The Ecological Studies of Shrimp Penaeus monodon Fabricius, 1798 (Penaeidae) in The Segara Anakan Lagoon (SAL), Cilacap, Central Java, Indonesia

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Abstract. The purpose of this study was to examine the effect of environmental variables by combining information about the immigration of juveniles during one year. The study of population structure, growth, and morphometric relationships of Penaeus monodon Fabricius in 1798 was carried out in four zones of the Segara Anakan Lagoon (SAL): Zone I (mesotrophic/ in two main rivers Cibereum and Citanduy): Zone II (eutroph/ in the northeastern part of the lagoon): Zone III (eutroph/ in the south-eastern part of the lagoon): Zone IV (mesotrophic/ near the western channel) for one year (December 2016 - January 2017). The average carapace length (CL) during the rainy season was 36.35 mm in October and 28.61 mm in December, reflecting changes in shrimp size in the population. The morphological relationship, in terms of total length (TL, mm) and carapace length (CL, mm) of male and female shrimps were significantly correlated with TL = 15,825 + 3,225 CL (r = 0,960) and TL = 25,462 + 2,897 CL (r = 0,978), each. The allometric equations for carapace length (CL mm) and weight (W, g) are W_{male} = 10^{-3} 2.834 CL^{2.528}, and W_{female} = 10^{-3} 1.520 CL^{2}. The local distribution of the shrimps suggested that the SAL represent an important nursery ground in its life history.

1. Introduction
Segara Anakan is a large lagoon located along the southern coast of Java, Cilacap district, Indonesia, fringed by the large estuarine-mangrove forest left in Java. Segara Anakan Lagoon (SAL) is a semi-enclosed lagoon that consists of the central lagoon as primary and bounded by mangrove forest and tidal land (intertidal) important roles for fisheries. The lagoon is of high ecological and economic value because of its richness and diversity in living natural resources, comprising commercially important fish, crabs, shrimps, and mangrove species. During the last decades, the coastal habitats in this region have been changed as a result of increased urbanization and expansion of agriculture and...
aquaculture activities, leading to problems such as rural encroachment on agricultural land, reclamation of swamps, silt deposition in the lagoon, and a decrease in fishery catches [1] [2] [3].

This area is the only major estuarine-mangrove zone in Java serves as a protective habitat for spawning and represents nursery and feeding grounds for several aquatic organisms such as fish, crustacean, and shellfish, including many commercial species [3] [4] [5] [6] of marine fish and shrimps [1] [7] [8]. An abundance of larvae of commercially important marine fish and shrimps in the lagoon [8] demonstrates the strong ecological links between offshore fishery and lagoon waters, confirming the high value of tropical coastal estuaries for offshore fishery stocks [1] [9]. The shrimp *P. monodon* Fabricius, 1798 (local name udang Windu) is the important commercial shrimp from SAL, and other species of Indonesian waters e.g., [10] [11] [12] [13] [14] [15] [16] [17] [18].

SAL is a unique lagoon, where a lot of rivers enter into the lagoon such as Citanduy, Cibeureum, Cikonde (three major rivers), and small rivers. These rivers bring the sediment materials from upstream to the lagoon areas and are resisted by Nusa Kambangan Island [19]. At present SAL is facing some ecological problems, one of them is sedimentation. The sedimentation that came from Citanduy, Cibeureum, Cikonde Rivers, caused the narrowing of SAL [4] [19] [20] [21] [22]. In (give the year) SAL had around 4603 ha of mangrove areas [reference]. Between 1974 and 1987 the mangrove area decreased by only around 1454 ha due to illegal logging [23] [24]. In 1989, about 16.5 ha of mangrove forest in the SAL had been converted into shrimp ponds [25]. A high rate of exploitation and decline of the SAL areas are presumed to directly impact its animal communities, including fish assemblages and the ecological role of SAL [26]. Moreover, due to the degradation of the mangrove forests in the SAL region [27] [28] [29] and its fast sedimentation [30] [31] [32], caused the spatial distribution and its individual sizes of *P. monodon* is not certain until the present study.

With the increasing catching effort of *P. monodon*, particularly in the SAL since early 1970’s [33] [34], this species previously considered abundant has become declining [35]. During a survey from 1970 to 1985 by the Badan Penelitian Perikanan Laut Jakarta (formerly Badan Riset Kelautan dan Perikanan-Dinas Kelautan dan Perikanan, Jakarta), sufficient numbers of *P. monodon* have been taken seasonally. This survey enables some of the basic morphological characteristics of the species to be measured and for the habitat requirements and local geographic range to be documented [36] [37] [38] [39] [40] [41]. The present study is part of a wider program on the management of SAL and its mangroves, conducted by Badan Pengelolaan Kawasan Segara Anakan (BPKSAn, Cilacap [29], and the commercial marine species in the SAL e.g., *P. monodon* that has long been studied [42].

The aims of the present study were to examine the effects of environmental variables (rainfall, water temperature and salinity, pH, DO, nutrient and turbidity) on the adult (CL > 25 mm) *P. monodon*, and to combine these results with information on the migration of juveniles (CL 3-25 mm) as a means of interpreting changes observed in the structure of the juvenile shrimp population throughout the year.

