Notes

An Ecological Study of the Mantis Shrimp *Lysiosquilla macutala* Fabricius (Crustacea: Stomatopoda) in the Reef Flat, Pari Island, West Java, Indonesia: 1. The Relationship Between Environmental Factors and Mantis Shrimp Population

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Abstract

Lysiosquilla maculata Fabricius, mantis shrimp population density and size distribution were studied in 37 different transects of the reef flat from May 1994 - March 1998 (46 months) in order to determine relationships between the densities and size distribution of the *L. maculata* and 21 different physical-chemical parameters of their substrates and water. Site plots at 20 m to 120 m from the reef edge exhibit significantly higher population densities (mean density: 62/ha to 71/ha). Lower population densities were found at the site plots about 170 m to 220 m from the reef edge (mean density: 37/ha to 43/ha). The reef flat habitat of Pari Island had clear population fluctuation with four peak densities in January in 1995, in 1996, in 1997 and January in 1998 of the West Monsoon. On the reef flat the mantis shrimp grew up to a total length (TL) 390 mm. This higher sizes (TL: 390 mm) of mantis shrimp were found in June 1996 and 1997 at the area of about 50 m from the reef edge only. A total length of 132.15 mm which is first seen in November of the Post Monsoon, represent as lower size to the population. Higher population density and higher size of mantis shrimp are related to waters having high concentrations of total Carbon organic and nitrates. The mantis shrimp was absent from the coral reef flat where very low levels of phosphates and nitrates were observed. These studies indicate relationships between water and sediment quality, and densities of mantis shrimp. A positive correlation between area of distribution and biomass, and biomass with the density indicates the rarity of mantis shrimp in the reef flat.
Key words: Pari island, mantis shrimp, population, reef flat, environmental parameters.

Introduction

The stomatopods, or mantis shrimps, include some 300 species of relatively large (5-35 cm) predatory crustaceans. They occur primarily in the tropics, although a few are found in temperate waters. Most occupy burrows in benthic sediments, or crevices in rock or coral,

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from which they may emerge to feed or swim (BARNES 1980, MAUCHLINE 1984), occasionally congregating in swarms near the surface.

The reef flat on the Pari Island represents a habitat of marine living resources, includes crustacean stomatopods and fishes. The great varieties of species (fishes, phytoplankton, zooplankton, meroplankton and benthic fauna) found in the seagrass bed of the reef flat shown that this ecosystem is a very productive site for marine biota (HUTOMO and MARTOSEWOYO 1977, HUTOMO and DJAMALI 1980, NONTJI *et al*. 1980, ROMIMOHTARTO and JUWANA 1995). TORO (1979) has noted the occurrence of 28 species of mangrove crustaceans associated with coral reef along the Pari island coast, and 21 species of the echinoderm (ROBERT and DARSONO 1984). Only specialized animals are capable of with standing the physical stresses existing in the reef flat environment, such as sand abrasion and unstable substrate (See: DARSONO *et al*. 1978, AZIZ *et al*. 1980, AZIZ 1981, REAKA and MANNING 1981, ROBERT and DARSONO 1984, SUKARDJO and TORO 1988). Most of the animals found in such habitats are proficient burrowers and very diversified (SNELLING 1959, MACNAE and KALK 1962, TRUEMANS 1968, ABELE 1974). There are many factors which may control or influence density and diversity in these reef flat resources. For conservation biologists, the study of the distribution and abundance of organisms in the reef flat of Pari Island acquires a special meaning.

Ecology has been defined as the study of the distribution and abundance of animal and plant species (ANDREWARTHA and BIRCH 1965, KREBS 1985). Distribution can be quantified by the number of sites in which a species is present (HANSKI 1982, GOTELLI and SIMBERLOFF 1987), or on the bio-geographical scale by the area of the distributional range (RAPOPORT 1982). Abundance refers to local population density, the number of individuals that are found in a given site (BROWN 1984).

To date, ecological work on Pari Island crustacean stomatopods has been surprisingly scant. These burrowing animals found in the reef flat habitat of Pari Island are mostly relatively small in size. The mantis shrimp, *Lysiosquilla maculata* Fabricius is a species of Crustacean (Stomatopoda) that is most commonly found in the reef flat zone and is an important source of sea-food. Mantis shrimp, *L. maculata* is distributed along the coast of the Pari Island and in the favorable sites it’s found to be abundance (TORO and SUKARDJO 1992, 1989, SUKARDJO and TORO 1987). Components of the environment which might be important in determining the distribution of these mantis shrimp are substratum, food, salinity, exposure or tides, and other animals.

In Pari Island, this mantis shrimp is of considerable interest chiefly because of its commercial economic potential, and abundance up to a distance of 400 m from the reef edge (TORO and SUKARDJO 1992, 1989). It can also develop enormous population densities (up to 475 individual/ha) (TORO and SUKARDJO 1989) in the unstable environment of the reef flat.

Despite their apparent significance in the traditional fishery and the marine food web, no attempt has yet been made to survey systematically in Indonesia, nor to investigate any aspects of their population biology. In our serial reports on the aspect of population ecology of the mantis shrimp *L. maculata* concern more to the general pattern of their abundance and size distribution. The present study pays particular attention to the effect of various physical-chemical parameters of the substrate on the abundance and size distribution of this mantis shrimp. The objectives of this study were:

1. to determine annual variation in the various parameters measured,
2. to measured the abundance and size distribution of *L. maculata* in the reef flat, and
3. to determine if the parameters measured could be related to the different population densities and total length (TL, mm) size distribution.

Materials and Method

Study site

The Pari island group is located about 35 km north-west of Jakarta (Fig. 1). It has a reef flat surrounding the island, and its sand is composed mainly of coral fragments and calcium carbonate materials, quartz and igneous rock fragment, and terrigenous rock fragments. The study area is located on the south shore of Pari island with a shoreline of about 5.92 km.

