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

RIANTA PRATIWI* AND SUKRISTIJONO SUKARDJO

Research Centre for Oceanography, Indonesian Institute of Sciences (LIPI), Jakarta 11048, Indonesia

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ABSTRACT

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

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

INTRODUCTION

Segara Anakan Lagoon (SAL) is a habitat for a variety of aquatic and terrestrial organisms, including various species of shrimp. Predominant 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 (*Parapenaopsis* sp.) and tiger shrimp (*P. semisulcatus* and *P. monodon*), all of which belong to the Penaeidae family (Sukardjo 2004; Saputra 2008). SAL's mangrove territories function as nurseries for shrimp and fish, such as certain species of penaeids that are dependent on mangrove forests during the juvenile stage (Sukardjo 2004). The shrimp *Penaeus monodon* Fabricius – known as "udang windu" in the region and in Indonesia – live in estuaries with silty clay and sandy clay substrates in SAL (Toro & Sukardjo 1987), as well as in the inshore oceanic waters of the Indian Ocean in Nusa Were (Toro & Sukardjo 1988a; Naamin 1991). Though the shrimp species's habitat is extensive, with wide distribution specifically in estuaries, large juvenile populations are usually found in abundance in few estuaries. There were decreasing salinity gradients in the large estuaries, namely in Citanduy, Cibereum and Kawunganten (Toro & Sukardjo 1988a).

In Indonesia, the relationship between annual fluctuations in rainfall and penaeid shrimp catch has not been examined. We have insufficient knowledge of the effects of rainfall on the behavior and abundance of shrimp. The objectives of the present study were to determine the effects of rainfall on the distribution of the *Penaeus monodon* Fabricius in

*Corresponding author: r_pratiwi_99@yahoo.com; pratiwiafriadi@gmail.com

SAL and/or mangroves waters, and to determine the cause of yearly fluctuations in the region's shrimp catch during a 13-year period from 1998 to 2011.

MATERIALS AND METHODS

Area of Study

The Segara Anakan area is located at approximately 7°40'00''–7°45'00''N and 108°46'00''–109°00'00''E in the southern coast of the Java Province (Fig. 1). Segara Anakan has many rivers and estuaries, which carry freshwater and sediment runoffs from the highlands (Napitupulu & Ramu 1982; Sukardjo 2004; Sutrisno & Prayitno 2013). Today, SAL faces several ecological predicaments, among others, high sedimentation rates along the lagoon, causing a narrowing of the rivers from the Citanduy, Cibeureum, and Cikonde Rivers (Sutrisno & Prayitno 2013). In the past, Segara Anakan had around 4603 ha of mangrove area. However, illegal logging has reduced the region's mangrove cover. Between 1974 and 1987, the region's mangrove cover came to 1454 ha. In 1989, around 16.5 ha of Segara Anakan's mangrove forest had been converted into shrimp ponds (Nuryanto & Susanto 2010). According to Sutrisno and Prayitno (2013), SAL's mangrove extent went from 9,163.19 ha in 2002 to 8,433 ha in 2003, 7,764 ha in 2004, 7,252.72 ha in 2005 and 6,213.80 ha in 2006. The mangrove extent continued to decline and was recorded at 5,575.16 ha in 2007, 4,987 ha in 2008, and finally to 4,267.13 in 2009. SAL's mangrove coverage has decreased by approximately 677 ha annually. The decrease in SAL's mangrove cover is followed by a decrease in the lagoon's extent. According to Suryawati *et al*. (2011), SAL's extent came to 1,178 ha in 2001, and had declined to 800 ha in 2007, which meant an average decrease rate of 63 ha/year. The decrease was caused by high sedimentation rates and in turn resulted in the decrease of SAL's mangrove extent (Dudley 2000). As much as 6 million cubic meters of sediments were deposited annually to SAL, where 1 million cubic meters would settle (Rohmat 2005). Sediments accumulated in SAL and filled the lagoon area, soon turning into land (Sutrisno & Prayitno 2013).

The high rate of exploitation and declining mangrove cover in Segara Anakan are presumed to have direct impacts on its animal communities, including fish assemblages and SAL's ecological role (Setijanto & Rukayah 2016). Moreover, the region's mangrove area is estimated to be at 7,500 ha due to a fast rate of sedimentation and illegal occupation (Sutrisno & Prayitno 2013).

Segara Anakan has the largest single block of mangrove in Java. Moreover, Segara Anakan's mangrove is the richest in terms of true mangrove species (Sukardjo 1984a, 1984b; Hardjosuwarno *et al*. 1982; Sunaryo 1982) with both primary and secondary successions actively occurring (Djohan 2007). Segara Anakan is also a fishing ground for artisanal fishery (Amin & Hariati 1991; Suwarso & Wasilun 1991). During the periods of this study, we listed 25 plant species, 25 gastropod species, 20 mollusk species, and 12 crustacean species.

Segara Anakan's mangrove has an inestimable economic value to the Cilacap District and the Central Java Province, notably as a source for firewood (Sukardjo 1984a) (illegal logging was recorded as 12-18 m^3/day, as reported by BPKSA in 2006) and as a recruitment ground for important fisheries organisms (Naamin 1991), with shrimp exports reported at over US$1.13 million annually (Central Statistics Agency/BPS 2016).