### 2. Materials And Methods

#### 2.1. Study area

The 12-month’s (December 2016 – January 2017) ecological study of the shrimp, *P. monodon* was done in the four zones of SAL (Figure 1). The climate at SAL is tropical and humid, with the southeast monsoon dry season during the months (April – October) and the northwest monsoon rainy season (November – March). Rainfall during the rainy season exceeds 300 mm/month and falls to 100 mm/month or less in the dry season [43]. Tides are semidiurnal with an amplitude) within the lagoon is 1.48 m on average [44].

The area of the present study was divided into four zones including the SAL. Zone I (mesotroph): Representing the area significantly affected by two main rivers i.e. Cibeurem and Citanduy, where low salinity and relatively high sedimentation were expected (sampling stations at 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 due to freshwater inflow from two rivers i.e. Kawunganten and Muara Dua (sampling stations: approximately 0.9-1.2 km from Nusawere) were expected. 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. High sedimentation was expected at the sampling stations, approximately 1.2-1.5 km from Nusawere). Zone IV (mesotroph) representing the area near the western channel, where the highest salinity (33‰) and relatively low sedimentation were expected due to prevailing strong tidal currents (sampling stations: approximately 0.4-0.7 km from Nusawere) (Fig. 1).

2.2. Procedures

*P. monodon* was caught by *Anco* (a traditional stationed left-net method) [45] and treated as follows:

1. The carapace length (CL, mm) and total length (TL, mm) were measured, to 0.10 ± 0.05 mm, from the postorbital margin to the posterior margin of the carapace; and from the anterior tip of the rostrum to the posterior tip of the telson, respectively; while the weight (W, g) was measured, to 0.10 ± 0.05 g, after excess water has been removed by shaking.

2. The number and size of shrimps that were caught every month depending on the location, the tide, and the depth of water. To provide results, which were representative of the total population, monthly changes in population structure were examined by taking the sum total of all shrimps caught at each station. The growth in wet weight was subsequently calculated from the CL - W relationship.

Additional data on the local distribution of shrimp *P. monodon* in SAL were collected incidentally during field surveys of the Kelompok Kerja Mangroves Nasional team.

2.3. Data analysis

To determine the CL-TL relationships, straight lines were fitted to the raw data for males and females separately using the least squares method [46] [47] [48]:

The least squares method of linear regression analysis involves using the following formulae for a and b in $Y = a + bX$.

$$b = \frac{n\Sigma XY - \Sigma X \Sigma Y}{n\Sigma X^2 - (\Sigma X)^2}$$

$$a = \overline{Y} - b \overline{X}$$

Where $n$ is the number of pairs of data

$\overline{X}$ is the mean X value of all the pairs of data

$\overline{Y}$ is the mean Y value of all the pairs of data

To relate carapace length to the weight of the shrimps, the allometric equation of the form:

$W = a \cdot CL^b$: where:

$W$ = total weight in grams

$a$ = a constant of the relationship represents the intersecting part of the “y” axis

CL = carapace length

$b$ = a constant of the relationship represents the slope of the equation

were fitted to the raw data using log-log regression.
3. Result and Discussion

3.1. Morphological relationships
A total of 6,854 individual of *P. monodon* consist of 3,370 males and 3,384 females were measured for TL, CL, and W. To determine the CL-TL relationships, straight lines were fitted to the raw data for males and females separately using the method of least squares [46] [47] [48] (Figure 2).

![Figure 1](map.jpg)

**Figure 1.** Map showing the SAL and the fourth zones sites [49].

![Figure 2](graph.jpg)

**Figure 2.** The relationship between total length (TL, mm) and carapace length (CL, mm) for male (♂) and female (♀) *P. monodon* in SAL Cilacap, Central Java, Indonesia, December 2016- January 2017.
In order for the carapace length and weight of the shrimp to be known, an allometric equation is used: \( W = a \cdot CL^b \) using log-log regression (Figure 3). The result for male \( P. \text{monodon} \) \( W = 10^{-32.834} \cdot CL^{2.528} \) \((r = 0.89)\) and for the female were \( W = 10^{-31.520} \cdot CL^{2.034} \) \((r = 0.903)\), respectively.

The females (31.15 ± 2.03 mm) in this study had larger mean CL than the males (30.11 ± 1.46 mm), however, the males were slightly larger in both total length and weight than females. This is due to their morphological feature of the bodies [11] [15] [16] [18] [50].

![Figure 3](image.png)

**Figure 3.** The relationship between weight (\(W, \text{gr}\)) and carapace length (\(CL, \text{mm}\)) for male (○) and female (□) \( P. \text{monodon} \) in the SAL, Cilacap, Central Java, Indonesia, December 2016 - January 2017.

Both sets of equations were found to be significantly different at the 0.01 level using analysis of covariance [46] [47]. This difference between the morphology of sexes appears to be a general characteristic of \( P. \text{monodon} \) which is also noted for other shrimp species e.g., \( P. \text{merguiensis} \) de Man, 1888 [17] [18] [34] [38] [42] [50] [51].

The CL-TL and CL-W relationships for \( P. \text{monodon} \) are of interest because of their similarity to those of \( P. \text{merguiensis} \) e.g. [40] [52] [53] [54], a species of which \( P. \text{monodon} \) is most often associated within the mangrove waters in SAL.