Pari Island is a pseudo-atoll, and has been studied by some research workers e.g., DARSONO (1977) studied sessile benthos of this coral island, SUHARSONO and SUKARNO (1983) investigate the zooxanthella content the stony coral, SUKARDJO and TORO (1987 and 1988) reported nutrient status of mantis shrimp (*L. maculata*) and stony crab (*Thalamita crenata* Latreille) substrates in the reef flat, respectively, while a phenologiocal study of *Rhizophora stylosa* Griff. of this island has been done by SUKARDJO *et al*. (1987), AZKAB and SUKARDJO (1987) dealing with the structural characteristic of mangrove seedling community in the reef flat, and SUHIRMAN *et al*. (1987) studied of the marine wood borers in the Pari Islands waters. Fish inventory and their abundance has been done by HUTOMO and MARTIOSEWOYO (1977) and HUTOMO and DJAMALI (1980), and for molluscans fauna by SOEMODIHARDJO (1974). Primary productivity of phyto-plankton in the coral reef waters in Pari Island has been investigated by NONTJI *et al*. (1980).

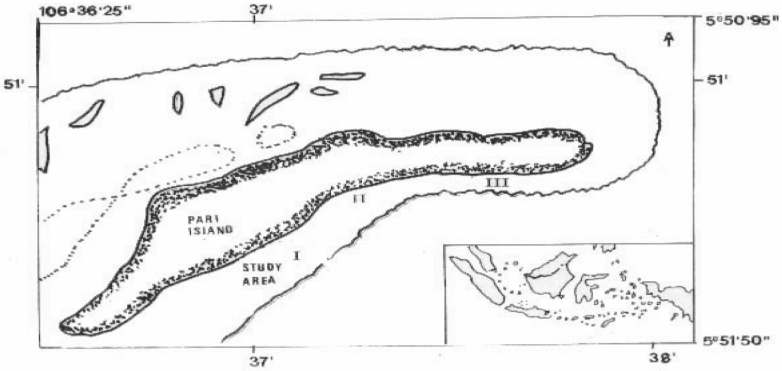

Fig. 1. A map showing the aproximate study plot in the reef flat of Pari Island

Sampling

At the reef area (site 1-III), 37 transect lines (12 transects in site I, 12 transects in site II and 13 transects in site III) running perpendicular to the shoreline were laid systematically from sea edge to reef edge throughout the entire reef flat zone with a distance between each transect of 50 m. In each transect at 10 m interval, 100 m^2 quadrates (10 m x 10 m) were placed to the left and right of transects. In every quadrate, mantis shrimp found in their holes were captured by using traditional fishing stick. They were measured using dial caliper and weighed with a triple beam balance.

Physical-chemical parameters

Water and substrate samples were collected from every hole of mantis shrimp during low ride. Water temperature in every mantis shrimp hole was taken with a Celsius thermometer and salinity was measured with a refracto-salinometer.

The physical and chemical properties of the water and substrate samples were performed by the Department of Natural Sciences, Bogor Agricultural University, Bogor.

The slope of the reef flat in the study site was determined by using an inclinometer. Period of wave splash was recorded using a stop-watch and wave height at its breaking point was measured with a calibrated meter stick. Measurements were made at monthly intervals at all sites.

Data analysis

A two factors analysis of variance was used to test for differences between season, years and sites for each variable (SOKAL and ROHLF 1981, SNEDECOR and COCHRAN 1986). The variation between the size distributions of the populations was tested for significance using goodness of fit chi square comparison (SIMPSON *et al*. 1980).

Results

Mantis shrimp, *L. maculata* Fabricius population density

The density and biomass of mantis shrimp in the three sites at different seasons during the period of study are presented in Table 1. There are referred to as individual per ha. Table 2 shows the significant correlation between density of mantis shrimp and selected environmental factors of their habitat. The density also correlate positively with biomass (r= 0.951-0.991; P<0.01), and the biomass with the site plots distribution in transects (r=0.921-0.989; P<0.01) (Table 2).

The density of population of *L. maculata* differs clearly between 1994, 1995, 1996, 1997 and 1998 ($F_{4, 41}$ = 2.665; P<0.05) and the population was significantly larger in 1994 ($t_{0.001, 41}$ = 2.630; P<0.001) apparently due to a higher shrimp number during Post Monsoon (September-November) and December of the 1994 (Fig. 2). The highest densities were recorded at the high rainfall of the West Monsoon with 150 individuals per ha in January 1995 (Fig. 2). Density remained high until May 1995 (45 individuals per ha), they declined

Table 1. Density per hectare (D), biomass per ha (B, kg) of mantis shrimp, *Lysiosquilla maculata* Fabricius in the coral reef flat of Pari island

Season	Site							
	I		II		III		Total	
	D	B	D	B	D	B	D	B
West Monsoon (December - February)	78	11.720	94	12.696	88	11.720	260	36.136
Pre Monsoon (March -May)	64	10.948	76	11.915	70	10.949	210	33.811
East Monsoon (June -August)	46	7.031	50	7.680	38	6.711	134	21.422
Post Monsoon (September - November)	70	11.254	78	12.058	74	11.522	222	34.834
Total	258	40.953	298	44.349	270	40.902	826	126.203

Table 2. Correlation and significant levels between density of mantis shrimp, *Lysiosquilla maculata* Fabricius and selected environmental factors and biomass, and biomass with number of plots distribution in the reef flat of Pari island **: significant level 1%.