The climate in this area is defined as humid tropical within the A and B climate types (Schmidt & Ferguson 1951). Intensity of rainfall occurrence is high all year long. 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 SAL were used as sites of study, namely: Zone I (mesotroph): representing the area significantly affected by the two main rivers of Cibereum and Citanduy, where low salinity and relatively high sedimentation were expected (sampling stations: approximately 0.6–0.9 km from Nusa Were);

Zone II (eutroph): representing the area located in the northeastern part of the lagoon affected by the western channel, where highest sedimentation and low salinity were expected due to the freshwater inflow from the two rivers of Kawunganten and Muara Dua (sampling stations: approximately 0.9–1.2 km from Nusa Were); Zone III (eutroph): representing the area located in the southeastern part of the lagoon mainly affected by the eastern channel, while inflow from the western channel might have been slightly affected by both channels—high sedimentation was expected (sampling stations: approximately 1.2-1.5 km from Nusa Were); and Zone IV (mesotroph): representing the area near the western channel, where a highest salinity of 33‰ and relatively low sedimentation were expected due to prevailing strong tidal currents (sampling stations: approximately 0.4-0.7 km from Nusa Were) (Fig. 1).

Sample Collection

Shrimp samples taken in Zone I-IV are arbitrarily referred to as adults, carapace length (CL) of more than 25 mm, immature 18-25 mm CL, and post-larvae and juvenile 3-18 mm CL (Toro 1996; Staples 1989). A shrimp population is referred to as recruit population if it has CL≤30 mm (Toro & Sukardjo 1988b). The distribution and relative abundance of adult, immature and post-larvae and juvenile shrimp *P. monodon* were investigated using *Anco* ("stationed traditional lift-net") (Fig. 2) sampling at selected 53 stations (Zone I: 15 stations, Zone II: 9 stations, Zone III: 16 stations, and Zone IV: 13 stations) (Fig. 1) during daylight hours in SAL and its estuarine rivers at monthly intervals in December 2002–November 2003 and in August–November 2006). A description of the *Anco* (stationed traditional lift-net) was given in Subani (1980). The net, with an 18-mm mesh, effectively collected shrimp over 3 mm CL. The CLs of all shrimp caught using *Anco* were measured using dial calipers, read to the millimeter unit as seen below, and calculated. Additional information was obtained from local fishermen directly in the field.

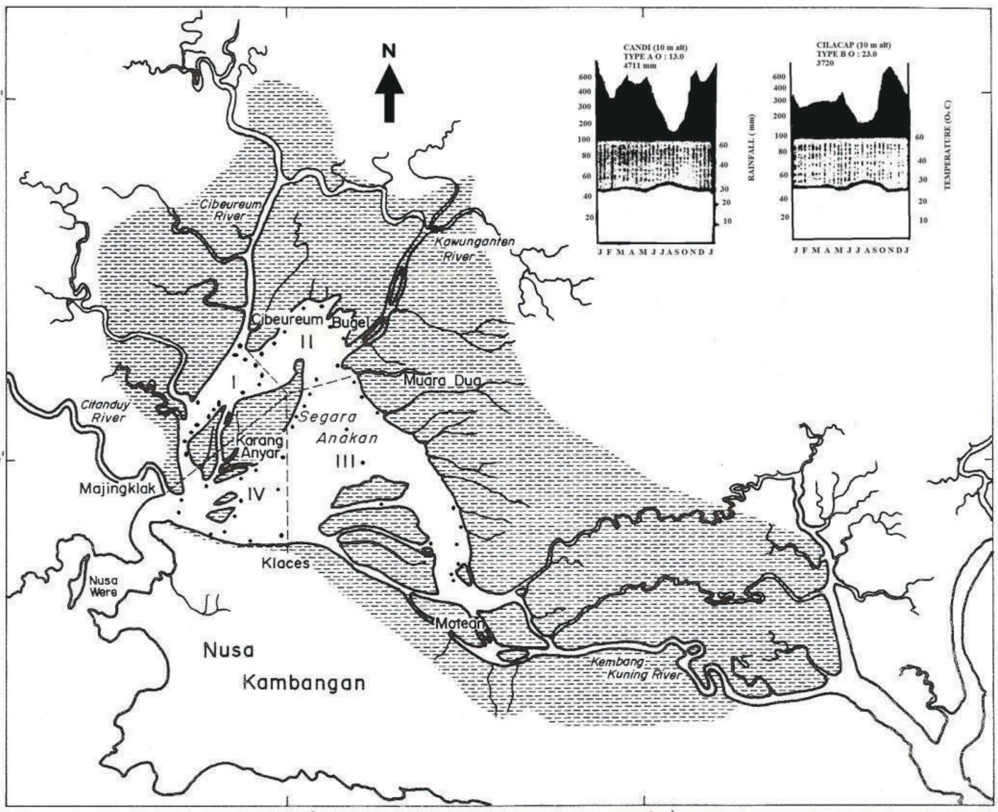

Figure 1 Map showing SAL and its aquatic zones (I-IV) as study sites

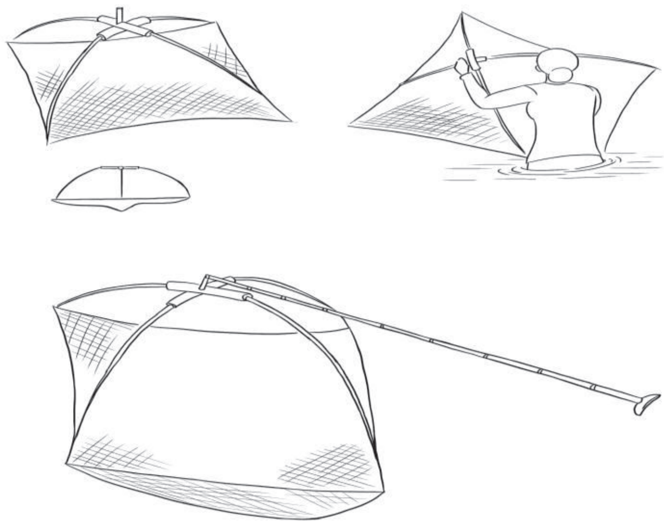

Figure 2 *Anco* (a traditional stationary lift-net method) (Subani 1980)