### 3.2. Size of adult shrimp

Marked variability was seen in the size of adult shrimps (CL >25mm) (Figure 4). This is in conjunction with shrimp biology to select their nursery area preference [55] [56] [57] [58] [59]. The growth of adult \( P. \text{monodon} \) was strongly influenced by changes in environmental factors (Appendix Table 1). Differences in the size of adult shrimps (see Figure 4), therefore, reflect changes in both size of shrimps present in the SAL at the time of migration and the strength of the stimulus to migrate [60] [61] [62] [63]. At times, during high rainfall (more than 100 mm/month), the size of adult shrimps found was 31.01 ± 3.562 mm, and at times low rainfall (less than 50 mm/month), the size of adult shrimp tended to be larger, viz. 31.974 ± 3.870 mm, and statistically to be different \((\chi^2 = 3.84, p<0.05)\). It is not known whether the adult shrimp were actively leaving the SAL or were simply being flushed out of the lagoon during the period of high rainfall. There is a strong positive relationship between...
rainfall and commercial adult shrimps [60] [61], probably due to flushing from the mangrove habitat as a result of heavy rain, as it was in SAL (R² = 0.956). However, a large member of relatively small-sized shrimps (mean CL ranging from 28.606 ± 3.310 mm, n= 50 in December 2016 to 30.670 ± 3.514 mm, n= 86 in February 2017) were found to be abundant in the SAL during the wet season of 2016-2017. It is suggested that rainfall was a very important factor for the migration of adult *P. monodon* in SAL. The extent and health of coastal mangrove wetlands are positively correlated with shrimp (*Penaeus* spp.) yield which coincided with [13] [64] [65] [66] [67] [68], statement in adjacent waters.

**Figure 4.** Size of adult *P. monodon*, Fabricius, 1798 at the time of study period in SAL, Cilacap, Central Java, Indonesia, December 2016 – January 2017. Vertical bars indicated a 95% confidence limit of the means.

### 3.3. Population structure: seasonal changes in population structure

The population was changed seasonally from July to December, 454 individuals of large size (give the size), and from February to April, only 210 individuals of large size (give the size) were collected (Fig. 4). All belong to subadult and adult shrimp categories, indicating that the population structure of shrimp *P. monodon* occurs in their nurseries [69]. The seasonal pattern of adult distribution was given in Figure 5.

During the month (October and November 2016) of high rainfall of more than 100 mm, the lower size limit remained relatively constant at 28.146 to 28.619 mm CL, but the upper limit decreased steadily from 31.915 to 31.435 mm CL by November 2016. During the dry season, it was recorded that a gradual increase in lower and upper size limits of CL followed by monthly rainfall less than 50 mm that was found in July to September 2016. The sex ratio of population (1.05) greater than 1.00 remained at 1:1 over the year (X² = 6.63, p = 0.01).

The monthly size-frequency data analysis indicated that the population structure demonstrated much more clearly the dynamic changes, which occurred in the population during this study. Moreover, represent a recruit population; cf. [70]. Large year-to-year variations in yield characterize all “Penaeid” shrimp populations although those species, which use estuaries as nursery areas for the juvenile phase, fluctuate [71] [18].

### 3.4. Growth

Growth in CL for the December-February (DF) period (Figure 6a), for March-May (MM) period (Figure 6b), for the June-August (JA) period (Figure 6c), and September-November (SN) period (Figure 6d) was essentially linear over the periods considered, with an average increase in CL of 7.80 mm per week (TL 3.80 mm/day). Water temperatures during the four periods were almost similar
(mean temperature DF: 28.80 ± 0.399°C, MM: 29.27 ± 0.344°C, JA: 28.30 ± 0.801°C, and SN: 28.67 ± 1.753°C), salinity had almost constant during the September-November period (22.748 ± 0.877‰) (Figure 6d).

The differences in growth rate between the four periods suggest that the differences in salinity have an influence on growth. At intermediate salinities, the densities of shrimp *P. monodon* are highest, suggesting that the local distribution of juveniles within the SAL study area are strongly influenced by salinity, cf. [72] [73]. In addition, as the shrimp grows, they may eventually leave the mangroves. The population sample of shrimp indicated that 4.149 individuals per ha were found in the mangroves but only 2,705 individuals per ha in the adjacent mudflats [74] [75] [76] [77] [78]. However, biomass was approximately the same in both areas, suggesting that larger individuals move out of the mangroves. The length-weight relationship for the adult *P. monodon* was $W = 10^{-2} 1.6728 CL^{2.0284}$. By substituting for $CL$ in the linear growth equation $CL = 27.6426 + 0.4512T$ (Figures 6abcd) where $T$ is time in week, the growth in weight of adult *P. monodon* was $W = 10^{-2} 1.6728 (27.6426 + 0.4512T)$ 2.0284.

3.5. Habitat and spatial distribution

The first survey by BPPL had recorded the shrimp species as mangrove dependent [35], Cilacap District (1988–2002). Our observation in 1985, e.g. [39] [79] to 2004 indicated that juveniles were abundant in mangroves than in the adjacent mudflat waters at Cikeperan, and that the mature specimens captured during the mangrove study were from areas close to Cikeperan [79].