Density (D) compared	r	Regression equation
D vs substrate-Sand	0.895**	Y= 86.297 + 0.218X
D vs substrate-N total	-0.786**	Y= 0.4070 - 0.0053X
D vs substrate-Salinity	-0.945**	Y= 34.187 - 0.079X
D vs waters-DO	-0.882**	Y= 3.0495 - 0.0007X
D vs waters-Temperature	0.985**	Y= 23.723 + 0.069X
D vs Frequency of wave splash per month	-0.788**	Y= 228.6248 - 0.4056X
Site I: D vs biomass	0.951**	Y= 0.157 + 0.229X
Site II: D vs biomass	0.952**	Y= 0.120 + 2.141X
Site III: D vs biomass	0.991**	Y= 0.148 + 0.390X
All sites: D vs biomass	0.991**	Y= 0.148 + 0.391X
Site I: Biomass vs plots	0.989**	Y= 0.065 + 143.675X
Site II: Biomass vs plots	0.978**	Y= 0.021 + 148.796X
Site III: Biomass vs plots	0.921**	Y= 0.058 + 139.026X

sharply to 9 individuals per ha in April.

Population density also varied significantly among season. Differences between 4 seasons were consistent from the 3 sites of the 46 months study ($F_{season: 3, 6} = 49.44$; $P<0.001$) (Table 3). The monthly changes in population densities of mantis shrimp during 46 months observations are presented in Figure 2. The change in population densities causes by change in reef flat profiles or by changes in their occurrence and/or distance from the reef edge caused by tidal fluctuation are shown in Table 4. It indicates the number of mantis shrimp perpendicular to shoreline extending from above high water mark into the surf zone. Table 4 further suggests that population density differs substantially between the reef edge ward and shorelines ward of the reef flat. A rank correlation between mean density and site distance from the reef edge is highly significant ($F_{sites: 2, 8} = 90.29$, $P<0.01$; $F_{distances: 4, 8} = 1023.46$, $P<0.001$) (Table 5). The population of mantis shrimp in the reef flat area has a specific zonation in terms of their local density and biomass (Table 4).

L. maculata inhabited the reef flat from the edge to shorelines of the Pari Island. Site

Table 3. ANOVA of parameters and densities (Significant F statistics are underline)

Parameter	Factor	F	df	P
Densities	Seasons	49.44	3; 6	<0.001
	Sites	3.96	2; 6	>0.05
Sand	Seasons	32.24	4; 8	<0.001
	Sites	1.47	2; 8	>0.05
Salinity	Seasons	220.11	4; 8	<0.001
	Sites	16.30	2; 8	<0.001
Water temperature	Seasons	2.014	3; 6	>0.05
	Sites	0.403	2; 6	>0.05
DO	Seasons	1.492	3; 6	>0.05
	Sites	1476.67	2; 6	<0.001
Splash period	Seasons	48.225	3; 6	<0.001
	Sites	43.879	2; 6	<0.001
C organic	Seasons	1.829	4; 8	>0.05
	Sites	4.792	2; 8	<0.05
N total	Seasons	222.222	4; 8	<0.001
	Sites	74.074	2; 8	<0.001
Available P_2O_5	Seasons	50.465	4; 8	<0.001
	Sites	4.806	2; 8	<0.05
P_2O_5 total	Seasons	16.683	4; 8	<0.001
	Sites	8.112	2; 8	<0.05
PO_4 (waters)	Seasons	125	3; 6	<0.001
	Sites	110.42	2; 6	<0.001
NH_4-N (waters)	Seasons	15.09	3; 6	<0.01
	Sites	12.05	2; 6	<0.01
NO_3-N (waters)	Seasons	3.21	3; 6	>0.05
	Sites	15.44	2; 6	<0.01

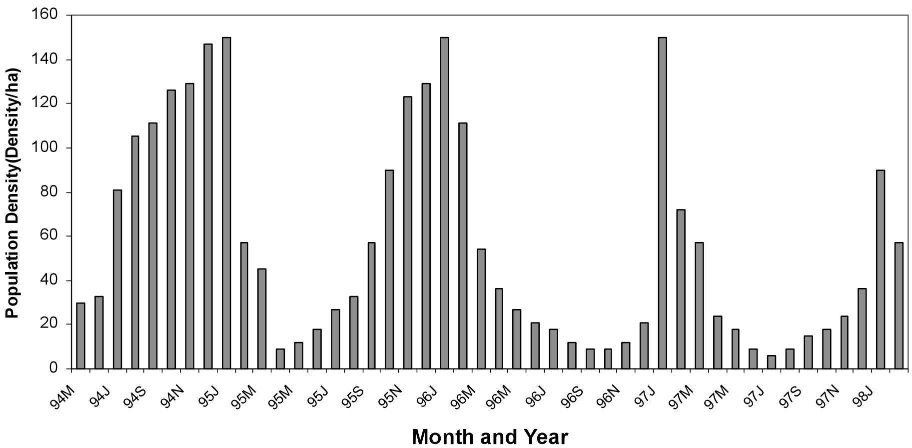

Fig. 2. Population density/ha (D) of mantis shrimp, *Lysiosquilla maculata* Fabricius and their peaks in the reef flat of Pari Island.

Table 4. The density per ha (D) and mean biomass (MB, g) of mantis shrimp, *Lysiosquilla maculata* Fabricius according to their distance from the reef edge

Distance from the reef edge (m)	Site Area					
	I		II		III	
	D	MB	D	MB	D	MB
20	75	145.068 (27.648)	86	148.822 (28.362)	79	140.875 (29.077)
70	58	150.172 (27.667)	66	150.925 (17.621)	60	140.982 (27.622)
120	52	151.522 (27.731)	60	151.875 (27.795)	54	151.068 (27.696)
170	44	157.739 (28.136)	51	153.441 (28.092)	46	151.331 (28.101)
220	29	160.918 (29.450)	35	153.725 (28.362)	31	153.545 (28.101)
Total	258	153.084 (28.126)	298	151.176 (25.925)	270	147.560 (28.119)

Values in parentheses are standard deviation.