Commercial shrimp-catch figures of over 13 years (1998-2011) were used as information (secondary data). *Anco* was in permanent use elsewhere in SAL. Salinity was measured *in situ* 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, a total of 6,854 *P. monodon* shrimp were caught in multiple *Anco* at all stations in the 4 zones in SAL, and female shrimp (3,384 or 49.37%) dominated the population. The carapace lengths (CL, mm) of the population ranged from 17.1 to 59.0 mm; males ranged from 20.00 to 42.50 while females ranged from 17.1 to 59.0 mm (Table 1).

Table 1 also shows the different CL sizes of shrimp between two substrates in the 4 zones, based on a statistical test with a 1% significance (Toro & Sukardjo 1987, 1988a, 1995a). The CL size distribution of the population is presented in Fig. 3, which shows that, during Transition Period I: March to May (Musim Peralihan I), shrimp sizes were highest for both males (a mean of 31.7 mm CL) and females (a mean of 33.3 mm CL) (Table 2).

Table 1 Carapace lengths (mm CL) of *Penaeus monodon* Fabricius in each zone in both substrates (significant at p 1%)

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

Table 2 Effects of rainfall on the local seasonal movement of the *Penaeus monodon* Fabricius in terms of their abundance from December 2010 to November 2011 in SAL

Zone	Annual catch (number of individual)	Seasonal catch (number of individual)			
		West Monsoon (December 2010–February 2011)	Transition Period I (March–May 2011)	East Monsoon (June–August 2011)	Transition Period II (September–November 2011)
I	1,041	284	142	94	521
II	1,123	345	257	81	440
III	1,169	356	258	67	488
IV	1,414	487	221	192	514
Total (I-IV)	4,747	1,472	827	354	1,963
I-IV	**Male (Mean CL, mm)**	30,431	31,706	29,330	28,976
	Female (Mean CL, mm)	31,741	33,321	29,706	29,770

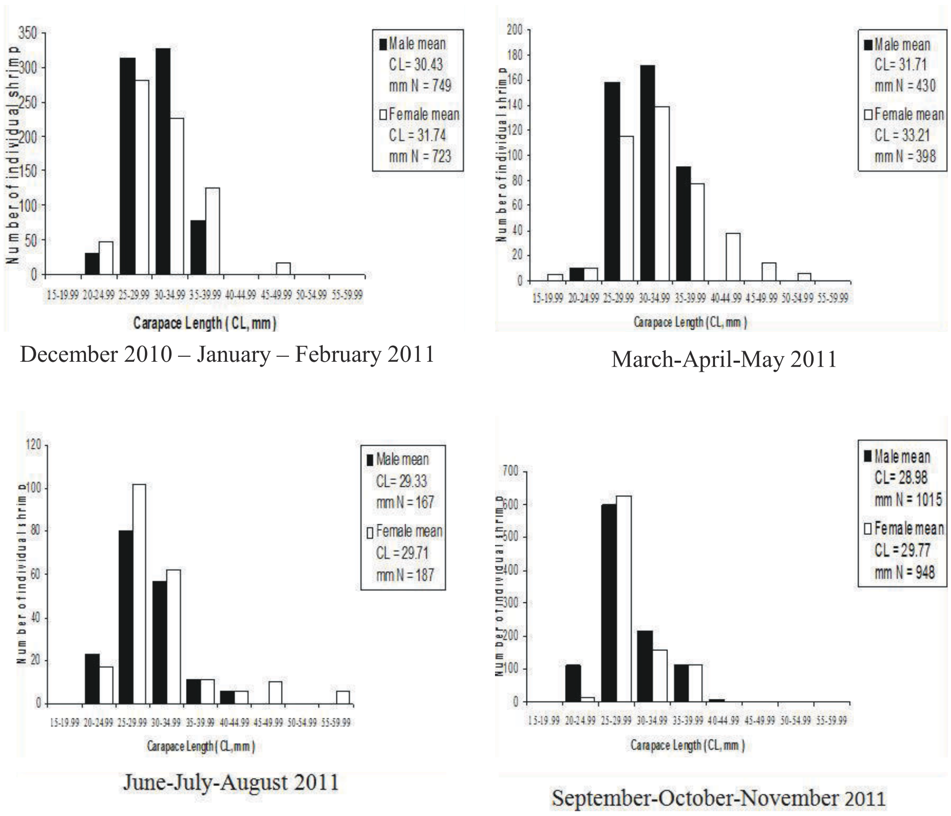

Figure 3 *Penaeus monodon* Fabricius length frequency distribution in SAL

A *P. monodon* shrimp with a CL of 17.1-24.9 mm in the juvenile and/or immature stage: (Staples 1989; Toro 1996; Toro & Sukardjo 1988b) enters SAL from the Citanduy, Cibereum, Kawunganten and Muara Dua Rivers during Transition Period II (September to November) (Table 2, Fig. 3). Individual shrimps 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 substrates (male: 21.9 mm CL, female: 21.4 mm CL) in Zone II, where salinity was invariably less than 14‰ due to the freshwater discharge from the Kawunganten and Muara Dua Rivers (Table 1, Fig. 4).

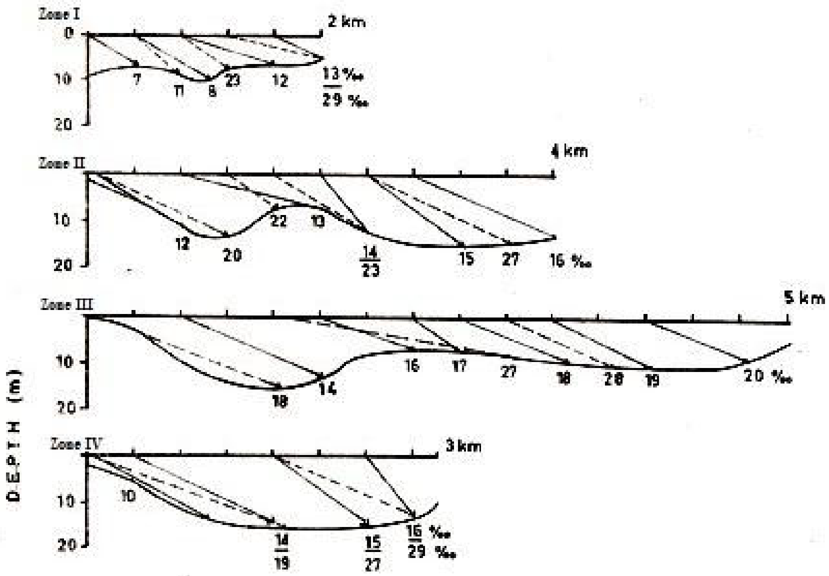

Figure 4 SAL's longitudinal transects, showing salinity regimes (‰ in zone I-IV)
Note: (------): salinity during lower rainfall; (____): salinity during high rainfall

In their adult stages (>25 mm CL), the *P. monodon* shrimp in SAL normally remain in the sandy-clay and silty-clay substrates of the estuaries and inhabit areas with a salinity of more than 30‰ (cf. Toro & Sukardjo 1987). During high rainfalls (>1,000 mm per 3 months), we found that the adult shrimp would move to Zone IV (with a salinity range of 16-29 ‰) (Fig. 4), usually inhabiting site areas with a salinity of less than 29‰. The highest number of individual shrimp *P. monodon* was found in Zone IV (1.41 individual shrimp) (Table 2), near the mouth of the channel leading to the Indian ocean, and where the majority of the population's CL ranged from 41.1 to 59.0 mm (Table 1, 2). There were few shrimp, both male and female, with a CL of 54.5-59.0 mm. The high shrimp populations in the 4 SAL zones correspond to the highest rainfalls in the region (Table 3), shown to be statistically significant at $p<0.01$ (Table 4). Fig. 5 demonstrates seasonal fluctuations in the abundance of adults (>25 mm CL).

In SAL, Transition Period II (Musim Peralihan II), from September to November 2011, represents the season with the highest shrimp population (1,963 individual shrimp) but with a CL range of 28.98-29.80 mm (Table 2). The shrimp grew rapidly with a mean of 1.69 mm CL as the water warmed (28.7 $\pm$ 1.75°C) in the September–November 2011 period, or Transition Period II. During the dry season (June–August 2011 or East Monsoon), shrimp growth was virtually slow with a mean of 0.38 mm CL. Furthermore, direct evidence of growth during the five-month period from the end of the West Monsoon (February) to the start of the East Monsoon (June), showed an increase in average weight (15.0 g in February to 21.4 g in June).

Table 3 Abundance of *Penaeus monodon* Fabricius in periods of high rainfall to lower rainfall in December 2010 to November 2011 in SAL, Cilacap

Zone	Abundance of *P. monodon* (number of individual shrimp) during:		
	High rainfall (300-450 mm/month)	Medium rainfall (200-300 mm/month)	Lower rainfall (100-200 mm/month)
I	790	186	65
II	901	173	49
III	936	197	36
IV	972	392	50
Total (I-IV)	3,599	948	200

Data taken during a 12-month period from December 2010 to November 2011 showed that the local movement of adult shrimp (male: mean of 28.1-31.8 mm CL; female: mean of 29.7-33.3 mm CL) continued throughout the year (Table 2). Table 1 shows the increase in the CL of the *P. monodon* shrimp, from Zone I to Zone IV, and from Zone II to Zone III, in SAL, as a result of the shrimp's history outlined above. The maximum and average CL sizes of females in these samples are greater than those of males (Table 1, 2).

Initial Effects of Rainfall and Monthly-Annual Catch

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

Anco samplea taken in December 2010–November 2011 indicated that the number of *P. monodon* shrimp in SAL increased by 124.2% after a flood (Fig. 5), and adult shrimp (>25 mm CL) were most abundant (Table 2). Large catches (more than 7,000 gram/month) harvested using *Anco* were sampled in April, May and June of 2011 (Fig. 5).