*P. monodon*, from SAL, has been collected from a depth of 5 m in Madjingklak [37] an area close to the Indian Ocean by the Nusawere. Simultaneously, a number of juvenile banana shrimps (*P. merguiensis*), another mangrove-dependent species were also captured. This is suggesting that juveniles of Penaeidae shrimp species (primarily *P. monodon* and *P. merguiensis*) are common in SAL mangroves. However, since the lagoon received considerable sediment particles from the upland, the shrimp captured appears likely to vary in size. These may have resulted from local movement of adult, juvenile and pelagic larvae of both shrimp species (*P. monodon* and *P. merguiensis*) due to the turbid water with clay particles, e.g., [62] [63].

At SAL, the monthly surveys conducted during the study period can be used to delineate the distribution of *P. monodon* stock, also recorded 173 individuals of *P. merguiensis* de Man, 1888. Of these, 79 individuals were taken from depths of 5–7 m at east of Karang Anyar, and 94 individuals were taken in depths of 7-10 m along the Cikeperan borders of the major traditional fishing ground.

In most of the surveys where *P. monodon* was taken, the by-catch contained a large number of mud crabs, *Scylla serrata* (Forskål, 1775) suggesting that these locations are typified by an abundance of mangrove dependent species, e.g., [81]. In addition to these records, juvenile (CL: 3–25 mm) *P. monodon*, were also captured occasionally. These observations on catches of *P. monodon* and the catch of associated benthic fauna suggest that a variety of benthic communities in addition to Anco (a traditional method stationed left net) mangrove areas suitable for adults (CL >25 mm) habitat for the *P. monodon*.

Of additional interest is the spatial relationship between *P. monodon* and *P. merguiensis*. In surveys of SAL, *P. monodon* was most frequently taken from locations along the mangrove border of the *P. merguiensis*’s nursery grounds, e.g. [21] [76] [80] [81]. Although the distributions of these two species in SAL were not completely separate, significant overlapping of the two populations appears to be presented by the requirements of *P. monodon* for a habitat containing a relatively muddy sandy clay habitat preferred by *P. merguiensis*.

Since the habitat types required by both juvenile and adult of *P. monodon* and *P. merguiensis*, occur along with the SAL and associated small islands i.e. Karang Anyar, it appears likely that *P. monodon* will be ultimately recorded from most of these areas when exploratory “Anco” occurs. For
these reasons, it is suggested that the mangrove forests in SAL should be conserved, and rehabilitation of the forest and a reforested option should be implemented immediately.

Figure 5. Monthly size (carapace length – CL, mm) frequency distribution for adult *P. monodon* in SAL, Cilacap, Central Java, Indonesia, December 2016 – January 2017.
Figure 6. Growth in carapace length (CL, mm) of adult *P. monodon* shown together. With temperature (°C) and salinity (‰) values for the periods: a. December-February period (West monsoon = WM); b. March-May period (Transition period I = TP-1); c. June-August period (East monsoon = EM); d. September-October period (Transition period II = TP 2).

3.6. Influence of habitat

The major habitat in the SAL is (i) depositional areas of soft fine sediment (silty clay substrate) associated with pioneer mangrove species (*Avicennia* spp. and *Sonneratia* spp.) with less than 2 m depth, and (ii) Lagoon habitat opposite the mangrove forest, which is characterized by sandy clay substrate cf. [52] [53] [82]. These habitats are suitable for *P. monodon* juveniles to live in since they will provide nutrition and shelter from predators. SAL is a complex environment with water depths ranging from 10 to 15 m, therefore provides a variety of niches for *P. monodon* (Table 2) cf. [71] [82] [84] [85].

The shrimp *P. monodon*, is also a burrower, but burrowing activity is size-dependent and increases as the animal grows, e.g. [18]. Table 1 showed that shrimp *P. monodon* occurs in both habitats. This is indicated that both habitat types support the burrowing activities, cf. [82] [85] [86] [87]. Therefore, adult shrimp were found in varying number in both habitats (Table 2), and although large catches were occasionally taken in waters of 10-15 m depth, shrimps generally favor the soft mud (silty clay substrate) immediately in front of the mangrove fringe ($F_{1, 12} = 9.33, p <0.01$). The density of shrimps in the second type of habitat was consistently lower, implying that adult shrimp *P. monodon* selected habitat preference.

