the shrimp size was highest for both male (mean of 31.7 mm CL) and female (mean of 33.3 mm CL) (Table 2).

A shrimp *P. monodon* with 17.1-24.9 mm CL of juvenile and/or immature stages: (Staples, 1989, Toro, 1996, Toro & Sukardjo, 1988) enter the SAL from the Citanduy, Cibereum, Kawunganten and Muara Dua rivers during the Transition Period II (September to November) (Table 2, Figure 3). Individuals shrimp with 17.1-21.9 mm CL were apparently more tolerant of freshwater, and were found in both silty-clay (male: 20.0 mm CL, female: 17.1 mm CL) and sandy-clay...

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**Table 1.** The ranges of carapace length (CL) of *Penaeus monodon* Fabricius at each zone in both different substrates. Significantly at the p 1%.

<table>
<thead>
<tr>
<th>Stations with</th>
<th>Size range (CL, mm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Silty-clay substrate:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Zone I</td>
<td>20.0-42.5</td>
<td>17.1-59.0</td>
</tr>
<tr>
<td>2. Zone II</td>
<td>22.7-41.5</td>
<td>21.4-53.5</td>
</tr>
<tr>
<td>3. Zone III</td>
<td>20.0-4.5</td>
<td>17.1-48.3</td>
</tr>
<tr>
<td>4. Zone IV</td>
<td>21.5-4.3</td>
<td>22.5-48.8</td>
</tr>
<tr>
<td>Sandy-clay substrate:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Zone I</td>
<td>23.6-4.5</td>
<td>23.9-59.0</td>
</tr>
<tr>
<td>2. Zone II</td>
<td>21.9-4.1</td>
<td>21.4-54.5</td>
</tr>
<tr>
<td>3. Zone III</td>
<td>23.1-3.5</td>
<td>26.5-39.5</td>
</tr>
<tr>
<td>4. Zone IV</td>
<td>21.9-29.7</td>
<td>21.4-33.3</td>
</tr>
<tr>
<td></td>
<td>24.9-38.3</td>
<td>24.3-38.8</td>
</tr>
<tr>
<td></td>
<td>25.0-41.1</td>
<td>27.5-54.5</td>
</tr>
</tbody>
</table>

**Table 2.** Effect of rainfall to the local seasonal movement of *Penaeus monodon* Fabricius in term of their abundance during December 2010 to November 2011 in SAL.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Annual catch (number of individual)</th>
<th>West Monsoon (December 2010 - February 2011)</th>
<th>Transition Period I (March - May 2011)</th>
<th>Transition Period II (September - November 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1,041</td>
<td>284</td>
<td>142</td>
<td>521</td>
</tr>
<tr>
<td>II</td>
<td>1,123</td>
<td>345</td>
<td>257</td>
<td>440</td>
</tr>
<tr>
<td>III</td>
<td>1,169</td>
<td>356</td>
<td>258</td>
<td>488</td>
</tr>
<tr>
<td>IV</td>
<td>1,414</td>
<td>487</td>
<td>221</td>
<td>514</td>
</tr>
<tr>
<td>Total (I-IV)</td>
<td>4,747</td>
<td>1,472</td>
<td>827</td>
<td>1,963</td>
</tr>
<tr>
<td>I-IV</td>
<td>Male (Mean CL, mm)</td>
<td>30,431</td>
<td>31,706</td>
<td>29,330</td>
</tr>
<tr>
<td></td>
<td>Female (Mean CL, mm)</td>
<td>31,741</td>
<td>33,321</td>
<td>29,706</td>
</tr>
</tbody>
</table>

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substrates (male: 21.9 mm CL, female: 21.4 mm CL) of the Zone II where salinity is invariably less than 14‰ due to freshwater discharge from the Kawunganten and Muara Dua rivers (Table 1, Figure 4).

