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Effect of different harvesting practices on the dynamics of *Paphia textile* (Gmelin 1792) (Bivalvia: Veneridae) populations at two sites in Zamboanga del Norte, Southern Philippines

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Abstract

Paphia textile Gmelin is a commercially-important bivalve clam in Zamboanga Del Norte, Philippines. In two municipalities, different fishing methods are practiced by *Paphia* fishers. Hookah diving is widespread in Manukan while only free-diving is allowed in Roxas. Higher degree of human disturbance was experienced by the *P. textile* population in Manukan. Some aspects of growth, mortality and recruitment were studied to assess the impacts of the fishing activities. Asymptotic length (L_∞) was higher in Roxas (69.95 mm) compared to that in Manukan (67.90 mm). Growth coefficient (K = 1.00 year^{-1}) values were similar in both clam beds. Estimated fishing mortality was high in Roxas (F = 2.65 year^{-1}) but it appeared that the clam bed can still sustain the fishery. Recruitment in Manukan showed two seasonal pulses while one main recruitment pulse was derived in Roxas. Significantly higher ($P < 0.05$) clam density and more larger-sized individuals were observed in Roxas. The estimated maximum sustainable yield in Roxas was 9.36 times higher than in Manukan. Environmental conditions were similar in both clam beds. Differences in the dynamics of *P. textile* populations in the clam beds were influenced by density-dependent processes enhanced by the degree of human exploitation.

Key words: catch per unit effort, fishing pressure, *Paphia textile*, population biology, Venus textile clam.
Abbreviations: CPUE, catch per unit effort; E, exploitation rate; F, fishing mortality; K, growth coefficient; L_∞, asymptotic length; M, natural mortality; MSY, maximum sustainable yield; VBGF, von Bertalanffy growth function; Z, total mortality; $\bar{B}$, average annual biomass.

Introduction

The venerid bivalve *Paphia textile* (Gmelin), commonly known as the Venus textile clam, is an important commercial species in the central and southern Philippines. Its meat is consumed locally and abroad, while the empty shells are utilized for shellcraft. Paphia fishery is a major source of livelihood, particularly in the coastal waters of Sorsogon (Soliman et al. 1999), Negros Occidental (Villarta, Del Norte-Campos 2010), Cebu (Ilano et al. 2007), Samar and Leyte (Germano et al. 2003) and Zamboanga Del Norte (Naguit, Campiseño 2009).

P. textile is an infaunal filter-feeding clam commonly found in the sandy-muddy bottoms of the intertidal and sublittoral zones of the coastal environment (Poutiers 1998). This bivalve has a solid, equivalve, inequilateral shell with beige to pale yellow external color banded with greyish brown zigzag lines (Naguit et al. 2004). It is dioecious but does not exhibit external sexual dimorphism. Spawning of *P. textile* is year-round with 40-mm shell length size at first maturity (Ilano et al. 2007). *P. textile* exhibits negative allometric growth (Cesar et al. 2003).

In the province of Zamboanga Del Norte, *P. textile* has been harvested in the municipal coastal waters of Manukan and Pres. Manuel A. Roxas (Roxas). Two different types of fishing practices are observed in clam beds of each municipality. *Paphia* fishers in Manukan practice hookah diving while harvesters in Roxas use free-diving in their operations.

Hookah divers use air compressor to aid breathing underwater, and hence, they can stay longer below surface. This method is very efficient, and can yield a considerable volume of catch per operation. In Cebu, hookah divers harvest an average of 200 kg day^{-1} of *Paphia* (Dacles 1996). Free-divers do not use any breathing apparatus. Instead, the diver must hold his breath while harvesting the clams. On average, a diver can hold his breath for one minute underwater (Cesar et al. 2003). Accordingly, the diver must dive several times during operation to harvest a marketable volume of catch. In Leyte, free-divers of *P. textile* have mean catch range of 5.07 to 12.53 kg fisher^{-1} day^{-1} (Cesar et al. 2006).

The local government of Roxas has imposed a total ban for hookah operations for several years. From this time, only manual diving is practiced in the Venus textile clam beds of this municipality. On the other hand, the clam beds of the nearby town of Manukan are the harvesting havens for hookah divers. There is no local legislation prohibiting hookah diving in this municipality. Since the free-divers cannot compete with the hookah divers, only the latter operate in the area.