Table 1. Distribution of adult *P. monodon* in two different habitat types in the SAL during the study period.

| Month          | Habitat Type          | Total | CL (mm) Silty Clay substrate | CL (mm) Sandy Clay substrate |
|----------------|-----------------------|-------|-----------------------------|------------------------------|
| December 2016  | 49 Silty Clay substrate 1 Sandy Clay substrate | 50     | 18.98 - 26.98               | 0.39 - 0.56                  |
| January 2017   | 49 Silty Clay substrate 0 Sandy Clay substrate | 49     | 18.98 - 22.98               | 0 - 0                        |
| February       | 73 Silty Clay substrate 13 Sandy Clay substrate | 86     | 18.98 - 42.98               | 3.33 - 7.65                  |
| March          | 48 Silty Clay substrate 2 Sandy Clay substrate | 50     | 18.98 - 22.98               | 0.79 - 0.96                  |
| April          | 16 Silty Clay substrate 58 Sandy Clay substrate | 74     | 18.98 - 26.98               | 0.19 - 0.13                  |
| May            | 74 Silty Clay substrate 1 Sandy Clay substrate | 75     | 18.98 - 26.98               | 0.26 - 0.37                  |
Table 1 suggests that *P. monodon* have different preferences or tolerances to sandy-clay and silty-clay substrates. The shrimp *P. monodon* is a common inhabitant of estuarine and mangroves areas [88] [89] [90]. The shrimps are known to inhabit mangrove estuaries at the SAL as juveniles (3–25 mm CL), and migrating offshore on the assumption that they feed on mangrove detritus e.g., [91] [92]. Based on the size (17.10-59.00 mm CL) (Subadult-Adult) and growth of adult, *P. monodon* in the SAL generally migrates back to Indian Ocean through Nusa Tenggara were after attaining a size of more than 41.10 mm of CL. Furthermore, the local variation in catches of adult shrimp can be related, at least on semi-quantitative basis, to some obvious regional variations in rainfall (one or two years).

A positive correlation between rainfall and commercial shrimp catch has been reported e.g., by [93] [94] [95] [96]. In these studies, the catch of *P. monodon* in SAL was related to the rainfall within a given year and related to the combined rainfall of the preceding 15 years. Hence, apart from shrimp abundance, rainfall’s immediate effect affected the shrimp *P. monodon* reproductive success, recruitment of post-larvae, growth, and survival of all life-history stages. As a result, other biological and environmental factors can be shown in (Appendix Table 1) on the production of juvenile shrimp *P. monodon* as the basis of continuing growth in the SAL.

4. Conclusions

Mangrove habitats and shrimp populations are tightly linked in many regions, as it was in SAL. Analyses of commercial shrimp catches have shown that the SAL supports a small Penaeid shrimp fishery. The main species caught in SAL, in order of importance, are *P. monodon*, *P. merguensis*, and *P. semisulcatus*. However, solid evidence is still recommended to be investigated and a field to be studied in detail, although limited correlation results point to an existing relationship between mangrove forests and fisheries. A strong correlation between abundance and biomass of *P. monodon* and extent of the surrounding mangrove areas in the SAL indicated that the areas are a nursery habitat for juvenile *P. monodon* (CL 3–25 mm). The presence of juveniles in the mangrove area is more abundant than in SAL proved that mangrove is a primary habitat.

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References

[1] Ardli ER and Wolff M 2009 *Reg Environ Change* 9 235–43
[2] Ardli ER and Wolff M 2008 *Asian Journal of Water, Environment and Pollution* 5 59–67
[3] Triyanti R, Wijaya RA, Koeshendrajana S and Priyatna FN 2010 *J. Bijak dan Riset Sosek* 5 31–46
[4] Pribadi R 2003 Pusat kajian pesisir dan laut tropis lembaga penelitian Universitas Diponegoro, Semarang
[5] Saputra SW, Sukimin S, Boer M, Affandi R and Monintja DR. 2005 Jurnal Ilmu Kelautan. 10 41 – 49
[6] Widiyanto B, Sastranegara MH and Ismangil 2013. Seminar Nasional Biologi 22 Perhimpunan Biologi Indonesia (Purwokerto) 1-7
[7] Paw JN, Chua TE 1991 Marine Pollution Bulletin 23 779-83
[8] Staples DJ 1989. UNESCO-IOC Workshop Report 64 41
[9] Naamin N 1982 Proceeding of the workshop on coastal resources management in the Cilacap region (Gajah Mada University Yogyakarta) 51-6
[10] Naamin N 1991 ICLARM Contribution 552 119-30
[11] Dall W 1957. Aust. J. of Mar. freshwater. Res. 8 136-231
[12] Macnane W 1974. Mangroves and fisheries. FAO Rome 35
[13] Soegiarto A, Toro AV and Soegiarto KA 1979 Udang Lembaga Oceanolog LIPI eds Soegiarto A, Toro AV, Soegiarto KA (Jakarta) pp 245
[14] Motoh H 1981 SEADEC Technical Report 7 1-128.
[15] Dall W 1985 A review of penaeid prawn biology research in Australia eds Rothlisberg P.B, Hill BJ and Staples DJ (Cleveland, Queensland Australia) 11-21
[16] Rothlisberg PC, Hill BJ and Staples DJ 1985. Second Australian National Prawn Seminar eds Rothlisberg, PC, Hill, BJ and Staples DJ (Cleveland Australia) pp 368
[17] Hill BJ 1987 Biology of penaeid prawns in northern Australia. CSIRO Marine Laboratories (Cleveland, QLD Australia) pp 190 +xii
[18] Harty C 1997 Mangroves in New South Wales and Victoria (Commonwealth of Australia) pp 47
[19] Ardli ER 2007 Spatial and Temporal Dynamics of Mangrove Conversion at the Segara Anakan Cilacap, Java, Indonesia eds Yuwono E, Jennerjahn T, Sastranegara MH and Sukardi P (Research Institute University of Jenderal Soedirman, Purwokerto) 61-70
[20] Jennerjahn T, Holtermann P, Pohlenga I and Nasir B 2007 Environmental conditions in the Segara Anakan Lagoon, Java, Indonesia eds Yuwono E, Jennerjahn T, Sastranegara MH, Sukardi P, Yuwono E, Jennerjahn T and Sastranegara MH (Research Institute University of Jenderal Soedirman, Purwokerto) pp 28-32
[21] Ismail Sulistiono, Sigid H and Madduppa H 2018 AACL Bioflux 11 1055-068
[22] Sastranegara MH and Marhaeni B 2005 Penebangan mangrove di Segara Anakan Cilacap. Seminar Nasional Biologi dan Akuakultur Berkelanjutan dalam rangka (Dies Natalis UNSOED ke-42 di Fakultas Biologi UNSOED Purwokerto) pp 19
[23] Sastranegara MH, Yuwono E and Sukardi P 2007 Illegal logging of mangroves in Segara Anakan, Cilacap: A conservation constraint eds Yuwono E, Jennerjahn T, Sastranegara MH and Sukardi P Synopsis of ecological and socio-economic aspects of tropical coastal ecosystem with special reference to Segara Anakan (Research Institute University of Jenderal Soedirman, Purwokerto) 21-7
[24] Nuryanto A and Susanto AH 2010 Biotropia 17 22-30
[25] Setijanto and Rukayah S 2016 Omni Akuatika 12 13–21
[26] Sukardjo S 1984a The Leeds Symposium (UK) 53-67
[27] Sukardjo S 1984b Mangrove ecosystem eds TE-FPIPB Ecological aspects of Segara Anakan in relation to its future management (Institute of Hydraulic Engineering in cooperation with Faculty of Fisheries BAU, Bogor) 54-71
[29] Badan Pengelolaan Kawasan Segara Anakan (BPKSA) 2006. *Lokakarya Nasional Pengelolaan Ekosistem mangrove* (Jakarta) pp 16