Fig. 6 (1998–2011 data) shows that the total annual catch in SAL fluctuated between 4.80 tons in 2011, after a long period of dry season, and 190 tons, recorded in 1998, after a year of very heavy rainfall and peak discharge in the Citanduy, Cibereum, Muara Dua and Kawungaten Rivers (Meteorological Stations in Cilacap 1998–2011). Fig. 6 also shows that catches that were higher and lower than average were clearly recorded. Fig. 7 shows the average monthly catch from December 1998–November 2011 and large catches (>100 tons) taken in SAL in November (West Monsoon) and December (Transition Period II). Monthly catches in the months of October and November 1998–2011 increased by 124.1% after a large-scale flooding of the Cintaduy, Cibereum, Muara Dua and Kawunganten Rivers (Fig. 7). Monthly catches recorded in 1998 (190 tons) after repeated large-scale floodings in the Segara Anakan region in October, November, December and January (see: Meteorological Data in 1996), were at 23.1 tons, 51.9 tons, 30.2 ton and 21.3 ton, respectively. These numbers show 1 to 2.5 times of the January average of 21.3 tons.

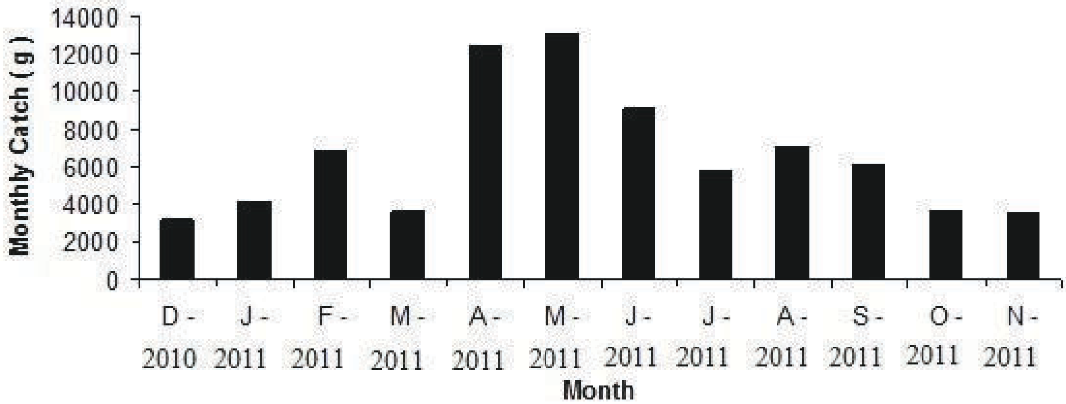

Figure 5 Monthly fluctuations in *Penaeus monodon* Fabricius catch during the December 2010–November 2011 study period

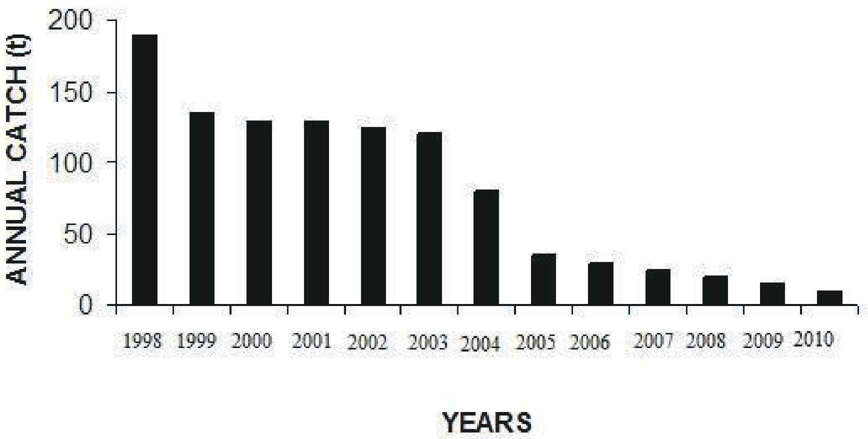

Figure 6 Annual fluctuation index for the *Penaeus monodon* Fabricius

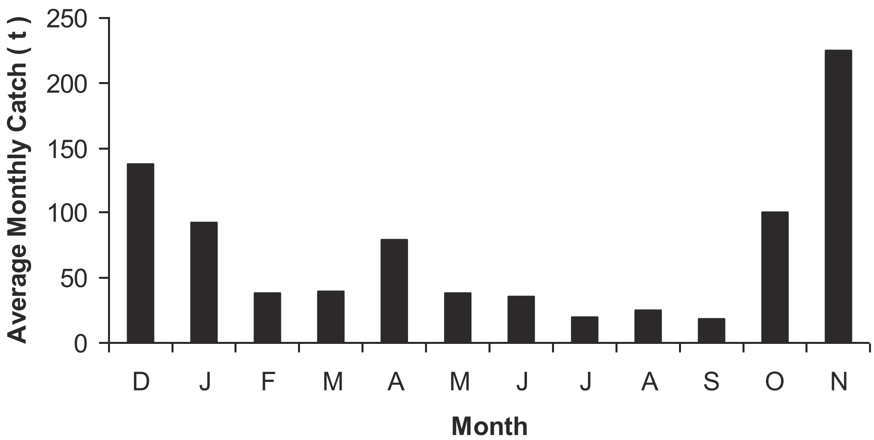

Figure 7 Seasonal fluctuations in the abundance of adult *Penaeus monodon* Fabricius (determined from average catch in 1998–2011)

Tables 3 and 4 show that annual rainfall significantly correlated with the annual catch of the *P. monodon* shrimp. The annual rainfall's effect on catch production of the preceding year is shown by their positive correlation ($r_{1998-2011}$=0.939, $r_{2010-2011}$=0.956, $r_{Des-April\ 2012}$=0.922) (Table 4). December 2010 to November 2011 (12 months) and December 2011 to April 2012 (4 months) figures also show significant correlation between *P. monodon* shrimp catch and rainfall (Table 4, 6). For the December 2010 to November 2011 (12 months) period, the relationship between monthly catch (Y, individual-g) and monthly rainfull (X, mm) is described by the equation: Y =13.246+5.386 X (r=0.956) (Fig. 8).

Table 4 Correlation coefficient between annual *Penaeus monodon* Fabrcius catch and rainfall in SAL, Cilacap

Comparison	R	Degree of freedom
1. 1998-2011 shrimp catch with a +++ rainfall	0.939**	13
2. December 2010–November 2011 shrimp catch with a ++ rainfall	0.956**	12
3. 2011 (December to April) fish catch with a rainfall of +	0.922**	4

Note: Sources: +++: Annual report, Cilacap District Fisheries Services 1998–2011, plus additional data collected directly in the field by communicating with the fishermen; ++: Data in December 2010 to November 2011; +: Data in December 2011 to April 2012; Data for 1990-1994: not available
(** Significant at p<0.01)

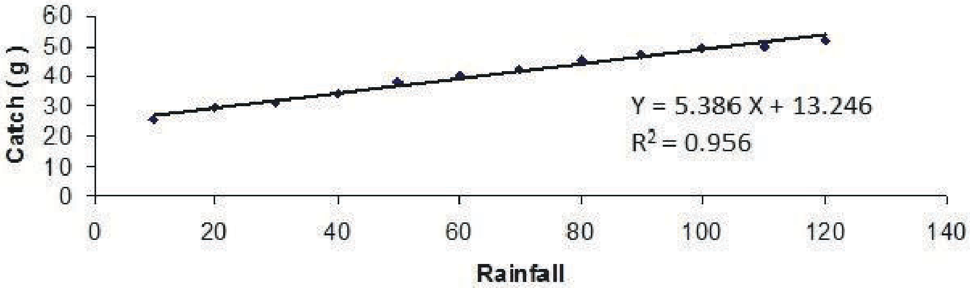

Figure 8 The relationship between monthly rainfall (x, mmm) and monthly *Penaeus monodon* Fabricius catch (y, individual-g) in SAL in the December 2010–November 2011 period

Rainfall and abundance

The normal seasonal abundance (Fig. 6, 7) and CL sizes (Fig. 3) of the *P. monodon* changed considerably right after rainfall with sufficient intensity, as shown in the 13-year period from 1998 to 2011. Fig. 4 and 5, which describes the one-year period from 2010 to 2011, indicate that the initial duration for producing shrimp substantially increased in Zones I-IV, with freshwater flowing into SAL.

These results show that prolonged and heavy rainfall is required over a substantial area of the Segara Anakan catchment to produce a noticeable increase in the abundance of shrimp. 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 the major flood recorded in October that year (2010). Large catches were also found in the annual yields from 1998 to 2011 (> 65 tons) (Fig. 6).

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

Fig. 3 shows a striking change in the CL frequency distribution of samples from 53 stations in SAL, which were observed in December 2010 to November 2011. The decrease in mean CL for both sexes (female: 33.3 to 29.7 mm, male: 31.7 to 28.2 mm), and the increased frequency of small size (25.0-30.0 mm CL) (female: 4.1-48. 5%, male: 14.3-37.5%) adults in the samples 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 *P. monodon* shrimp that had moved locally with the flood from the upper reaches of the estuary's rivers in each zone of the lagoon. The strong uni-modal size distribution of both male and female shrimp illustrates the usual occurrence of shrimp in mangroves waters as a result of heavy flooding and a very high volume of freshwater flowing into SAL. Also, Segara Anakan's mangrove waters represent both nursery and feeding ground for the *P. monodon* shrimp. There was no sample of re-entry for these smaller shrimps into the estuarine habitat once flood waters receded, which indicates that rainfall affects the local movement of shrimp (Table 5).

In the Cilacap region, it was reported that the marketable size of adult shrimp was 27.5-94.6 mm CL, based on the result of inshore trawl catch (Naamin 1982). However, shrimp with sizes between 17.1 mm and 59.0 mm CL were also normally considered as locally marketable. Shrimp that fall into this size category were abundant in SAL during the 12-month study period (Fig. 5).

The results above, concerning *P. monodon*'s size distribution and seasonal abundance, confirm the general account of the bio-ecology of *P. monodon* Fabricius with a CL of 17.1-59.0 mm in SAL and its different seasons (Table 1, 2). This is an indication that shrimp populations in the lagoon, in the 4 zones with two different substrates, are in the mixed juvenile (CL<18.00 mm) to immature (18-25 mm CL) and adult stages (CL>25 mm), as well as recruitment size (CL>30.0 mm) (cf. Staples 1980a, 1980b, 1989; Toro 1996; Toro & Sukardjo 1995b). Within estuaries with dense mangrove in the Citanduy, Cibereum, Kawunganten and Muara Dua, *P. monodon* is closely associated with dense mangrove cover, and their abundance is signifcantly correlated with rainfall rates (r=0.956) (Table 4). This correlation appears to be due to the cumulative effect of rainfall on the shrimp's bio-ecological aspects (e.g. reproductive potential, recruitment, growth, and survival) (Toro & Sukardjo 1988a) and factors of condition (Toro & Sukardjo 1990). The correlation also indicates that the *P. monodon* is estuarine-dependent throughout the CL range of the species. This is supported by the fact that Segara Anakan is a shallow tropical lagoon with a salinity regime of less than 33‰ and with a very active sedimentation process typified by the presence of clay particles (Napitupulu & Ramu 1982), and therefore offers ideal silty-clay and sandy-clay substrates for the growth and nusery of *P. monodon* (17-59 mm CL) as well as facilitates burrowing for juveniles. These findings 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 estuaries in the lagoon's 4 zones need to be studied in detail (Table 5) (Toro & Sukardjo 1987). In general, burrowing by the *P. monodon* shrimp in a silty-clay substrate is well established by Toro and Sukardjo (1988a), which suggests that SAL represents their natural habitat, as shown in the variant analysis using randomized blocks (Table 5, 6).

The male adults were smaller than the females in CL size in all seasons (Table 2). This might be regarded as a general characteristic of Penaeid shrimp in SAL, with predominantly mangroves lining its coast (cf. Motoh 1981). It's also interesting to note that males were sexually mature at a smaller CL size than female by 29.0 mm CL. Juvenile (17-18 mm CL) and adolescent *P. monodon* were recorded from water surface in the 4 SAL zones (cf. Hughes 1966). Therefore, the *P. monodon* does not require a particular water depth to spawn in SAL (Fig. 5) (cf. Staples 1989). It's quite possible that the juveniles are able to cope with the high temperatures of particular water depths due to their burrowing behavior (e.g. Joshi *et al.* 1979). Thus, Segara Anakan's mangrove areas are nursery grounds for *P. monodon*'s post larval and early juvenile stages (17-25 mm CL). Consequently, the recruitment of young shrimp (<30 mm CL) into the estuarine mangrove environments of Citanduy, Cibereum, Kawunganten and Muara Dua is a critical stage in their life, and the estuarine discharge of fresh or brackish water plays an important part in this process. Additionally, there are fewer potential predators for young shrimp in low salinity (7-11‰) habitats (Fig. 4) (e.g. Robertson 1988), hence such areas are favorable for juvenile *P. monodon* (17-25 mm CL).

Table 5 ANOVA showing the results of *Penaeus monodon* Fabricius catches in 2 substrate types (silty-clay and sandy clay) in 12 randomized blocks by rainfall in mm/month with (p>0.05)

Source of variance	Df	SS	MS	$F_{cal.}$	$F_{0.05}$	$F_{0.01}$
Among treatments (Rainfall/month)	11	669,217.125	60,837.921	1.499 <	2.28	4.46
Block (substrate types)	1	30,317.042	30,317.042	0.757 <	4.84	9.65
Error	11	446,285.458	40,571.405			
Total	23	1,145,819.625				

Table 6 ANOVA showing the results of *Penaeus monodon* Fabricius catches in 8 locations, in 12 Randomized Blocks by rainfall in mm/month with 9 missing values (p<0.01)

Source of variance	Df	SS	MS	$F_{cal.}$	$F_{0.05}$	$F_{0.01}$
Among treatments (Rainfall/month)	11	143,527.029	13,047.912	7.217 >>	1.916	2.489
Block (Locations)	7	16,244.696	2,320.671	1.284<	2.126	2.882
Error	77	139,198.895	1,807.777			
Total	95	298,970.6201				

The local movement of shrimp (Table 2, 3) from the estuarine environment (Citanduy, Cibereum, Kawungaten and Muara Dua) in each zone after floods was due to the decreased salinity (Fig. 5) (e.g. Mair 1980; Primavera 1996). A strong fresh water inflow from these rivers will enhance the reproductive success of *P. monodon*. This is supported by the tidal periodicity of the movement of adult shrimp from Zone I into Zone IV, and Zone II into Zone III, as demonstrated by the changes in the number of shrimps with 18-25 mm CL (sub-adult) caught in *Anco* stations at the mouths of the Cibereum and Citanduy, and Kawunganten and Muara Dua Rivers (Table 2). These changes coincide with Hughes's 1966 report that juvenile and adolescent *P. monodon* were recorded from water surfaces in estuaries. It can be concluded that the *P. monodon* shrimp with 25-59 mm CL belong to the hypo-osmo-regulator species (e.g. Dall 1981). These findings suggest that river flooding in each zone does not produce osmotic stress in adult shrimp. This is also in agreement with Toro and Sukardjo (1988a), who found that adult (37.2 $\pm$ 5.8 mm CL) *P. monodon* shrimp can tolerate large drops in salinities. In shallow waters up to a water depth of around 5 m, fine sediments made up of clayey silt cover the *P. monodon* shrimp's substrates. This implication should also serve to protect fisheries interests in SAL, as supported by catch productions in the 1998-2011 period, as well as in December 2010–November 2011 and December 2011–April 2012 (Table 4, 5, 6). The linear relationship observed between monthly rainfall and monthly catch (Fig. 8) suggests that the enhanced local movement of *P. monodon* after effective rainfall was a response to the increased river flow and the subsequent disturbance of bottom sediments (cf. Robertson 1988). Table 4, 5, 6, and Fig. 7 show an association between *P. monodon* catch in SAL and regional rainfall (annual and monthly) with the highest correlation coefficient (r) ($r_{1998\text{-}2011}$: 0.939, $r_{\text{December 2010–November 2011}}$: 0.956, $r_{\text{December–April 2012}}$: 0.922). The correlation (Table 4) was attributed to the cumulative effect of rainfall on the shrimp's reproductive success, on the recruitment of young shrimp to estuaries in each zone, and on growth and survival in all of the shrimp's life stages (cf. Buckworth 1992). Similar phenomena were also observed among *P. monodon* populations in the Godavari estuarine system in India (Subrachmanyan 1966).

Segara Anakan's mangrove forests produce a litterfall of about 270-791 dry t/ha/year (Sukardjo 1984b). Such materials will be processed and fed on by most mangrove crabs (e.g. Ashton 2002; Skov & Hartnoll 2002; Dahdouh-Guebas *et al.* 1999), decomposed on the surface of mud in mangrove forests (e.g. Camilleri & Ribi 1986), and transported (e.g. Boto & Bunt 1981; Sukardjo 1995) to SAL by the tides, which greatly benefit the growth and survival of *P. monodon*. These points indicate that the lagoon has the highest DOM (dissolved organic matter) (Sukardjo & Toro 1995). Previous studies have emphasized the importance of mangrove detritus (Leh & Sasekumar 1984) in the diet of juvenile *Fenneropenaeus merguiensis* Fabricius. The detrital material also plays a particularly important part in the nutrition of juvenile *P. monodon* (e.g. Motoh 1981; Tiews *et al.* 1976; Dall 1968; Chong & Sasekumar 1981). Additionally, rainfall indirectly contributes to food supply in all of the *P. monodon*'s life stages (17.1-59.0 mm CL) in the 4 SAL zones. Tim Ekologi- Fakultas Perikanan Institut Pertanian Bogor (TE-FPIPB) (1984) stated that food investigation and water conservation purposes in the upper reaches of the 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 as well as large tidal fluctuations in the lagoon's salinity from each zone to the mouth of the estuary (Fig. 3) would facilitate the local movement of larval and post larval (17.10-25 mm CL) *P. monodon* (cf. Buckworth 1992; Mair 1980).

Citanduy, Cibereum, Kawunganten and Muara Dua estuaries are important in the study of SPM (Suspended Particulate Matters) and substrate preferences of juvenile *P. monodon* Fabricius (17.1-25.0 mm CL) (e.g. Rulifson 1981; Primavera 1998), as rivers carry materials, water and sediment into SAL (Napitupulu & Ramu 1982). The deposit of suspended matters is controlled largely by sediment concentration, settling velocity, and shear flow (cf. Mazda *et al.*

2007; Purba 1991). Deposits occur 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 the Citanduy estuary, where a decreasing trend in SPM is observed toward the high salinity region near the mouth.

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

The year-to-year changes, i.e., increase or decrease (Fig. 6), in shrimp catch agree with the preceding yearly changes in rainfall from 2.6 mm to 5.7 mm per year in the Cilacap District. In 1998–2011, rainfall in the Cilacap District was slightly below the yearly average (<2.5mm). Additionally, the Citanduy, Cibereum, Kawunganten and Muara Dua Rivers were subjected to small-scale flooding, which may have accounted for the large shrimp catch in 1998 (190 tons) (Fig. 6). This indicates that the fluctuations in shrimp catch may have been due to salinity changes caused by rainfall. Fig. 6 and 7 suggest that a decline in *P. monodon* fishery of up to 80-100 tons per year indicated less influx of fresh water carried by the rivers. Finally, continued diminution of fresh water flow into many of SAL's estuaries will probably have a long-term detrimental effect on *P. monodon* supply. Thus, the effects of dry or rainy season on the population ecology of *P. monodon* through a hydrology of the lagoon must be pursued intensively. There has been a long-term trend in lower catch from 1998 to 2011 (Fig. 6), but the remarkable correlation between catch fluctuations in SAL and annual rainfal in the Cilacap District (Table 4, 6) corresponds to the maxima and minima in monthly rainfall, as shown in the December 2010–November 2011 study (Fig. 5).

Moreover, the high number of shrimp in SAL, especially in Zone IV, also suggests that *P. monodon* may move/migrate short distances (Table 2, 3). These movement patterns underline three key points about SAL's management: first, greater water flow regulation is increasingly devastating to natural fisheries; second, the benefits of SAL's mangrove forests are felt at considerable distances from their locations; third, mangrove forests, rivers, SAL, and the open sea off the Cilacap region (Indian Ocean) are so strongly linked as already described, that upsetting the region's water regime, which has retained the area's mangrove system and flood cycles, can have considerably negative effects.

CONCLUSION

It's very important to note that, in SAL, rainfall is a very important factor in the distribution, abundance and reproductive success of the *Penaeus monodon*. Furthermore, SAL's mangrove plays an important role in the development and growth of the area's *Penaeus monodon* shrimp populations. This should be interesting for a detailed study of the long-term development of *Penaeus monodon* populations, to characterize their size variations in and around the shrimp's mangrove habitats (cf. Hugesh 1966). Our study also proves that SAL is a very important resource in fisheries (cf. Amin & Hariati 1991).

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