The uniqueness in the fishing practices of the two municipalities presents an opportunity to examine the impacts of the fishery on *P. textile* stocks. Potential effects of the harvesting activities on the dynamics of *P. textile* populations are not clear at present. An assessment of the population is necessary to aid conservation and management of the clam beds.

The present work aims to quantify some aspects of the population biology of *P. textile* in order to assess the impacts of the different anthropogenic disturbances. This paper (1) determines certain growth, mortality and recruitment parameters, (2) estimates the density, catch per unit effort (CPUE) and maximum sustainable yield (MSY) of Venus textile clam beds and (3) describes some environmental parameters that may influence *P. textile* populations.

Materials and methods

The Venus textile clam beds in the municipal coastal waters of Dequis, Manukan (8.52695°N, 123. 08278°E) and Langatian, Pres. Manuel A. Roxas (8.52553°N, 123.23234°E), Zamboanga Del Norte were the sampling sites of this study. The distance between the two sites is approximately 16.8 km. The clam beds are characterized by sandy-muddy bottom with depth range from 7 to 11 m.

Clams were collected monthly (March to December, 2008) with the assistance of two commissioned *Paphia* fishers. The *Paphia* fishers were instructed to randomly lay and collect clams from 0.25 m^2 quadrats within clam beds. Clams collected from each quadrat were placed in pre-labeled net bags for processing. However, sample collections from March to May did not use quadrats, hence were not included in the estimation of clam density. The monthly densities of the clams between sites were compared using T-test statistics.

Shell lengths (Lomovasky et al. 2005) of the samples were measured using a Vernier caliper (0.05 mm precision) and recorded to construct a monthly frequency dataset. The dataset were used to determine growth, mortality and recruitment parameters with the FiSAT II (FAO-ICLARM Stock Assessment Tools) program package.

Growth of the *P. textile* populations was assumed to be described by the von Bertalanffy growth function (VBGF) (Sparre, Venema 1998). Growth parameters, such as asymptotic length (L_∞) and growth coefficient (K) of the VBGF were estimated using ELEFAN I (Electronic Length Frequency Analysis). Growth rates (mm day^{-1}) of *P. textile* were analyzed by means of the Bhattacharya method (Sparre, Venema 1998). The computation of growth rates by cohort can be done by dividing the increments between the modal lengths (mm) derived using the Bhattacharya method with their respective time increments (Del Norte-Campos 2004). The mean growth rates for each cohort were averaged to estimate the total mean growth rate for all cohorts. Growth rates of *P. textile* from the clam beds were compared using T-tests to determine significant differences.

Estimation of the rate of total mortality (Z) of clam populations from the two municipalities was carried out from a length-converted catch curve using pooled monthly length-frequency data. Z corresponds to the negative slope of the linear regression of the descending arm of the catch curve (Gayanilo, Pauly 1997). Natural mortality (M) was estimated by averaging M/K values derived from other *Paphia* species and multiplying the result with the estimated K value from this study (Del Norte-Campos, Villarta 2010). Fishing mortality (F) was estimated by subtracting M from Z and the exploitation rates (E) by dividing the F by Z (Gayanilo, Pauly 1997).

Recruitment patterns were predicted by reconstructing the recruitment pulses from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse. Recruitment patterns were obtained by backward projection, onto the length axis, of a set of length frequency data.

Estimates of catch per unit effort (CPUE) were based on actual interviews with free- and hookah divers operating within the sampling sites. A total of 14 (nine free- and five hookah divers) out of 48 (33 free- and 15 hookah divers) *Paphia* fishers were interviewed. Information obtained from interviews were the (1) fishing method; (2) number of hours spent per trip; (3) number of days of trip per month; and (4) average amount of catch per operation. Results of the interviews were arbitrary for most respondents, as they gave only answers based on their perceptions. Computation of CPUE (kg $manhour^{-1}$) was based on the equation (Eq. 1) used by Argente et al. (2013a).

$$CPUE = \text{Total weight of catch (kg)} / \text{No. of hours fishing} \times \text{No. of fishers} \quad \text{Eq. 1}$$

Estimation of the maximum sustainable yield (MSY) for both sites was based on the formula (Eq. 2) proposed by Cadima (Sparre, Venema 1998) for exploited stocks for which only limited stock assessment data are available.

$$MSY = 0.5 \times \text{Total mortality } (Z) \times \text{Average annual biomass } (\bar{B}) \quad \text{Eq. 2}$$

The average annual biomass ($\bar{B}$) for both clam beds was estimated based from the results of the CPUE multiplied by number of fishers, average number of hours fishing, average number of days fishing in a month and 12 months.

Environmental parameters were monitored monthly at the two sampling sites. Water temperature (8 m depth) was recorded based from the readings of a Min-Max thermometer. Salinity measurement was done with a field refractometer. Chlorophyll *a* concentration in the nearbottom water was determined based on the trichromatic method described by Aminot and Rey (2000). Five replicates of 1 L water samples were collected on each study site. Additional five replicates of 1 L water samples were collected and filtered using a filtration apparatus and pre-weighed Whatman™ GFC 47 mm filters to estimate total suspended solids. Five replicates of sediment samples were collected for the determination of total organic matter. Loss-on-ignition technique was used to determine total organic matter of the substrate (Luczak et al. 1997). Results obtained on the environmental parameters monitored from the study sites were compared using T-tests to determine significant differences.

Results

The derived L_∞ and K values from the restructured frequency data of *P. textile* samples in Manukan (Fig. 1) were 67.90 mm and 1.00 year^{-1}, respectively. On the other hand, higher L_∞ (69.95 mm) and similar K (1.00 year^{-1}) values were observed from the restructured frequency data of the Roxas samples (Fig. 2).

A total of five cohorts were derived from the samples collected in Manukan (Table 1). The estimated growth rate of *P. textile* population in this clam bed was 0.064 ± 0.043 mm day^{-1}. Consequently, five cohorts were also established from the Roxas samples with estimated growth rate of 0.027 ± 0.028 mm day^{-1} (Table 2). Growth rates of *P. textile* in Manukan were significantly faster ($P < 0.05$) than in Roxas.

The estimated Z of *P. textile* populations in the clam beds of Manukan and Roxas were 3.19 year^{-1} and 4.63 year^{-1}, respectively. Based on the M/K values derived from other *Paphia* species (Table 3), the M estimate for both Venus textile clam stocks was 1.98 year^{-1}. Consequently, F values were 1.21 year^{-1} and 2.65 year^{-1} for Manukan and Roxas, respectively. The derived E values were 0.38 in Manukan and 0.57 in Roxas.

Two recruitment pulses were derived from the *P. textile* samples collected in Manukan, whereas a single recruitment pulse was predicted from Roxas (Fig. 3). These recruitment pulses indicate recruitment peaks. Based from the monthly samples, recruitment peaks occurred on May to July and November to December in Manukan and from March to June in Roxas.

Monthly mean densities of *P. textile* in Manukan and Roxas (Fig. 4) were 5 ± 3 clams m^{-2} and 11 ± 5 clams m^{-2}, respectively. Significantly higher ($P < 0.05$) clam density was observed in Roxas. Moreover, higher density

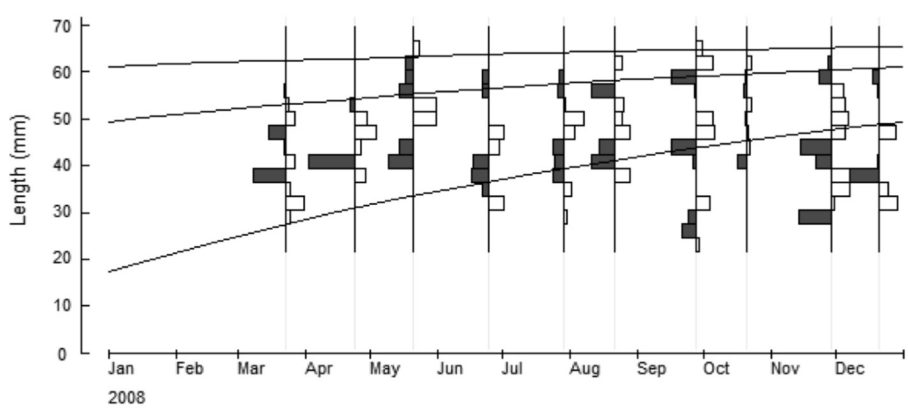

Fig. 1. Restructured length-frequency data of *Paphia textile* samples taken from Langatian, Roxas clam bed with superimposed growth curve estimated by ELEFAN I (L_∞ = 69.95 mm; K = 1.00 year^{-1}; R_n = 0.212).

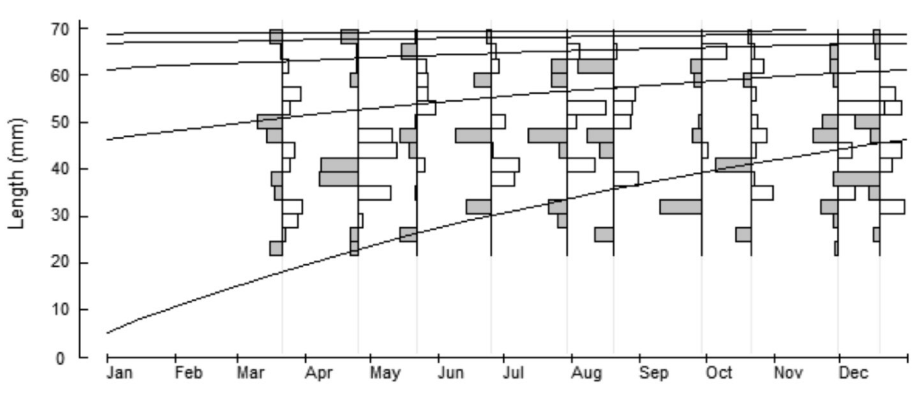

Fig. 2. Restructured length-frequency data of *Paphia textile* samples taken from Dequis, Manukan clam bed with superimposed growth curve estimated by ELEFAN I (L_∞ = 67.90 mm; K = 1.00 year^{-1}; R_n = 0.219).

Table 1. Daily growth rate of the derived cohorts of *Paphia textile* in the clam bed of Dequis, Manukan

Cohort No.	Collection date	Mean SL (mm)	$SL_2 - SL_1$ (mm)	$t_2 - t_1$ (days)	Growth rate (mm day^{-1})
1	3/22/2008	37.83	-	-	
	4/23/2008	41.5	3.67	32	0.115
	5/20/2008	42.68	1.18	27	0.044
	10/20/2008	51.78	9.1	153	0.059
2	3/22/2008	46.07	-	-	
	8/20/2008	56.19	10.12	151	0.067
	11/28/2008	59.69	3.5	100	0.035
3	6/23/2008	38.5	-	-	
	7/28/2008	40.98	2.48	35	0.071
	8/20/2008	42.79	1.81	23	0.079
	9/27/2008	43.25	0.46	38	0.012
4	7/28/2008	57.71	-	-	
	9/27/2008	58.41	0.7	61	0.011
5	9/27/2008	26.9	-	-	
	12/20/2008	39.5	12.6	84	0.150
				Mean	0.064
				SD	0.043

Table 2. Daily growth rate of the derived cohorts of *Paphia textile* in the clam bed of Langatian, Roxas

Cohort No.	Collection date	Mean SL (mm)	$SL_2 - SL_1$ (mm)	$t_2 - t_1$ (days)	Growth rate (mm day^{-1})
1	3/21/2008	38.52	-	-	
	4/24/2008	39.13	0.61	34	0.018
	10/21/2008	41.65	2.52	180	0.014
2	3/21/2008	49.2	-	-	
	7/29/2008	51.5	2.3	130	0.018
	10/21/2008	57.5	6	84	0.071
3	5/21/2008	45.95	-	-	
	6/24/2008	46.2	0.25	32	0.008
	8/19/2008	47.4	1.2	56	0.021
	12/18/2008	47.78	0.38	121	0.003
4	6/24/2008	57.5	-	-	
	7/29/2008	60.5	3	35	0.086
5	7/29/2008	46.08	-	-	
	9/28/2008	47.4	1.32	61	0.022
	11/29/2008	47.65	0.25	62	0.004
				Mean	0.027
				SD	0.028

of relatively larger-sized individuals was also observed in Roxas based from the size-frequency distribution of the collected samples (Fig. 5).

Based from the interviews with the *Paphia* fishers, an average of 4.67 ± 0.66 h and 2.83 ± 0.29 h operation^{-1} were spent by the free-divers and hookah divers, respectively. Free-divers operated an average of 29 ± 3.33 days month^{-1} while hookah divers operated an average of 28 ± 2.89 days month^{-1}. Estimated mean CPUE were 1.12 ± 0.26 kg manhour^{-1} for hookah diving (Manukan) and 1.92 ± 0.76 kg manhour^{-1} for free-diving (Roxas).

The estimated $\bar{B}$ in Manukan was 15 974.78 kg year^{-1} while in Roxas estimated $\bar{B}$ was 102 970.14 kg year^{-1}. Based on these results, the projected MSY in the clam beds was 25 479.77 kg year^{-1} in Manukan and 238 375.87 kg year^{-1} in Roxas.

The monitored environmental parameters (Table 4) showed no significant differences ($P > 0.05$) between

Table 3. Natural mortality (M, year^{-1}) and growth coefficient (K, year^{-1}) literature estimates for different *Paphia* species used to compute the M values for *Paphia textile* in this study

Species	M (year^{-1})	K (year^{-1})	M/K	Source
Paphia textilis	1.50	0.75	2.00	Dacles 1998
Paphia undulata	2.89	1.20	2.41	Agasen et al. 1998
Paphia malabarica	1.17	0.84	1.39	Appukuttan et al. 1999
Paphia undulata	2.40	0.80	3.00	Soliman et al. 1999
Paphia textile	0.97	0.56	1.73	Cesar et al. 2006
Paphia textile	0.93	0.52	1.79	Cesar et al. 2006
Paphia malabarica	1.82	0.92	1.98	Thomas, Nasser 2009
Paphia undulata	1.57	1.00	1.57	Del Norte-Campos, Villarta 2010
		Mean	1.98	

Manukan and Roxas *P. textile* beds. However, it was noteworthy to mention that the mean concentrations of chlorophyll *a* in Manukan (1.83 ± 0.41 mg m^{-3}) and Roxas (1.63 ± 0.09 mg m^{-3}) during dry season (March to May) were higher than in the wet season (June to December). Mean concentrations of chlorophyll *a* during wet season were 1.06 ± 0.26 mg m^{-3} in Manukan and 1.14 ± 0.20 mg m^{-3} in Roxas.

Discussion

Anthropogenic activities influence the condition of the marine benthic environment (Lenihan, Peterson 1998; Argente et al. 2013b). As a result, human-induced perturbations affect the dynamics of marine invertebrates in the benthic ecosystem (Rossi et al. 2007; Fryganiotis et al. 2013; Baek et al. 2014). The degree of anthropogenic disturbances in a marine ecosystem is directly associated with the extent of its impact to aquatic inhabitants (Murray et al. 1999). This study showed the effects of different harvesting activities in *P. textile* beds in Zamboanga Del Norte, Philippines.

The hookah diving method of harvesting *P. textile* is widespread in Manukan, while only free-diving method is allowed in Roxas. The use of hookah had been reported to be a very efficient yet destructive fishing method (Godoy et al. 2010). On the other hand, the free-diving method of harvesting marine bivalves is relatively sustainable (Cesar et al. 2006). Hence, the *P. textile* population in Manukan experienced higher degree of human disturbance as compared to that in Roxas.

Higher L_∞ was derived from the *P. textile* population in Roxas. The estimation of L_∞ is dependent on the presence

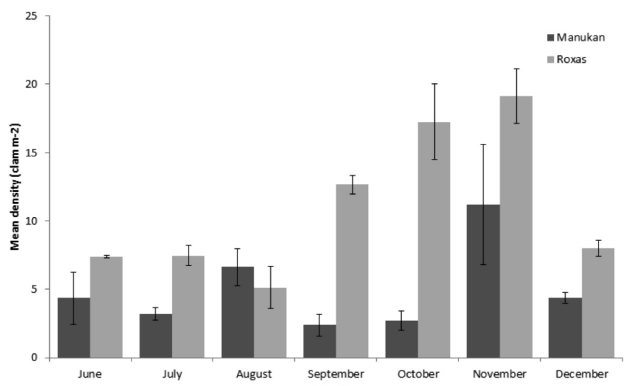

Fig. 4. Monthly mean density of *Paphia textile* in Manukan and Roxas. Bars indicate SD of the mean.

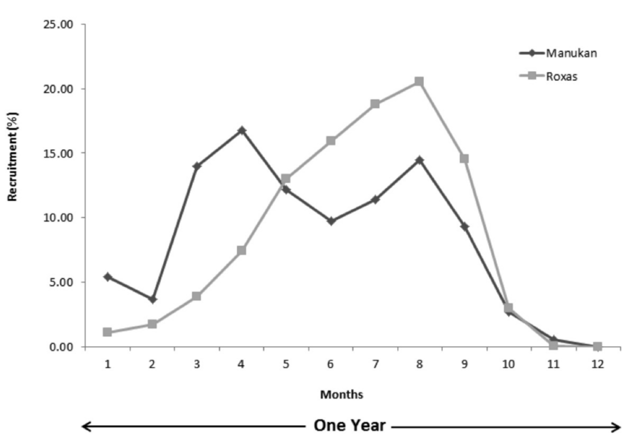

Fig. 3. Predicted recruitment patterns of *Paphia textile* populations in Manukan and Roxas.

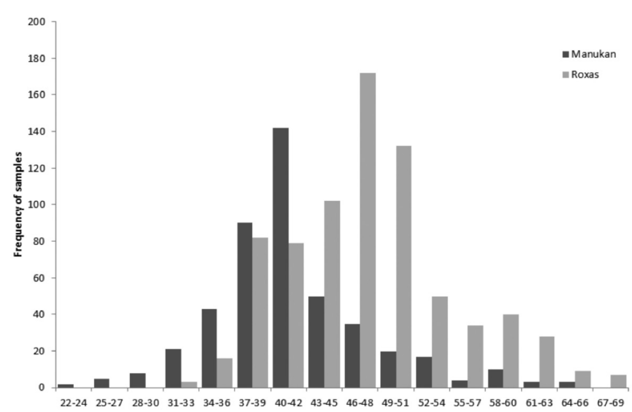

Fig. 5. Size-frequency distribution of *Paphia textile* collected in Manukan and Roxas.

Table 4. Monitored environmental parameters in the *Paphia textile* beds of Manukan and Roxas. TSS, total suspended solids; TOM, total organic matter

Parameter	Manukan			Pres. M.A. Roxas		
	Range	Mean	SD	Range	Mean	SD
Water temperature (°C)	26.00 –29.33	28.02	1.01	25.67 – 29.65	28.29	1.11
Salinity (ppt)	32.20 – 34.60	33.96	0.60	23.00 – 34.80	32.02	3.86
Chlorophyll *a* (mg m^{-3})	0.82 – 2.23	1.29	0.15	0.78 – 1.69	1.29	0.10
TSS (mg L^{-1})	21.40 – 29.40	24.81	1.02	18.40 – 50.80	26.98	2.95
TOM (% loss)	8.50 – 17.34	13.95	3.01	6.07 – 12.12	10.13	10.13

of large individuals in the population (Urban, Campos 1994). The higher estimate of L_∞ in Roxas can be explained by the relatively high density of larger or adult individuals in the clam bed. The free-divers apply less fishing pressure. Hence, the adult population is not fully exploited. The L_∞ is interpreted as the mean length of a very old species (Sparre, Venema 1998).

The growth rate of *P. textile* in Manukan appeared faster than in Roxas. Young bivalves grow faster than adults (Fiori, Morsan 2003; Verweenet al. 2006; Wong et al. 2012). It was observed that higher density of smaller or younger individuals were left in Manukan, which may be caused by the prolific harvesting of the hookah divers. Larger individuals are the target of the fishery due to high demand in the market. Moreover, less density of adult individuals means less competition for food and space for the young clams. This is a condition favorable for rapid growth. Defeo (1996) reported depressed growth of young bivalves due to starvation instigated by the high density of the adult population.

It appeared that Z of Venus textile clam was slightly higher in Roxas than in Manukan. Moreover, higher F and E values were estimated in Roxas as compared to Manukan. There were fewer identified hookah divers operating in the clam bed of Manukan. This can be attributed to the low catch volume, making the fishing activity less lucrative. Roxas banned hookah diving, but no other regulations were imposed on the fishery. The number of identified free-divers in Roxas was 45.50% higher than the hookah divers in Manukan.

Fortunately, it seems that the clam bed in Roxas can still endure the fishing activities. Significantly higher densities of clams were observed in Roxas. The limited time underwater makes it difficult for free-divers to target all the large sizes of clams. As a result, relatively more adult individuals were retained in the clam bed. Adult clams are a potential parent stock for new recruits. As the parent stock starts to increase in size, recruitment also increases (Gayanilo, Pauly 1997). It is plausible that the recruitment of *P. textile* in Roxas compensates for the degree of exploitation.

Recruitment of *P. textile* in both sites was year-round but exhibited different patterns. Two recruitment pulses were derived in Manukan while a single pulse was observed in Roxas. The sizes of the parent stock had direct relationship with spawning and recruitment (Gayanilo, Pauly 1997). Smaller clams dominate the clam bed of Manukan, hence, smaller sizes of the parent stock. In such a case, recruitment peaks for smaller-sized parents should be more than once-a-year to increase the volume of recruits. A similar recruitment pattern derived from smaller-sized individuals was reported for bivalves, *Amusium pleuronectes* (Del Norte 1988) and *Gari elongata* (Del Norte-Campos 2004). The bimodal recruitment pattern of *P. textile* in Manukan is typical for tropical bivalves, which are fast-growing and short-lived species (Del Norte 1988; Mohammed, Yassien 2002; Del Norte-Campos 2004).

A unimodal recruitment pattern was derived from the *P. textile* population in Roxas. The parent stocks on this clam bed are larger, and likely to produce more recruits. However, the relatively high density of the adult population may limit the frequency of recruitment (Defeo 1996). If the adult population is increased, new recruits may experience high level of competition for food and space. Brazeiro and Defeo (1999) reported high recruitment of the clam *Mesodesma mactroides* when adult density was low due to extensive fishing pressure.

To deal with such a scenario, the peak of recruitment should be when food is abundant and space for settlement is unfilled. High concentration of chlorophyll *a* was observed during dry season (March-May), suggesting an abundant food source for *P. textile*. Moreover, increased fishing pressure was experienced by the adult population during dry season, since the condition of the environment was appropriate for *Paphia* harvesting. Consequently, the number of small individuals (< 40 mm) sampled in Roxas increased during dry season.

The CPUE was similar between the clam beds. However, estimated $\bar{B}$ and MSY differed between Manukan and Roxas. The $\bar{B}$ in both clam beds did not exceed the current estimation of the MSY. Nevertheless, $\bar{B}$ in Manukan was already 62.70% of MSY while $\bar{B}$ of Roxas was only 43.20% of MSY. The estimated MSY in Roxas was 9.36 times higher than in Manukan. The above implies that hookah diving had more impact than free-diving on *P. textile* populations, and provides evidence on the extent of exploitation between the clam beds.

The condition of the environment influences the population dynamics of bivalve populations (Schweers et al.

2006; Carmichael et al. 2012). However, this study showed that the environmental conditions in the clam beds were similar. In view of this, it appeared that the fishing activities in the clam beds were prime factors that influenced the dynamics of *P. textile* populations. Specifically, the degree of exploitation modified density-dependent processes, which affected some aspects of growth, mortality and recruitment of *P. textile* stocks.

The different types of fishing practices in Manukan and Roxas revealed interesting effects on the population dynamics of *P. textile*. It appeared that the degree of exploitation regulates some aspects of population biology of the clams. The extent of human disturbance influenced density-dependent factors, which affected population growth, mortality and recruitment. The efficiency of hookah diving in harvesting *P. textile* resulted in lower density of larger-sized clams. However, the magnitude of fishing pressure promoted positive growth rates, particularly in younger clams, and a bimodal recruitment pattern. Higher density of adult clams was retained in the free-diving *P. textile* fishery. This supported population longevity and a unimodal recruitment pattern. Population mortality appeared to be influenced not only by the fishing method but also with the amount of effort. Hookah diving is destructive and should be discouraged. Free-diving appeared to be sustainable, but should be regulated.

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