[30] TE-FPIPB 1984 *Ecological aspects of Segara Anakan in relation to its future management* (Institute of Hydraulic Engineering in cooperation with Faculty of Fisheries BAU Bogor) pp 97 + 26 App.

[31] Napitupulu M and Ramu KLV 1982 *Development of the Segara Anakan area of Central Java* eds Birds ECF Soegiarto A and Soegiarto K *Proceeding of the Workshop on Coastal Resources Management in the Cilacap Region* (LIPI Jakarta and the UNU Tokyo) 66-82

[32] Purba M. 1991. *Impact of high sedimentation rates on the coastal resources of Segara Anakan, Indonesia* ed Chou LM (ICLARM Contribution) 552 143-152

[33] Toro AV and Djamali 1978 *Mimeograph* pp 21

[34] Annual Report of the Fisheries Service, Cilacap district 1988-2002 *Fisheries report statistics. Unpublished Report*

[35] Toro AV and Sukardjo S. 1987 *Substrat udang windu Penaeus monodon Fabricius di perairan mangrove Segara Anakan Cilacap* ed Anantawirya S and Notosudarmo S *Prosiding Seminar Ilmiah Ekologi Tanah dan Ekotoksikologi* (UKSW Press, Salatiga) 42-61

[36] Toro AV and Sukardjo S1988b *Perairan mangrove Segara Anakan Sumber perikanan dan habitat udang Penaeidae* ed Jangkaru Z *Prosiding Seminar Nasional Perbenihan Ikan dan Udang*. (Badan Litbang Pertanian dan Universitas Padjadaran Bandung) 454- 481

[37] Toro AV and SukardjoS1990 *J. Mar. Biol. Ass. India* 32 150-53

[38] Toro AV and Sukardjo S 1995 *Badan Penelitian dan Pengembangan Pusat Penelitian dan Pengembangan Perikanan* (Jakarta) 496- 521

[39] Rao RM and Gopalakhasin V1970 *Proceedings IPFC 13th Session, Brisbane* 128-31

[40] Villaluz DK, Villaluz A, Ladrera B, Sheik M and Gonzaga A1972 *J. of Sci.* 983-4

[41] Toro AV and Sukardjo S 1992 *Mimeograph* pp 19

[42] Tomascik T, Mah AJ, Nontji A and Moosa MK1997 *Periplus Editions* Part II chapter pp 13-23

[43] White AT, Martosubroto P and Sadorra MSM 1989 (ICLARM Technical Reports on Coastal Area management) 25.