Table 5. ANOVA for table 4 (Significant F statistics are underline)

Parameter	Factor	F	df	P
Densities	Sites	90.29	2; 8	<0.001
	Distances	1023.46	4; 8	<0.001
Biomass	Sites	5.06	2; 8	<0.05
	Distances	6.22	4; 8	<0.05

II exhibits higher population densities of mantis shrimp than those in sites I and III. Here an average of 298 shrimps per ha was observed. This number is rather high when compared to 258 shrimps obtained in Site I and 270 shrimps in Site III (Table 1). Clearly that population density also varied among sites. During the period of 46 months, typical fluctuations were noted in the population of *L. maculata* (Fig. 2) viz. from May 1994 to January 1995 increased smoothly and than decreased sharply up to April 1995, and then increased smoothly again up to January 1996, then decreased up to September 1996. From November 1996 increased drastically up to January 1997, and then decreased sharply up to July 1997. This is an indication that the population consists of different body size classes (TL, total length) of the mantis shrimp.

Forty-sixth months observations show that the lower population of mantis shrimp with 12 shrimps per ha was observed in April 1995, September 1996, and than only 9 shrimp per ha appeared in October 1996 and increased again in November 1996 when a population having a 132.15 mm TL with abundance class 10% (Figure 3). TL range class of 130-150 mm of mantis shrimp had the peaks abundance in June 1994 (40%), in December 1995 (16%), in December 1996 (14%) and in November 1997 (20%) (Fig. 3).

Mantis shrimp, L. maculata Fabricius biomass and body size (TL, total length) frequency

Fig. 3 illustrates the relative frequency distribution of size intervals of the data obtained for monthly collection in sites I to III populations. On the Pari island reef flat the mantis shrimps grew up to TL 390 mm. This was observed during June 1996 and June 1997. The relation between total length (X, mm) and fresh weight (Y, g) on a Log/Log basis

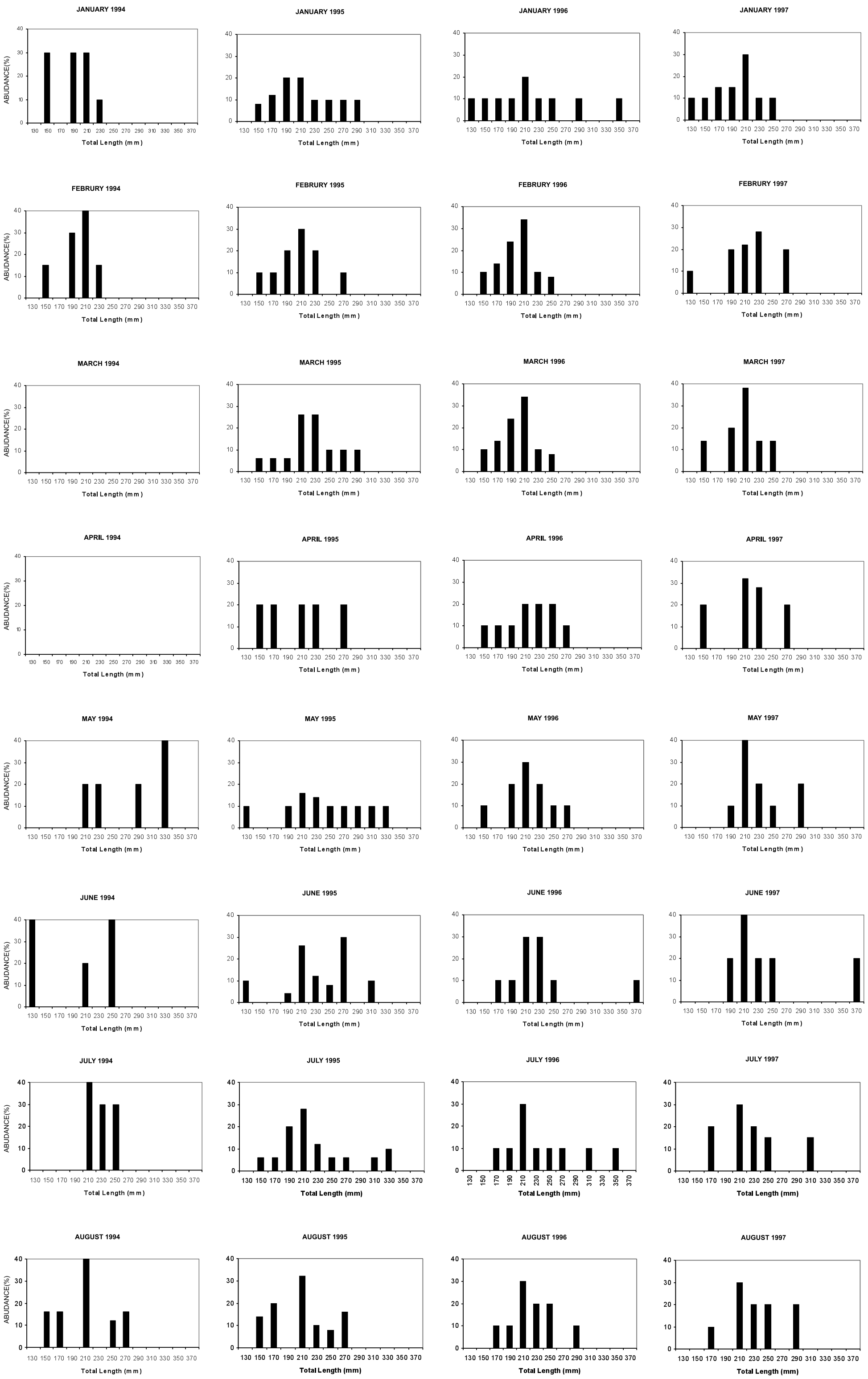

Fig. 3. Size frequency graphs of *Lysiosquilla maculata* Fabricius colleted at reef flat, Pari Island

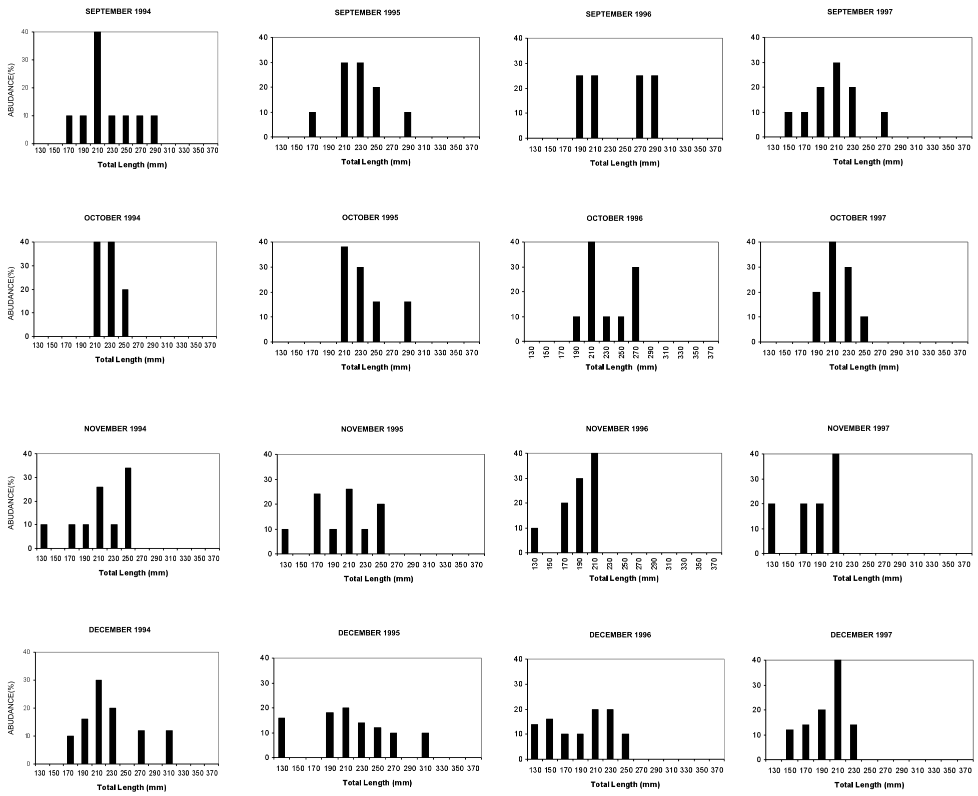

Fig. 3. Size frequency graphs of *Lysiosquilla maculata* Fabricius colleted at reef flat, Pari Island. (Contd.)

the equation is straight line of Y= -3.995 + 2.609X (r = 0.970).

Total biomass of each season is shown in Table 1 and a mean biomass in term of their occurrences from reef edge is presented in Table 4, and both closely parallel density. Biomass was highest (Total = 36.136 kg/ha) in the sample of West Monsoon (Table 1). Figure 3 shows the size frequency curves for 46 months examined. The size of mantis shrimp to the population was first seen at a total length (TL) of 132.15 mm in June and November for 1994. This is represents the lower TL size of mantis shrimp during the study period. The peak number of these individuals was recorded in June 1994 and November 1997. The first class interval (TL 130-150 mm) showed individual discontinuity of the mantis shrimp. Individuals with TL class of 210-230 mm were present in all months, and with TL class of 370-390 mm only present in June 1996 and 1997 (Fig. 3).

Physical factors

In the reef flat of Pari Island the wave height averaged 0.25 m (± 0.02). In the study area typically by seagrass bed (site II), waves were found to be the smallest, having a mean height of 0.09 m (+ 0.01). The most intense wave action was found on the north Coast of Pari Island. Here, the higher waves were those of site III which measured an average of 0.38

m (± 0.03). In site I the mean wave height was observed to the 0.19 m (+ 0.01). The wave splash period in the habitat of *L. maculata* was found to be very stable through time. Average measures ranged from 5.0 s for site I to 6.3 s for site III. Seasonally, the frequency of wave splash per hour are high during the West monsoon season (December - February) (199 ±14.49) and lower during the East monsoon season (June - August) (174 ±12.67) (Table 6).

The monthly temperature fluctuation of substrate of *L. maculata* was not greater than 2℃. A high extreme of 32.9℃ (±1.678) was recorded during July-August (dry season) at the East monsoon season (Table 6).

Water quality factor

The highest salinity of 33.50‰ (± 0.35) was recorded during the extreme dry season in July. The lower level, 29.5‰ (± 0.55) was measured during high rainfall in December. Seasonal fluctuations of salinity in the substrate of mantis shrimp are shown in Table 6. Characteristically, the salinity values along transects, at the three sites (I, II and III) are presented at Table 7. Geomorphology and tides are dominant variables determining the distribution of salinity and circulation within the reef flats.

Phosphates (PO_4) values up to 0.1906 ppm were mostly obtained during the rainy season (West Monsoon: December-February), while the lowest values (0.1406 ppm) were recorded in March to May and during the first month of the East Monsoon (June) (Table 6).

The levels of NO_3-N, NO_2-N and NH_4-N of water in the shelter were obtained up to 3.6697 ppm, 0.0709 ppm and 0.0390 ppm respectively, were observed during West Monsoon, whereas concentration rose again to previous levels during Post Monsoon (Table 6).

Lower Dissolved Oxygen (DO) value (2.945 ± 0.477 ppm) was obtained frequently during East Monsoon, while greater concentrations (2.995 ± 0.485) were measured mostly during Post Monsoon (Table 6). Along the transect DO values in every site increased considerably with increasing their distance to the seaward.

Habitat factor

Along the transects, the particle size analysis shows that the habitat of mantis shrimp, *L. maculata* was sandy bottom with coarse sand as a dominant fraction (90.96-96.47%) (Table 7). Seasonally, the sand fraction was high in the substrate with values ranged from 90.96% (±0.296) to 95.40% (±0.402) (Table 6). Coarse sand was distributed throughout the reef flat area and there were no differences in sand content amongst sites (Table 3) but different between the seasons ($F_{season\ 4,\ 8}$ = 32.24; $P<0.001$) (Table 3). Homogenous sand is the primary habitat of mantis shrimp.

The highest concentration of the C organic matter content in the reef flat was of 4.70%, it was obtained in site II. Site I and site III obtained lower concentrations viz. 2.68% and 2.36% respectively. The highest extreme of 4.95% was obtained in site III during the Pre Monsoon, while lowest concentration of 1.75% was measured in site I during West Monsoon. The average values of C organic matter seasonally are presented in Table 6, and

Table 6. Mean value of selected environmental factors in the habitat of *Lysiosquilla maculata* Fabricius on the reef flat area during the study period (Mar 1994-February 1998)

Environmental Factor		Season			
		West Monsoon (December - February)	Pre Monsoon (March - May)	East Monsoon (June - August)	Post Monsoon (September - November)
Water in Shelter	PO_4 (ppm)	0.1936 (0.0164)	0.1406 (0.0141)	0.1606 (0.0191)	0.1809 (0.0141)
	NH_4-N (ppm)	0.03945 (0.0033)	0.0375 (0.0036)	0.0340 (0.0037)	0.0315 (0.0030)
	NO_3-N (ppm)	3.6211 (0.5370)	3.5979 (0.5650)	3.4697 (0.1045)	3.1657 (0.4970)
	NO_2-N (ppm)	0.0709 (0.0108)	0.0707 (0.0107)	0.0706 (0.0108)	0.0696 (0.0106)
Substrate	Sand (%)	93.40 (0.407)	95.40 (0.402)	90.96 (0.296)	94.96 (0.414)
	C organic (%)	2.10 (0.225)	2.59 (0.277)	2.68 (0.288)	2.35 (0.215)
	N Total (%)	0.35 (0.042)	0.30 (0.061)	0.30 (0.076)	0.29 (0.059)
	Available P_2O_5 (ppm)	22.582 (1.104)	14.627 (3.593)	13.388 (1.592)	18.358 (2.910)
	Salinity (‰)	31.838 (1.547)	32.094 (1.559)	32.762 (1.592)	31.900 (1.550)
	Temperature (C)	31.50 (1.607)	30.50 (1.556)	32.90 (1.678)	28.50 (1.454)
Waters	DO (ppm)	2.975 (0.482)	2.985 (0.483)	2.945 (0.477)	2.995 (0.485)
	Frequency of wave splash per hour	199 (14.49)	176 (12.82)	174 (12.67)	198 (7.14)

Values in parentheses are standard deviation.

Table 7. The average values of physical-chemical properties of the habitat of mantis shrimp *Lysiosquilla maculata* Fabricius along transect during the study period (May 1994 to February 1998)

Environmental Parameter	Site	Distance from the sea edge/coastline (m)				
		20	70	120	170	220
Sand (%)	I	96.47 (2.73)	90.96 (2.57)	90.96 (2.57)	90.70 (2.56)	90.20 (2.55)
	II	95.92 (2.04)	92.92 (1.98)	91.96 (1.96)	91.50 (1.95)	90.92 (1.94)
	III	95.40 (1.93)	92.40 (1.87)	92.40 (1.87)	91.40 (1.85)	90.40 (1.83)
Salinity (‰)	I	30.91 (0.74)	31.27 (0.75)	31.93 (0.76)	32.45 (0.77)	32.70 (0.78)
	II	30.95 (0.73)	31.57 (0.74)	32.07 (0.76)	32.51 (0.77)	32.85 (0.77)
	III	31.17 (0.67)	31.84 (0.72)	32.09 (0.72)	32.76 (0.74)	32.96 (0.74)
C organic (%)	I	2.97 (0.67)	2.97 (0.72)	2.87 (0.72)	2.66 (0.74)	2.61 (0.74)
	II	4.69 (1.35)	3.06 (0.88)	2.96 (0.85)	2.68 (0.77)	2.35 (0.68)
	III	2.52 (0.04)	2.10 (0.43)	1.22 (0.05)	2.57 (0.07)	2.10 (0.07)
N Total (%)	I	0.21 (0.05)	0.21 (0.05)	0.30 (0.07)	0.30 (0.07)	0.35 (0.08)
	II	0.74 (0.21)	0.83 (0.05)	0.91 (0.16)	0.98 (0.35)	0.95 (0.10)
	III	0.18 (0.04)	0.19 (0.04)	0.22 (0.05)	0.29 (0.07)	0.29 (0.07)
Available P_2O_5 (ppm)	I	3.52 (2.10)	8.36 (4.91)	14.63 (8.59)	22.39 (9.15)	22.39 (9.15)
	II	4.08 (2.22)	8.61 (4.70)	15.09 (8.23)	22.54 (9.29)	20.16 (9.99)
	III	3.04 (2.30)	5.91 (4.47)	6.23 (3.70)	21.63 (9.34)	18.01 (9.61)
Total P_2O_5 (ppm)	I	54.24 (9.21)	81.36 (5.32)	81.36 (9.32)	88.42 (9.65)	92.72 (9.46)
	II	61.74 (8.21)	83.83 (9.15)	83.91 (9.16)	89.08 (9.85)	83.48 (9.10)
	III	46.02 (9.20)	57.53 (9.98)	24.59 (9.26)	85.93 (9.84)	74.84 (9.22)

Values in parentheses are standard deviation.

their fluctuation values in the three sites along the transect are given in Table 7.

Statistical analysis

ANOVA statistical tests indicated significant differences between seasons for densities, biomass, sand, salinity, splash period, N total, available phosphorous, total phosphorus, PO_4 (waters), and NH_4-N (waters) (Table 5). Significant differences between sites were detected for salinity, DO, splash period, organic C, total nitrogen, available phosphorous, total phosphorous, PO_4 (waters), NH_4-N (waters) and NO_3-N (waters) (Table 3).

Discussion

The habitat of mantis shrimp (*L. maculata*) in the reef flat area always receives wave energy. Consequently, the proportion of coarse sand in particular site will be changes considerable (Tables 6, 7). Also, the coarse sand found in the study area is related to a very exposed beach receiving the wave energy. Here, *L. maculata* must be stressed by the influence of these environmental conditions (Table 2). Direct positive relationship was found between this sand and water temperature parameters with densities of the mantis shrimp ($Y = 86.297 + 0.218X$; $r = 0.895$ and $Y= 23.723 + 0.069X$; $r = 0.985$; $p<0.01$), and negative correlation with other substrate condition (Table 2). Table 2 also suggests that mantis shrimp have different sandy substrate preferences or tolerances.

Mean wave splash values in the reef flat zone were all within the range of the ecological preference for locations that the mantis shrimp lives in (SUKARDJO and TORO 1992, TORO and SUKARDJO 1989), e.g., for the density of mantis shrimp ($Y= 228.6248 -0.4056X$; $r = -0.788$, $p<0.001$) (Table 2). In this study results do not show any evidence of population which has been reported by PURWANTO (1987), to cause mortalities of *L. maculata*. The changes of densities of mantis shrimp (*L. maculata*) presented in Tables 1 and 4 more correspond to the sand content in their particular habitat. A 2-way ANOVA showed significant differences in the density and biomass of mantis shrimp between sites ($F_{site\ 2,\ 8} = 90.29$; $P<0.001$, and $F_{site\ 2,\ 8} = 5.05$, $P<0.05$), and between distance ($F_{distance\ 4,\ 8} = 1023.47$; $P<0.001$; $F_{distance\ 4,\ 8} = 6.22$; $P<0.05$) (Table 5).

The variation of salinity levels were recorded in the habitat of *L. maculata* was associated with the high amount of rainfall in this area (SUKARDJO *et al*. 1987). The salinity values and their variation during the study period are favorable for the *L. maculata* lives as expressed in their densities ($Y= 34.187 - 0.079X$; $r = -0.945$) (Table 2). And, their peaks density occurs during West Monsoon in January (Figure 2). The salinities recorded during the study were of similar range to those found for the *R. stylosa* seedling plots in the reef flat area by KISWARA *et al*. (1984) and SUKARDJO *et al*. (1987), and for the stony crab, *Thalamita crenata* Latreille habitat (SUKARDJO and TORO 1988); however, a high values of 35.50‰ (SD= 0.35) was observed in the *L. maculata* habitat during July (East Monsoon). Its could be possibly be due to reading error in the refractometer, because this did not affect the densities of *L. maculata* recorded in this month (July). Table 6 shows values of low magnitude but more marked seasonal variations. It is due to the fact that Pari Island is greatly influenced by severe changes in environmental conditions caused by the monsoon season.

Mantis shrimp reached a maximum size of 389.90 mm TL during June 1996 and June 1997 of East Monsoon (Fig. 3). In the East Monsoon, C organic at the substrates was higher (2.68 ± 0.288 %) and DO of the waters almost constant (2.945 ± 0.477) (Table 6). C organic is of considerable importance for *L. maculata* since this stomatopods are predator. ANOVA test demonstrated the support for that statement (Table 5). C organic values (2.10 ± 0.23% to 2.68 + 0.29%) are of almost similar magnitudes to those reported for habitats of stony crab *Thalamita creanata* Latreille (2.68 ± 0.29%) (SUKARDJO and TORO 1988) and lower than the fringe mangroves habitats (3.10 ± 0.59%) in the west side of Pari island (AZKAB and SUKARDJO 1987).

The concentration of most of the water quality parameters in the shelter of *L. maculata* tends to be low (Table 6). The primary reasons for this are stability of the water column observed in the shelter during the low tide. Increasing value of that water quality parameter in the shelter is possibly associated with the decomposition of organic materials. It was recorded that highest concentration of the organic matter was in site II (4.70%) and the lowest in both site I (2.58%) and III (2.35%). The concentration of organic material among season in the habitat of *L. maculata* was 3.25 + 0.78%. This value were of high magnitudes compared to the habitat of fringe mangroves (1.805 + 0.346%) obtained by AZKAB and SUKARDJO (1987). Secondly, the burrowing activity of *L. maculata* in the reef flat area may strongly affect the substratum topography, granulometry and substrate chemistry, and water in the shelter (Table 6). Finally support their own occurrences in the plot sites (Tables 1, 4). It is clear from the large number (abundance class: 16-40%) of local individual distribution records that sizeable mantis shrimp population with TL 210-230 mm occurs along the coast of Pari Islands for all over the 46 months study (Fig. 3). These trends was similar for stomatopods, *Pterygosquilla armara-capensis* (= *Squilla armata*) reported by MANNING (1969) from the west coast of South Africa.

During the period of study, the most conspicuous change in density was observed in June 1994, when the *L. maculata* mostly belong to the 130-150 mm TL size class, when the density changed from 30 to 33 mantis shrimps per hectare (Fig. 2). In East Monsoon, the values of nutrient concentrations were low than the West and Pre Monsoon seasons (Table 6). This condition might have not helped in the establishment of *L. maculata* population in the reef flat, as indicated by their negative relationship with total nitrogen in the substrate (Y= 0.3070-0.0053X, r = -0.786) (Table 2). The variation of density per hectare per season (Table1) seems to be related to environmental changes during the monsoon period (Table 3). But the *L. maculata* population did not show conspicuous density peaks in the East Monsoon during the study period (Figure 2) although the most abundant site was in the area zone closed to the reef edge (Table 4). In these areas, the maximum abundance is higher than in the other sites. The high abundance of *L. maculata* in this site also possible related to waters having higher concentration of C organic (2.25 ± 0.699% to 4.69 ± 1.348%)

(Table 7). These high levels of C organic supply the food necessary to maintain the biomass of the population. As it was happen for the stony crab *T. crenata* biomass in the west side of the island (r = 0.964, p<0.01) (SUKARDJO and TORO 1988). The lower biomass of *L. maculata* in the areas closed to reef edge mostly due to the present of the predator viz. *Portunus pelagicus* Linnaeus. Significantly lower levels of phosphorus (3.04-4.06 ppm) and nitrogen (0.21-0.74%) (Table 7) were observed in the area closed to the coastline, where lower densities of *L. maculata* were found throughout the study areas (site I: 29-44 shrimps per ha, site II: 35-51 shrimps per ha, site III: 31-46 shrimps per ha) (Table 4). This is coincide with the statement of EPPLEY *et al*. (1973) and GOLDMAN *et al*. (1979) that in the tropical sea waters, the lack of available P and N for photosynthetic organisms has commonly been considered the major restraint on the biomass, resulting in a very low density of organisms.

Fig. 3 explained the population condition in terms of total length (TL, mm) throughout the study period. Also, the relationship between TL (X, mm) and fresh weight (Y, g) on a Log/Log basis is straight line of Y= -3.995+ 2.609X (r = 0.970). These are an indication that mantis shrimp with 132.15 mm TL and/or the TL size class of 130-150 mm of the *L. maculata* population can be considered as young population measured. The young population in the reef flat of Pari Island, measured by increase in the absolute frequency of the 130-150 mm TL class not consisted (Fig. 3). The *L. maculata* population with 130-150 mm TL class never exceeded more 20% in total population of mantis shrimp recorded during the period of study, except for June 1994 (40%). From February to October 1996 the mantis shrimp population of 130-150 mm TL size dropped to 0%. The appearances of this TL group of individuals shrimp during November 1996 correspond to the death of the young mantis shrimp since they did not appear in February 1996. No conspicuous young population was observed in the reef flat of Pari Island. But individuals' mantis shrimp with TL 132.15 mm become more abundant during West Monsoon, where the concentration of nitrogen and phosphate of water in the shelter (NH_4-N, NO_3-N, NO_2-N) and in substrate (N total and available P_2O_5) are high (Table 6). ANOVA of these parameters also demonstrated highly support the mantis shrimp densities (Table 3).

In the coral reef flat of Pari island, *L. maculata* seems to spawn seasonally since mantis shrimp with TL 132.15 mm and/or 130-150 mm TL class were observed most of the time throughout the West monsoon (December to February). The first spawning season recorded in November. During the period of study this seasonal spawning has been observed from 11 months in the reef flat area of Pari Island (Fig. 3). In these populations of mantis shrimp with 130-150 mm TL size appear in any other months, viz. June (1994 and 1995), May (1995) and April (1996) during the study period. A very high density per hectare of *L. maculata* of more than 132.15 mm TL size (and/or 130-150 mm TL class) occurred during the first month of East monsoon (June 1994). Moreover, no causal relationship has been shown for the absence of a well defined spawning period in the reef flat area of Pari Island. Even though the Pari Island is located in the tropical zone, their more defined settlements in the reef flat zone seems to be associated with favorable salinity levels (28.50-32.76‰), proportion of sand contents in the substrates (90.96-95.50%) and nutrient concentration

(Table 1). The salinity range in Pari Island are similar trend to those found in the two tropical sandy beaches in southwest India, and favorable for burrowing animals (ANSELL *et al*. 1972)

In site II, where the population was more abundant (Tables 1, 4) and where the highest levels of C organic (2.55 $\pm$ 0.68 to 4.69 $\pm$ 1.35%) (Table 7) were observed, *L. maculata* grew to a length of 389.90 mm TL or to an average biomass of 148.83 g (SD = 27.98) (Table 4). This could be due to the influence of both high nutrient (Table 7) and high organic matter (4.70%) levels recorded on this site.

Observation in site I and site III show that *L. maculata* grew up to the TL class of 370-390 mm, but has a mean biomass of less than was observed in site II. Both sites (I and III) have lower organic matter values (I : 2.68%, III : 2.36%) and are more stressed by physical factors (higher wave, bigger grain size). According to these observation there seems to be relationship between C organic content of the substrate and the maximum size (TL 390 mm) reached by the mantis shrimp. Statistical analyses show that the maximum size of *L. maculata* correlated significantly with the organic materials (1.81 $\pm$ 0.063%) in the substrate at the 1% level. The reef flat of Pari Island is mostly stressed by physical factors and also by limited food availability. A positive correlation between biomass and site plots distribution in transect at 3 sites demonstrated that food available have some influence on biomass (Site I: $Y_{Biomass} = 0.065 + 143.675\ X$, r = 0.989; Site II: $Y_{Biomass} = 0.021 + 148.786X$, r= 0.979; Site III: $Y_{Biomass} = 0.058 + 139.026X$, r= 0.921). A positive correlation between biomass and density has been demonstrated for mantis shrimp during the 46 months study (Table 2). Also regression analysis showed that larger mantis shrim (TL= 370-390 mm) tend to have lower densities and wider distributional range in reef flat of Pari island. Biomass, that are related to local density and area of distribution are not independent of body size, e.g. TL. Biomass therefore, has a strong effect on rarity of mantis shrimp in the reef flat of Pari Island. Rarity of mantis shrimp, *L. maculata* is clearly associated with body size, e.g. TL. Therefore, widespread mantis shrimp 130-150 mm TL with low densities in the suitable habitat for population growth and development constitute a complex situation, and need further detail studies seasonally (cf. Table 3).

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