Adult stages (>25 mm CL) of shrimp *P. monodon* in the SAL normally remain in the sandy-clay and silty-clay substrates of the estuaries and inhabit areas with a salinity more than 30‰ (cf. Toro & Sukardjo, 1987). During the high rainfall (>1,000 mm per 3 months), we found the adult shrimp move to zone IV (with salinity ranges 16-29‰) (Figures 4), usually inhabits site areas with a salinity less than 29‰. The highest number of individual shrimp *P. monodon* were found in the zone IV (1,41 individual shrimp) (Table 2), at the near mouth of channel to Hindian oceans and where most of the population have a CL ranging from 41.1 to 59.0 mm (Tables 1, 2). There were few shrimps with 54.5-59.0 mm CL for both male and female. The high number of shrimp population in the 4 zones of SAL correspond to the highest rainfall in the region (Table 3), and shown statistically significant at the p <0.01 (Table 4). Figure 5 demonstrates the seasonal fluctuation in abundance of adults (>25 mm CL).

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**Figure 3.** *Penaeus monodon* Fabricius length frequency distribution in SAL.

**Figure 4.** Longitudinal transects of SAL showing salinity regime (‰ at zone I-IV) (-----): salinity during lower rainfall; (----): salinity during high rainfall.
In SAL, the Transition Period II (Musim Peralihan II): September to November 2011) represent the season with highest population (1,963 individuals shrimp) but with CL, ranging from 28.98 to 29.80 mm for shrimps population (Table 2). The shrimps grow rapidly with a mean of 1.69 mm CL as the waters warm (28.7 ± 1.75°C) in period September to November 2011 or Transition Period II. During the dry season (June to August 2011 or East Monsoon), the growth is virtually slow (mean of 0.38 mm CL). Furthermore, the direct evidence of growth during the period the end of West Monsoon (February) to the first of East Monsoon (June) five months increased in average wet weight occurred (15.0 g in February to 21.4 g in June).

Data of 12 months (December 2010 – November 2011) showed that the local movement of adults (male: mean of 28.1-31.8 mm CL, female: mean of 29.7-33.3 mm CL) shrimp continues throughout the year (Table 2). Table 1 shows the increased in the CL size of shrimp P. monodon, from zone I to the zone IV and from zone II to the zone III of the SAL, as result of the life history out line above. The maximum and average CL sizes of females in a sample are greater than those of males (Tables 1, 2).

<table>
<thead>
<tr>
<th>Zone</th>
<th>Abundance of P. monodon (number of individual) during the</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High rainfall (300-450 mm/month)</td>
</tr>
<tr>
<td>I</td>
<td>790</td>
</tr>
<tr>
<td>II</td>
<td>901</td>
</tr>
<tr>
<td>III</td>
<td>936</td>
</tr>
<tr>
<td>IV</td>
<td>972</td>
</tr>
<tr>
<td>Total (I-IV)</td>
<td>3,599</td>
</tr>
</tbody>
</table>

Initial effect of rainfall and monthly-annual catches

According to Schmidt & Ferguson (1951), Segara Anakan areas fall under the climate type of A and B. During the periods of study, the average annual rainfall was 3.7 to 4.7 mm with the ratio between the number of dry month (<60 mm/month) and wet month (>100 mm/month) or Q ratio was 13.0-23.0% (Figure 1).

The Anco sampling (December 2010- November 2011), it was indicated that the number of shrimp P. monodon in the SAL had increase by 124.2% after the flood (Figure 5), and adults shrimp (>25 mm CL) were most abundant (Table 2). A large catch (in term of more than 7,000 gram/month) by Anco sampling were taken in April, May and June of 2011 (Figure 5).

Figure 6 (Data 1998 – 2011) showed that the annual total catch from SAL has fluctuated between 4.80 ton, taken in 2011 after a long period of dry season, and 190 ton, recorded in 1998 after a year of very heavy rainfall and peak at Citanduy, Cibereum, Muara Dua and Kawungaten rivers discharge (Meteorological Stations in Cilacap 1998 -2011). Figure 6 showed also that the higher or lower than average catches were recorded clearly. Figure 7 showed average of

![Figure 5. Monthly fluctuation in Penaeus monodon Fabricius caught during the study period.](image)
monthly catch from December 1998 – November 2011, and the large catches (>100 ton) was taken in SAL in November (West Monsoon) and December (Transition Period II). The monthly catch of the period 1998-2011 (13 years) in October and November after a large-scale flood in the Citanduy, Cibereum, Muara Dua and Kawunganten rivers were increased 124.1% (October-November) (Figure 7). The monthly records catch in 1998 (190 ton) after repeated large scale flooding of the Segara Anakan region in October, November, December and January (see: Meteorological Data in 1996), were 23.1 tons, 51.9 tons, 30.2 ton and 21.3 ton, respectively. Those record calculated 1 to 2.5 times of the January average (21.3 ton).

It shows that annual rainfall correlated significantly with annual catch of shrimp *P. monodon* (Table 3 & 4). The effectiveness of the annual rainfall to the catch production of the preceding year was shown by their positive correlation ($r_{1998-2011} = 0.939$, $r_{2010-2011} = 0.956$, $r_{Dec-April 2012} = 0.922$) (Table 4). The figure from December 2010 to November 2011 (12 months) and December 2011 - April 2012 (4 months) shrimp *P. monodon* catch is also significantly correlated with rainfall (Tables 4 & 6). For the period of December 2010 to November 2011 (12 months) the equation of the relationship between monthly catch ($Y$, individual-g) and monthly rainfall ($X$, mm) was $Y = 13.246 + 5.386 X$ ($r = 0.956$) (Figure 8).
Rainfall and abundance

The normal seasonal abundance (Figure 6,7) and the CL sizes (Figure 3) of shrimp *P. monodon* changed considerably soon after rainfall with sufficient intensity as shown in the period 13 years (1998 -2011). Figure 4, 5 for the period 1 year (2010 -2011) indicated that initial duration to produce shrimp production substantially increase in the zone I-IV by freshwater flow into the SAL. These results showed that prolonged and heavy rainfall is required over a substantial area of Segara Anakan catchment to produce a noticeable increase in the abundance of shrimps. In the December 2010 - November 2011 study, the well above average shrimp catch of December 2010 - January 2011 (>524 individuals) was most likely due to the heavy rainfall (328-448 mm/month) and major flood recorded in October in that year (2010). Also, it was happening for the annual production in 1998 to 2011 (> 65 ton) (Figure 6).

In one-year (2010 -2011) period, local movement of shrimp *P. monodon* after prolonged heavy rainfall have been observed in the zones of SAL (Tables 2 & 3). The increased river flow after high rainfall (300-448 mm/month) enhanced the local seasonal movement from the zone I (790 individuals) to zone IV (972 individuals), and zone II (901 individual) to zone III (936 individuals) (Table 3). Monthly sampling for the December 2010-November 2011 revealed that a moderate rise in the freshwater flow into the lagoon enhances the local movement of only the shrimp *P. monodon* with 25 to 35 mm CL after heavy rainfall.

Figure 3 showed that the striking changed in the CL frequency distribution of samples from 53 stations in SAL observed in December 2010 to November 2011. The decrease in the mean CL for both sexes (female: 33.3 to 29.7 mm, male: 31.7 to 28.2 mm), and the increased frequency of the small size (25.0-30.0 mm CL) (female: 4.1 to 48.5%, male: 14.3 to 37.5%) adults in the sample taken during the 2002-2003 period of study were attributed to a large influx of the smaller to medium (30.0-34.0 mm CL) size group of adult shrimp *P. monodon* which have moved locally with the flood from the upper rivers reaches of the estuary in each zone of the lagoon. The strong uni-modal size distribution of the shrimp males and females illustrated the usual occurrence of shrimps in mangroves waters as a result of heavy flooding and a very high freshwater flow into SAL. Also, the areas of Segara Anakan mangrove waters represent a both nursery and feeding grounds of shrimp *P. monodon*. There was no sample of a re-entry of these smaller shrimp into the estuarine habitat after the flood waters receded. This is indicated that rainfalls affect the local movement of shrimp (Table 5).

In Cilacap region, it was reported that marketable size of adult shrimps was 27.5-94.6 mm CL. This is based on the result of inshore catch of trawl (Naamin, 1982). However, shrimps with 17.1-59.0 mm CL were normally also considered as local marketable sized, and abundant in the SAL during the 12 months study period (Figure 5).

The above results on the size distribution and seasonal abundance confirm a general account of the bio-ecology of shrimp *P. monodon* Fabricius with 17.1-59.0 mm CL in the SAL and its different seasons (Tables 1, 2). This is an indication that the shrimp population in the lagoon at the 4 zones with two different substrates are in mixed juvenile (CL <18.00 mm) to immature (CL 18-25 mm), adult stages (CL > 25 mm) and include recruitment size (CL > 30.0 mm) (cf. Staples, 1980a, b, 1989, Toro, 1996, Toro & Sukardjo, 1995 b). Within the estuaries with dense
mangrove trees in the Citanduy, Cibereum, Kawunganten and Muara Dua, *P. monodon* is closely associated with those dense mangrove vegetation, and their abundance have a significant correlation with rainfall ($r = 0.956$) (Table 4). This correlation appears to be due to the cumulative effect of rainfall on the shrimps' bio-ecological aspects (e.g. reproductive potential, recruitment, growth, and survival) (Toro & Sukardjo, 1988a), and condition factor (Toro & Sukardjo, 1990). These indicated also that *P. monodon* are estuarine-dependent throughout the CL range of the species. It is supported by the fact that Segara Anakan is a tropical shallow lagoon with salinity regime less than 33‰, very active sedimentation process typified by clay particle (Napitupulu & Ramu, 1982), and therefore represent an ideal silty-clay and sandy-clay substrates for the *P. monodon* (17-59 mm CL) growth and nurseries, and suggested facilitate burying for juveniles. These finding confirm those of Hughes (1966), Branford (1981a, 1981b), Freitas (1986), Subramania *et al.* (1983) and Naamin (1991). The sediment preferences and morphometric equations for *P. monodon* from estuarine at the 4 zones in the lagoon need to be studied in detailed (Table 5) (Toro & Sukardjo, 1987). In general, burrowing by shrimp *P. monodon* in the substrate of silty-clay is well established by Toro & Sukardjo, (1988a), which suggests that SAL represent their natural habitat as shown by analysis of variance using randomized block (Tables 5 & 6).

The male adults were smaller than the females in CL size at all season (Table 2). This might be regarded as a general characteristic of Penaeid shrimp in SAL with predominantly by mangroves lined at their coasts (cf. Motoh, 1981). It is also interesting to note that males were sexually mature at a smaller CL size than female by 29.0 mm CL. Juvenile (CL 17-18 mm) and adolescent *P. monodon* were recorded from surface waters in the 4 zones of SAL (cf. Hughes, 1966). Therefore, spawning of *P. monodon* does not require a particular water depth in SAL (Figure 5) (cf. Staples, 1981, 1982). It is quite possible that the juveniles could cope with high temperatures of particular water depth due to their burying behavior (e.g. Joshi, *et al.* 1979). Thus, Segara Anakan mangroves areas represent a nursery ground for the post larval and early juvenile stages (17-25 mm CL) of *P. monodon*. Consequently, the recruitment of the young shrimp (<30 mm CL) to the mangroves estuarine environments of Citanduy, Cibereum, Kawunganten and Muara Dua is critical stage of their life history, and the estuarine discharge of fresh or brackish water play an important part of this process. Also in the low salinity (7-11‰) habitat (Figure 4), there were fewer potential predator for young shrimp (e.g. Robertson, 1988), and, hence, this areas favorable for juvenile (CL 17-25 mm) *P. monodon*.

The local movement of shrimp (Tables 2, 3) from the estuarine environment (Citanduy, Cibereum, Kawunganten and Muara Dua) in each zone after flood was due to the decreased salinity (Figure 5) (e.g. Mair, 1980, Primavera, 1996). A strong fresh water inflow from those rivers will enhance the reproductive success of *P. monodon*. This supported by the tidal periodicity of movement of adult shrimp from zone I into the zone IV, and zone II into the zone III which are shown by the changes in the number of prawn
Effects of rainfall on the population of shrimps *Penaeus monodon* Fabricius

with 18-25 mm CL (sub-adult) caught in a set *Anco* at the mouth of Cibereum and Citanduy, and Kawunganten and Muara Dua rivers (Table 2). This is coinciding with the report of Hughes, (1966) that juvenile and adolescent *P. monodon* were recorded from surface waters in estuaries. It can be concluded that the shrimp *P. monodon* with CL 25-59 mm belong to the hypo-osmo-regulators species (e.g. Dall, 1981). These finding suggest that rivers flooding in each zone would not produce an osmotic stress in adult shrimps. This is also in agreement with Toro & Sukardjo, (1988a) that found the adult (37.2 ± 5.8 mm CL) shrimp *P. monodon* can tolerate large fall in salinity. In shallow waters up to water depth around 5 m, fine sediment comprising clayey silt cover the shrimp *P. monodon* substrates. This implies also serve to protect fisheries interest in the SAL. This suggestion is supported by the catch production in the period 1998-2011, December 2010 - November 2011 and December 2011 -April 2012 (Tables 4, 5, 6). The linear relationship observed between monthly rainfall and monthly catch (Figure 8) suggest that the enhanced local movement of *P. monodon* after effective rainfall was a response to the increased river flow and the subsequent disturbance of the bottom sediment (cf. Robertson, 1988). Tables 4, 5 & 6, and Figure 7 showed an association between the catch of *P. monodon* in SAL and the regional rainfall (annual and monthly) with highest coefficient of correlation (r) (\(r_{1998-2011} = 0.939\), \(r_{December 2010 - November 2011} = 0.956\), \(r_{December - April 2012} = 0.922\)). The correlations (Table 4) was attributed to the cumulative effect of rainfall on the shrimp reproductive success, on the recruitment of young to the estuaries in each zone, and on the growth and survival of all life history stages (cf. Buckworth, 1992). As it was happened for *P. monodon* in the Godavari estuarine system in India (Subrahmanyan, 1966).

The mangrove forests in Segara Anakan produced litterfall of about 270-791 dry t/ha/year (Sukardjo, 1984b). This material will be processed and feed by most mangrove crabs (e.g. Ashton, 2002, Skov & Hartnoll, 2002, Dahdouh-Guebas et al. 1999), and decomposed on the surface of the mud in the mangrove forests (e.g. Camilleri & Ribi, 1986), and will transport (e.g. Boto & Bunt, 1981, Sukardjo, 1995a) to the SAL by tides, which greatly benefit the growth and survival of *P. monodon*. These indicated that the lagoon has highest DOM (dissolved organic matter) (Sukardjo & Toro, 1995b). Previous studies have emphasized the importance of mangrove detritus (Leh & Sasekumar, 1984) in the diet of juvenile *Fenneropenaeus merguiensis* Fabricius. This detrital material plays also a particularly important part in the nutrition of juvenile *P. monodon* (e.g. Motoh, 1981, Tiews, 1976, Dall, 1968, Chong & Sasekumar, 1981). And, the rainfall indirectly contributes to the food supply for all life history stages (17.1-59.0 mm CL) of *P. monodon* in the 4 zones of SAL. TE-FPIP (1984) stated that the food investigation and water conservation purposes in the upper reaches of lagoon has probably had little or no adverse effect on the *P. monodon* in the Citanduy, Cibereum, Kawunganten and Muara Dua estuaries. Therefore, a moderate or high discharge of water from the Kawunganten, Muara Dua (Zone II), and Cibereum, Citanduy (Zone I) rivers, and the large tidal fluctuations in salinity of the lagoon from each zone to the mouth of the estuary (Figure 3) would facilitate the local movement of larval and post larval (CL. 17.10-25 mm) *P. monodon* (cf. Buckworth, 1992, Mair, 1980).

Estuaries of the Citanduy, Cibereum, Kawunganten and Muara Dua are important for study of SPM (Suspended Particulate Matters) and substrate preferences of juvenile shrimps *P. monodon* Fabricius (CL 17.1-25.0 mm) (e.g. Rulifson, 1981, Primavera, 1998), as through this conduit, rivers borne material, water and sediment; enter into SAL (Napitupulu & Ramu, 1982). Deposition of suspended matters is controlled largely by sediment concentration; settling velocity and fluid shear (cf. Mazda et al. 2007, Purba, 1991). Deposition occurs in slack water conditions when shear stress falls bellows certain critical values. It is a common observation that clay particles come under stress when they come in contact with water of high salinity and tend to flocculate and precipitate out of suspension, e.g. in zone IV. Most probably this process is very active in Citanduy estuary where a decreasing trend of SPM is observed towards high salinity region near the mouth.

Table 2 confirms the similarity in the fluctuations of rainfall and catch demonstrated by Figure 7, and shows that the correlation coefficient between the annual rainfall or monthly rainfall and the catch of the same year, is significant at the 1% level (Table 4) as humid tropical domain for species sustainability. Also,
the highest correlation between rainfall and the catch was found between the annual catch and the total rainfall of the 2010-2011 plus the 2012 study at the 1% level of significant. The significance of the results in Table 2 increases when it is noted that *P. monodon* is adult in the SAL of about in CL 25-35 mm, and they comprise a distinct recruitment stock (CL ≥ 30.0 mm) each year. This strong correlation between rainfall and the catch of the December 2010 -November 2011 and 2012 suggested that there may be a causal relationship between the two.

The year – to - year changes i.e. increase or decrease (Figure 6) in shrimp catch agrees with the preceding yearly changes in rainfall from 2.6 mm to 5.7 mm per year in Cilacap district. In 1998 -2011, the Cilacap district rainfall was slightly below the yearly average (<2.5mm), and the Citanduy, Gibeereum, Kawunganten and Muara Dua rivers was subjected to small-scale flooding, may account for the large shrimp catch of 1998 (190 ton) (Figure 6). This is an indication that the fluctuation of shrimp catch may be due to salinity changes as a result of rainfall. Figures 6, 7 suggest that *P. monodon* fishery declined up to 80 ton to 100 ton per year indicated the less influx of fresh waters carrying by rivers. Finally, continued diminution of the fresh water flow into many of the estuaries in the SAL will probably have a long-term detrimental effect on the *P. monodon* stocks. Thus, the effects of dry or rainy seasons on the population ecology of *P. monodon* through hydrology of the lagoon should be studied intensively. There has been long term lower trend in catch from 1998 to 2011 (Figure 6), but a remarkable correlation of the fluctuation in SAL catch, and the Cilacap district annual rainfall (Tables 4, 6) corresponding to the maxima and minima in monthly rainfall, as shown in the December 2010 to November 2011 study (Figure 5).

Moreover, the high number of shrimp in the SAL, especially in zone IV also suggest that *P. monodon* may mover/migrate short distances (Tables 2 & 3). These moving patterns underline three key points about the SAL management: First, increasing regulation of water flow is increasingly devastating to natural fisheries. Second, the benefits of mangrove forest in SAL are felt at some considerable distance from their locations. Third, such are the links between mangrove forest, rivers, SAL and the open sea of Cilacap region (Hindian Ocean) that up-setting the water regime which normally maintains a mangrove system and flooding cycle can have considerable not on effects.

CONCLUSIONS

It is very important to be noted in SAL that rainfall is very important factor for distribution, abundance and reproductive success of *Penaeus monodon*. Also, SAL with mangrove vegetation play important role for the development and growth of shrimps *Penaeus monodon* population. This is should be interesting to be studied in detail for longterm population development of *Penaeus monodon* to characterized their variation of sizes during in and around the mangrove habitat (*cf*. Hugesh, 1966). Our study also prove that SAL is very important fisheries resources (*cf*. Amin & Hariati, 1991).

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