[44] Subani W. 1985. Alat tangkap traditional di Indonesia (LPPL Jakarta)

[45] Snedecor GW and Cochran WG 1986 *Statistical methods* (Iowa State University Press, Ames) pp 90

[46] Sokal RR and Rohlf FJ 1981 *Biometry: The Principles and Practice of Statistics in Biological Research* (W. H. Freeman) pp 859

[47] Sokal RR and Rohlf FJ 1995 *Biometry: the principles and practice of statistics in biological research* (Freeman: New York) pp 887

[48] Dall W1968 *FAO Fish. Rep.* 57 251- 58

[49] Vance DJ, Haywood MDE, Heales DS and Staples DJ 1996a *Marine Ecology Progress Series* 135 43-45

[50] Vance DJ, HaywoodMDE, HealesDS, Kenyon RA, Loneragan NR and Pandrey RC. 1996b. *Marine Ecology Progress Series*. 131 114-24

[51] Branford JR1981a *Estuarine Coastal and Shelf Sciences* 13 349-54

[52] Branford JR 1981b *Coastal and Shelf Sciences* 33 473-76

[53] Rönnbäck P, Bryceson I and Kauntsky N 2002 *Ambio* 31 537-42

[54] Motoh H and Buri P 1984 *Res.Crust.* 13 1-120, 79 figs

[55] Hall DNF 1962 *Fish. Publ. Colon. Lond.* 17 1-229

[56] Hugesh DA 1966. *J. Appl. Biology* 3 349-54

[57] Subbrachmanyan M 1966 *Fluctuations in prawn landings in the Godavari estuarine systemProceeding of the Indo-Pacific Fish Council* 11 44-51
[58] Joshi PK, Kulkarni GK and Nagabhushanam R 1979. *Hydrobiologia* 65 195-98
[59] Rulfison RA 1981 *Contributions in Marine Science* 24 35-52
[60] Freitas AJ de1986 *Estuarine, Coastal and Shelf Science* 23 901-08
[61] Staples DJ 1980a *Austr. J. Mar. Freshwater Res* 31 635-752
[62] Staples DJ 1980b *J. Mar. Freshwater Res* 31 653-65
[63] Dall W 1981 *J. of Exp. Mar. Biol and Ecol* 54 55-64
[64] Buckworth RC 1992 *Aust. J. Mar. Freshwater Res* 43 879-912
[65] Paw JN and Chua TE 1989 . *Mar. Pollut. Bull.* 20 335-43
[66] Martosubroto  P and Naamin N 1977 *Marine Research in Indonesia* 18 81-6
[67] Lee SY 2004 *Marine Biology* 145 943-49
[68] Manson FJ, Loneragan NR, Harch BD, Skilleter GA and Williams L 2005a *Fish. Res* 74 69–85
[69] Loneragan NR, Adnan NA, Connolly RM and Manson FJ 2005 *Estuarine, Coastal and Shelf Sciences* 63 187-200
[70] Primavera JH 1998 *Estuarine, Coastal and Shelf Science* 46 457-64
[71] Rajendran N and Kathiresan K. 1999 *Hydrobiologia* 349 193-200
[72] Kirkegaard I 1975 *Observations on Penaeids larvae around Australia* ed. Young PC First *Australian National Prawn Seminar* (Australian Government Publication Service, Canberra) 54-59
[73] Mohan R, Selvam V and Azariah J 1995 *Hydrobiologia* 295 183-91
[74] Chong VC, Sasekumar A and Lim KH 1994 *Distribution and abundance of prawn in a Malaysian mangrove system* (eds Sudara S Wilkinson CRand Chou IM Proceedings of Thirds ASEAN-Australian Symposium on Living Coastal Resources (Ihula Long Corn University, Bangkok, Thailand) 2 437-44
[75] Chong VC, Sasekumar A, Leh MUC and D’Cruz R 1990 *Estuarine, Coastal and Shelf Science* 31 403-722
[76] Sasekumar A, Chong VC, Leh MU and D’Cruz R 1992 *Hydrobiologia* 247 195-207
[77] Toro AV and Sukardjo S 1988a *Penelitian tentang penangkapan, pemijahan dan recruitment udang windu P. monodon Fabricius di perairan mangrove Segara Anakan Cilacap*. ed Jangkaru Z, *Prosiding Seminar Nasional Perbenihan Ikan dan Udang*. (Badan Litbang Pertanian dan Universitas Padjadjaran Bandung) 644-671.
[78] Sukardjo S 2008 *Sustaining Ocean Productivities, Maritime Communities and the Climate* (Kuantan Malaysia) pp 24
[79] Suwarso and Wasilum 1991 *The crab fishery around the mangrove areas of Segara Anakan Cilacap Java Indonesia* ed, Chou LM *Towards on Integrated Management of Tropical Coastal Resource* (ICLARM Contribution) 552 57-64
[80] Wassenberg TJ and Hill BJ 1993 *Fish.res.* 17 343-52
[81] Primavera JH 1997 *Journal of Experimental Marine Biology and Ecology* 215 205-16
[82] Robertson AI 1988 *Aust. J. Mar. Freshwater Res* 39 467-78
[83] De Graaf GJ and Zuan TT 1998 *Mangroves and Salt Marshes* 2 159-66
[84] Manson FJ, Loneragan NR, Skilleter GA and Phinn SR 2005b *Oceanogr. Mar. Biol. Ann. Rev.* 43 483–513
[85] Kathiresan K. Moorthy P and Rajendran N 1994 *Indian journal of marine sciences* 23 168-69
[86] Kathiresan K and Bingham BL 2001 *Advances in Marine Biology* 40 181-251
[87] Rajendran N 1997 *Ph.D Thesis Annamalai University, India* pp 131
[88] Sheridam PF and Hays CG 2003 *Wetlands* 23 449-58
[89] Subramanayan M and Ganapati PN. 1975 *Bull. Dept. Mar. Sci. Univ. Cochin.* 7 653-70
[90] Robertson AI and Blaber SJM 1992 eds Robertson AI, Alongi DM (Wanshington DC, USA) pp. 173-224
[91] Daniel PA and Robertson AI 1990 *Estuarine, Coastal and Shelf Science* 31 599-619
[92] Lee SY 1995 *Hydrobiologia* 295 203-12
[93] Gunter G and Edward JC 1969 *FAO Fish Rep.* 57 875-92
[94] Staples DJ, Vance, DJ and Loneragan NR 1995 *Penaeid prawn recruitment variability: effect of the environment* eds A.J. Courtney and M.G. Cosgrove *Proceedings of the Workshop on Spawning Stock-Recruitment Relationships (SRRs) in Australian crustacean fisheries* (Brisbane, Queensland Australia) pp 41-50
[95] Pratiwi R and Sukardjo S 2018 *Biotropia* 25 156-69.
### Appendix Table 1. Simple correlation matrix, r for 19 selected environmental and growth parameters, *Penaeus monodon* Fabricius in the SAL, during the study period December 2016-November 2017. Key to Table: Significance level for p = 1% and 5% are 0.661 and 0.532, respectively. N= number of individuals, Wt.= total weight (g), W= average weight (g), TL= total length (mm), CL= carapace length (mm), AL= length of abdominal segments (mm), Tel= telson length (mm), CD= carapace depth (mm), HH= number of day rain, R= rainfall (mm), T= temperature (°C), S= salinity (%o), O= oxygen, P= Phosphate (PO4, ppm), N= nitrogen (NO3, ppm), N2= nitrogen (NO2, ppm), SiO3, pH, Tu= turbidity (ppm).

|         | N      | Wt     | W      | TL     | CL     | ABL    | TeL    | CD     | HH     | CH     | T'C    | S%o    | O2     | PO4    | NO3    | NO2    | SiO3   | pH     | Tu     |
|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| N       | -      | 0.940  | 0.418  | 0.236  | 0.281  | 0.431  | 0.369  | 0.169  | 0.154  | -0.739 | -0.518 | 0.137  | 0.669  | 0.306  | 0.686  | 0.031  | 0.317  | -0.068 |
| Wt      | 0.687  | -      | 0.498  | 0.511  | 0.685  | 0.424  | 0.135  | -0.656 | -0.364 | -0.426 | 0.098  | -0.604 | 0.590  | 0.075  | 0.592  | -0.389 | 0.338  | -0.065 |
| W       | 0.881  | 0.172  | 0.910  | 0.709  | 0.071  | -0.083 | -0.317 | 0.615  | 0.283  | 0.185  | -0.246 | 0.156  | 0.044  | 0.457  | 0.067  | 0.352  | 0.352  |
| TL      | 0.283  | -0.309 | 0.897  | 0.286  | 0.152  | -0.071 | 0.270  | 0.021  | -0.509 | -0.135 | -0.648 | -0.164 | 0.733  | 0.360  | 0.125  |        |        |        |
| CL      | 0.912  | -      | 0.604  | 0.170  | 0.074  | -0.174 | -0.092 | -0.239 | -0.338 | -0.266 | 0.286  | -0.266 | -0.142 | -0.158 | -0.096 |        |        |        |
| AL      | 0.480  | -      | 0.030  | -0.118 | -0.250 | -0.105 | -0.016 | -0.347 | 0.063  | -0.497 | -0.048 | 0.588  | 0.239  | -0.058 |        |        |        |        |
| Tel     | 0.561  | 0.016  | 0.217  | -0.130 | 0.408  | 0.048  | -0.574 | 0.168  | -0.287 | 0.092  | 0.755  | 0.366  | 0.123  |        |        |        |        |        |
| CD      | -      | 0.015  | 0.099  | 0.150  | 0.045  | -0.260 | 0.276  | 0.375  | -0.297 | 0.385  | 0.312  | 0.035  |        |        |        |        |        |        |
| HH      | -      | 0.487  | 0.171  | 0.230  | 0.230  | 0.165  | 0.786  | 0.547  | 0.804  | 0.195  | 0.059  | 0.562  |        |        |        |        |        |        |
| R       | 0.546  | -      | 0.846  | 0.532  | 0.689  | 0.545  | 0.154  | -0.352 | 0.120  |        |        |        |        |        |        |        |        |        |
| S       | -      | -0.293 | -0.095 | -0.533 | -0.472 | -0.549 | -0.340 | -0.147 | 0.159  |        |        |        |        |        |        |        |        |        |
| O       | -      | -0.132 | 0.181  | 0.029  | 0.155  | -0.081 | 0.673  | 0.774  |        |        |        |        |        |        |        |        |        |        |
| P       | 0.113  | -      | 0.192  | -0.069 | 0.741  | 0.238  | 0.212  |        |        |        |        |        |        |        |        |        |        |        |
| N       | -      | 0.771  | 0.691  | -0.069 | 0.016  |        |        |        |        |        |        |        |        |        |        |        |        |        |
| N2      | -      | 0.432  | 0.244  | -0.20  |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| pH      | -      | -0.213 | -0.165 |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Tu      | -      | 0.377  | -      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |