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Population parameters and exploitation of commercial scallop fishery for *Chlamys nobilis* in Asid Gulf, Philippines

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Abstract

Many scallop stocks have collapsed few years after their onset of harvesting as a result of unregulated fishing practices. Thus basically, studies on population parameters of exploited species are necessary to understand their states and dynamics that would provide foundation in formulating management scheme for the conservation and protection of the resource. For this study in Asid Gulf (Philippines), 300 specimens of *Chlamys nobilis* were randomly collected monthly from the catches of hookah divers. Shell height was measured and their length-frequencies were analysed using an objectives length-based computer program. Results of the study demonstrated that the estimated asymptotic length (L_∞) and growth coefficient (K) were 9.82 cm and 0.76 year^{-1}, respectively. All the computed values of fishing mortality (F_1=1.50, F_2=1.26, F_3=1.71) reveal high fishing pressure beyond the optimum resulting to a heavily exploited stock. Recruitment pattern was continuous displaying a single major annual peak event (May) corresponding to the reported major spawning of the species (December to February). The length-at-first-capture (6.28 cm) that is beyond the size-at-first-maturity (5.70-5.89 cm) and the high Fi among the largest scallops (6.0-8.5 cm) support the occurrence of recruitment overfishing. The current exploitation rate (E=0.76), found equal to its maximum exploitation rate (E_{max}=0.76), suggests the need to regulate harvesting. Appropriate management scheme is urgently needed to sustain the resource. Specifically, a substantial reduction in the current exploitation should be made along the aim of obtaining optimum yields. In addition, exploring the aquaculture potential of this species is recommended.

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Introduction

Scallops are invertebrate animals of Phylum Mollusca, Class Bivalvia and Family Pectinidae inhabiting the range of climatic zones from polar to tropical (Brand, 1991; Waller, 1991; Peña, 2001; Gosling, 2003; Telahigue *et al.,* 2018), that occur in most seas of the world from shallow intertidal waters up to a depth of 7,000 m (Brand, 2006). Worldwide, about 40 scallop species belonging to the Supra-genera *Chlamys, Mimachlamys, Aequipecten, Palliolum, Decatopecten* and *Pecten*; they are commercially exploited for human consumption, highly nutritious, rich in glycogen and protein and popular delicacies among local consumers as well as those in neighbouring countries (Waller, 1991; Minchin, 2003; Hardy, 2006). Similarly, they are of worldwide economic importance and support both commercial fisheries and mariculture efforts (Shumway, 2006). To date, many scallop fisheries have collapsed shortly after their onset, and most of the fisheries are currently harvesting stocks at maximum yield (Bourne, 2000).

This is an obvious result of the swelling population in coastal communities and the constant demand of fishery resources in both the local and export markets (del Norte-Campos and Villarta, 2010). Similarly, environmental changes, habitat deterioration, pollution, irregular recruitment and heavy fishing pressure were also generally expected to have played a role in most or all of those collapses (Gould and Fowler, 1991; Orensanz *et al.,* 1991; Bull, 1994; Lu and Blake, 1997; Strand and Vosltad, 1997; Stotz and Mendo, 2001). Toward the efficient and sustainable fishing of highly-valuable economic species like *Chlamys nobilis*, the harvesting needs to be regulated in accordance with scientific data utilized for sustainable yield determination. Stock assessment using FiSAT (FAO-ICLARM Stock Assessment Tools) has been implemented in estimating the population parameters of finfish and shellfish resources (Nurul-Amin *et al.,* 2009). Furthermore, stock assessment studies are important to estimate the species standing stock biomass and to understand the status of exploitation of particular stocks by applying mathematical models that fit available information to generate simplified representations of population and fishery dynamics (Cadrin and Collas, 2015). Armed with this knowledge, managers can adjust the level of fishing so that populations are harvested sustainably.

In the Philippines, *C. nobilis* locally known as "De-color" is one of the commercially important scallop species (Soliman and Dioneda 2004; Morillo-Manalo *et al.,* 2016). It is an important fishery product in Asid Gulf specifically at Naro Island, Cawayan Masbate that serves as food and livelihood or source of income of the Islanders (Cabiles and Soliman, 2018). The shells come in a variety of colors and are widely used in shell craft industry (Soliman and Dioneda, 2004; Laureta, 2008).

This species is widespread in the Indo-West Pacific (Poutiers, 1998) whereby it was heavily traded and exploited in Panay, particularly in northern Iloilo (Morillo-Manalo *et al.,* 2016). Despite the economic importance of scallops in Philippine fisheries, few published research works were available such as but not limited to *Amusium pleuronectes* (Llana, 1979, 1983 and 1988; Llana and Aprieto, 1983; del Norte, 1988; Belda and del Norte, 1988), *Chlamys senatoria* (Morillo-Manalo *et al.,* 2016*), Decatopecten striatus* and *Chlamys funebris* (Bobiles and Soliman, 2018).

In addition, previous work regarding quick stock assessment of commercial scallops including *C. nobilis* in Asid Gulf were published (Soliman and Dioneda, 2004). Due to the commercial importance of scallops specifically *C. nobilis*, as well as its mariculture potential, there is a need to re-assess its status as it will provide insights on the impact of unregulated exploitation on the resource. Thus, this study was carried out primarily to assess the current status of the scallop *C. nobilis*. Specifically, it aims to determine growth parameters, mortality rates, level of exploitation, recruitment pattern and yield-per-recruit using length frequency data of the species in the gulf. Knowledge on these aspects is essential basis in formulating management scheme for the conservation of this vulnerable resource.

Materials and method

Study site

Asid Gulf (Fig.1) is part of the Visayan Sea which is a large body of water bordered by five coastal towns from Jintotolo of Balud (in the southwest) through Milagros, Cawayan, Placer and Esperanza (in the southeast).

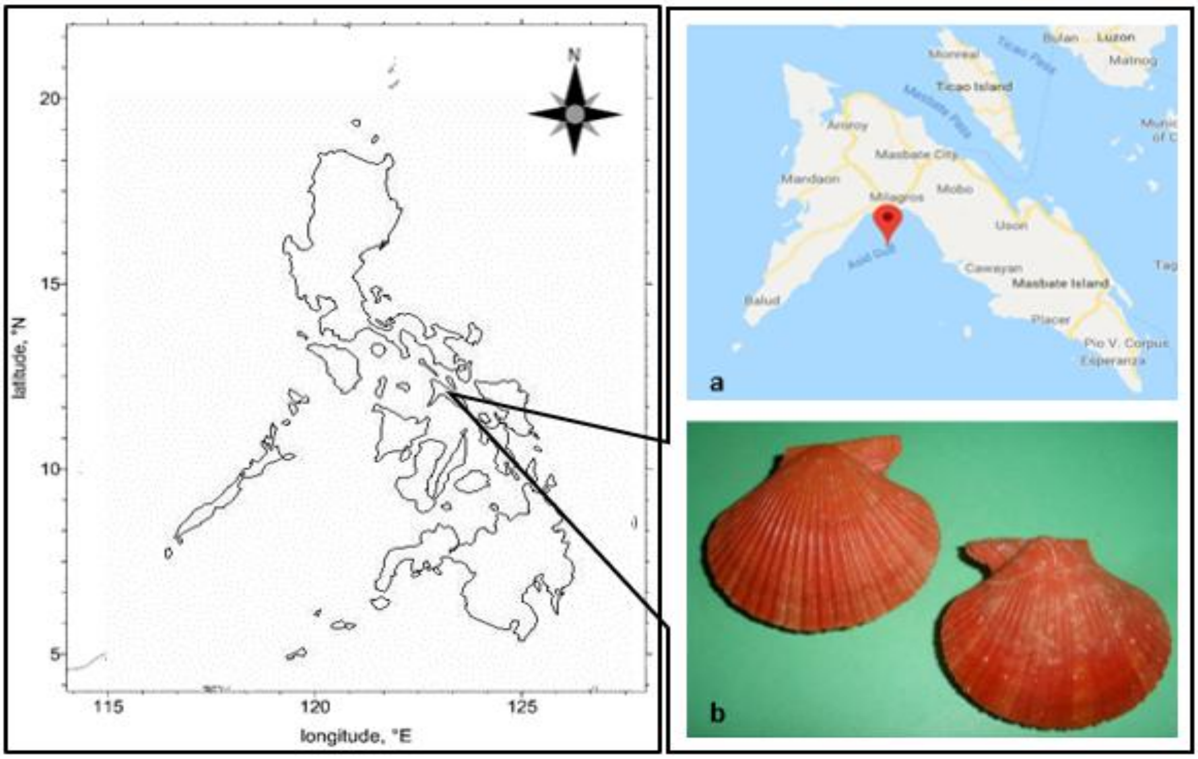

Fig. 1. Map of the study sites showing Asid Gulf, Masbate (a) where scallop *Chlamys nobilis* samples (b) were collected from the landed fishery catches of hookah divers during April 2018 to March 2019.

It is only the remaining site in the Philippines reported to have a large volume of scallops thriving in their natural habitat where they are fished commercially (Bobiles and Soliman, 2018). The scallop production beds in the Gulf are within the Recodo Marine Fishery Reserve (RMFR) and portion of the beds is in the adjacent coastal towns which include Pananawan, Malbug, Pina Island, Naro Island, Guinlubngan and Namatyan (Soliman and Dioneda, 2004; Mendoza and Soliman, 2017; Bobiles and Soliman, 2018). Scallop fishery is one of the primary sources of income of the Islanders in Naro Island, Cawayan Masbate specifically of Barangays Punta Batsan, Looc and Talisay. The three barangays are the landing, trading and processing sites of scallops harvested from the gulf. Five species of commercially important scallop has been identified inhabiting the gulf. These are the *Decatopecten striatus* (hereafter *Bratychlamys vexillum*), *Chlamys macassarensis, Chlamys funebris, Chlamys gloriosus* and *Chlamys senatoria nobilis*. (Soliman and Dioneda, 20014). Harvesting of these scallops is done by dive-fishers using hookah or a compressor for breathing (Soliman and Dioneda, 2004; Bobiles and Soliman, 2018). In the past, scallop fishery is almost unregulated, wherein harvesting is limited only by the capacity of boat used for scallop diving. According to Soliman and Dioneda (2004) way back 2003, a total of 1,100 mt of shell-on scallops were being harvested annually which was considered as one of the largest scallop productions in the Philippines. Today, due to the excessive and rampant collection of scallops including *C. nobilis*, the species are now facing serious threats on its biodiversity. Increase fishing pressure to satisfy the protein demand of the country as well as to sustain the livelihood of the poor fishers caused the wild stocks to be threatened both in terms of density and species diversity. Information on basic population parameters of the target species is theferore urgently needed.

Data collection

The sampling programme commenced in April 2018 and continued for 12 consecutive months covering the rainy and dry seasons in the study area. Samples were collected from various catches of different scallop divers from the three Barangays namely Talisay, Punta-Batsan and Looc wherein 300 of *C. nobilis* representing all size classes were randomly collected from the landed fishery catches by hookah divers every month. Thus, the question of selectivity in the sample does not arise and there is no chance of artificial or non-random predominance of particular size groups in the samples. Total of 3,600 specimens were measured throughout the study period. Individual shell height (SH – longest linear distance of the shell along the antero-posterior axis of the animal reckoned at right angle to the umbo; from Soliman and Dioneda, (2004) was measured using digital caliper accurate to 0.01 cm.

Data analysis

Length-frequency data were processed by the methodology of Gayanilo *et al.,* (2005) using the length-based approaches described in the FAO-ICLARM stock assessment tool (FiSAT II) package. Length-frequency data were grouped into classes of 0.5 cm interval and analyzed using FiSAT II software. Growth parameters such as asymptotic length (L_∞) and growth coefficient (K) were obtained using the ELEFAN programme from the fitted curve with maximum goodness of fit (Rn). This program was used to identify growth oscillations as expressed by the extended version of the Von Bertalanffy growth equation (1):

$$L_t = L_\infty (1 - e - K ((t-t_o) + C/2 \sin 2(t-t_s)) \quad (1)$$

where *Lt*, L_∞, t_o and *K* are the parameters of the Von Bertalanffy growth equation, *C* is constant, which represents the amplitude of growth oscillation; t_s is the starting point of oscillation with respect to t_o=0 (Pauly and Gaschuetz, 1979) and t_o is the theoretical age in years at which length of the species is equal to zero (usually negative) as estimated by the Pauly's equation (Pauly, 1984) (2).

$$t_o = -0.3922 – 0.275\log L_\infty - 1.038\log K \quad (2)$$

Since growth is not linear, growth comparisons using L_∞ and *K* separately may be inaccurate (Mendo and Jurado, 1993), considering this, Pauly and Munro (1984) proposed the following growth performance index (Φ) (3): $\Phi = 2\log 10 L_\infty + \log 10 K$ (3)

Mortality rate

Mortality coefficients, viz., total mortality (Z), instantaneous natural mortality (M), fishing mortality (F) and exploitation rate (E) were estimated using the FiSAT II programme (Pauly, 1980; Gayanilo and Pauly, 1997). The total mortality rate (Z) was estimated by length-converted catch curve analysis method (Pauly, 1983), as a requirement to extrapolate the probability of capture. On the other hand, to address the limitation of directly estimating M for scallops which is often difficult to estimate, this paper uses three empirical values of M_i, which are as follows:

$M_1 = 1$ (4)

$M_2 = K$ (5)

$M_3 = 0.55$ (Orensanz *et al.,* 1991) (6)

After the estimation of Z and M_i, fishing mortality (F_i) was calculated by:

$F_i = Z - M_i$ (7)

where *Z* is the total instantaneous mortality coefficient, *F* is fishing instantaneous mortality coefficient and *M* is the natural instantaneous mortality coefficient. To properly determine the size classes that have the highest rate of fishing mortality, Virtual Population Analysis was applied using the input values of asymptotic length, growth, natural and fishing mortality coefficients.

The exploitation level (E) was estimated as the ratio of F/Z (8). Current exploitation rate (E_{cur}) was compared with the E_{max} whereby the difference of E_{max} – E_{cur} (if positive) indicates that current exploitation is in sustainable level. If negative, it means exploitation is beyond the sustainable limit that the resource could support. However, if E_i =1, it means that F = Z (from 8) whereby the two (E_{max} & E_{cur}) represent exploitation at its maximum level. An optimum E = 0.50 has been adopted from Gulland (1971), where it can be inferred that when E is more than 0.50 the stock is generally considered to be overfished, thus

$$E = F / Z \quad (8)$$

Probabilities of capture

The probabilities of capture were estimated by backward extrapolation of the descending limb of the length-converted catch curve. A selectivity curve was generated using linear regression fitted to the ascending data points from a plot of the probability of capture against length, which was used to derive values of the lengths at capture at probabilities of 0.25 (L_{25}), 0.5 (L_{50}), and 0.75 (L_{75}). By plotting the cumulative probability of capture against mid-length, from this resultant curve, the length at first capture (L_c) was taken as corresponding to the cumulative probability at 50%.

Recruitment pattern

The recruitment pattern of the stock was determined by backward projection on the length axis of the set of available length–frequency data as described in FISAT programme (Gayanilo *et al.,* 1996). This technique reconstructs the recruitment pulses from the time series of length–frequency data, to determine the number of pulses per year and the relative strength of each pulse using the input parameters of L_∞, K and t_0 (t_0=-1) (Gayanilo *et al.,* 2005).

Yield per recruit analysis

The relative yield-per-recruit (Y'/R) model (9) of Beverton and Holt (1966) incorporated in the FiSAT programme was used to estimate the Y'/R. The computed exploitation rate (E) was compared with the expected values of E_{max} (the value of exploitation rate giving maximum Y'/R), E_{10} (the value of 'E' at which marginal increase in Y'/R is 10% of its value at E = 0) and E_{50} (the value of 'E' at 50% of the unexploited B/R) (Sparre *et al.,* 1992; Gayanilo and Pauly 1997), where

$$Y'/R = EU^{M/k}\ [1-(3U/1+m) + (3U^2/1+2m) + (U^3/1+3m)] \quad (9)$$

Results

Size structure of C. nobilis

For 3,600 *C. nobilis* collected during April 2018 to March 2019, the shell height (SH) ranged 2.96 to 9.49 cm. Mean SH ± SD of *C. nobilis* caught in Asid Gulf over the study period was recorded as 6.54±9.8. Fig. 2 showed length frequency distribution of the catch for this species. Maximum length (9.49 cm) was recorded in the length class of 8.96–9.56 cm.

Table 1. Growth parameter of *C. nobilis* in comparison with previous studies using other *Chlamys* species.

Location	Species	L_∞	K year^{-1}	Source
France	*C. varia*	4.98	0.76	Conan and Shafee, 1978
Ireland	*C. varia*	8.85	0.69	Burnell, 1995
Philippines	*C. funebris*	11.29	0.67	Bobiles and Soliman, 2018
Philippines	*C. funebris*	8.22	0.45	Soliman and Dioneda, 2004
	C. nobilis	7.89	0.45	
Philippines	*C. nobilis*	9.82	0.76	Present study

The highest frequency of catches belongs to the length class of 6.5–6.9 cm (20.59%), and the lowest frequency belongs to 3.0-3.4 cm (0.03%). As the length-at-first-maturity of the species was 5.89 cm, the proportion of *C. nobilis* length frequency sample that were below the length-at-first-maturity was calculated about 23.29% while 76.71% were beyond this size of maturity.

Growth parameters

The original length frequency distribution was restructured (0.5 cm class interval) and the best-fitting growth curve was obtained by the method of joining peaks using the ELEFAN-I routines incorporated in the FiSAT II package. The ELEFAN-I program estimated L_∞ and K of the BVGF were 9.82 cm (SH) and 0.76 $year^{-1}$ and the t_o value calculated using Pauly's equation was t_o = -0.539. Such value did not show much difference when compared to the K value estimated by other authors using other Pectinid species (Table 1). The longevity of the species was 5.9 years. The best value of the ratio of the number of peaks through which the curve passes (Rn) obtained was 0.282. On the other hand, the estimated values for the growth performance index (ø) for *C. nobilis* during the present investigation was 1.86. Fig.3 shows the corresponding growth curve, superimposed on the restructured length-frequency data.

Table 2. Values of natural mortality (M) used to estimate fishing mortality, exploitation rate as well as maximum yield per recruit.

M	Z	F	E	Lc/L∞	M/K	E_{max}
M_1 = K	2.26	1.50	0.66	0.63	1	0.80
M_2 = 1	2.26	1.26	0.56	0.63	1.31	0.87
M_3 = 0.55	2.26	1.71	0.76	0.63	0.72	0.76

Estimation of Mortality and Exploitation

The length-converted catch curve from mortality estimates of pooled population of *C. nobilis* from Asid Gulf, Masbate is depicted in Fig. 4.

The darkened loops in the figure represent the points used in calculating Z through the least square's line regression. The yellow circles represent points either not fully recruited or nearing to asymptotic length and hence discarded from the calculation. The instantaneous total mortality coefficient (Z) of *C. nobilis* was estimated as 2.26 $year^{-1}$. Using the different values of natural mortality (M_1=K, M_2=1 and M_3=0.55) reveal varying levels of fishing mortality (F_1=1.50; F_2=1.26 and F_3=1.71) as well as exploitation level (E_1=0.66; E_2=0.56 and E_3=0.76) (Table 2).

All the computed fishing mortality reveals heavy fishing pressure thus resulting to an exploitation beyond the optimum. On the other hand, the results of virtual population analysis showed that fishing mortality (F) increased to a maximum of 2.0 at 8.0 – 8.5 cm. This simply indicates that catches increase substantially from 4.0 – 4.5 cm and attained maximum at 8.0 – 8.5 size groups (Fig. 5). The exploitation rate (E = F/Z) was estimated as 0.76.

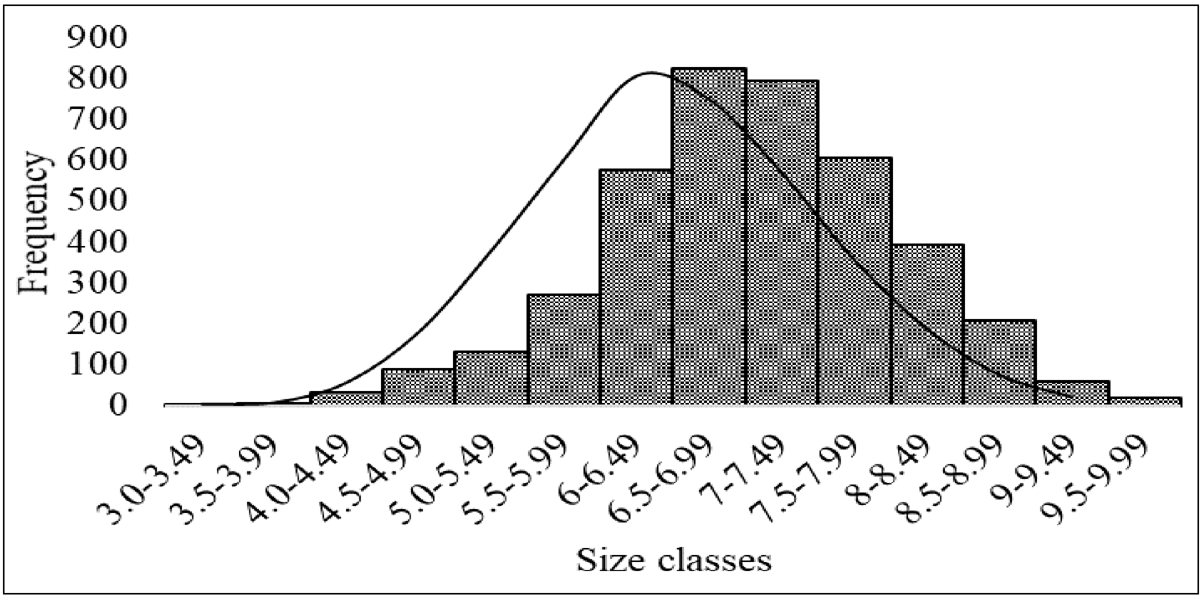

Fig. 2. Length-frequency distribution of *C. nobilis* from Asid Gulf during April 2018 to March 2019 (N = 3,600).

Probability of capture

The estimates of probabilities of capture and length-at-first-capture (L_c) values were calculated using the length-converted catch curve method that was plotted in Fig. 6. The values obtained in probabilities of capture were L_{25} = 5.83 cm, L_{50} = 6.28 cm and L_{75} = 6.72 cm.

Recruitment pattern

Fig. 7 shows the recruitment pattern of *C. nobilis* collected in Asid Gulf during April 2018 to March 2019. The recruitment pattern suggests that annual recruitment consist of one seasonal pulse. The highest peak pulse produced 21.01% of the total annual recruitment which was observed during warm month in summer (May). However, recruitment was continuous even after this peak with the lowest values during cold months (November – December).

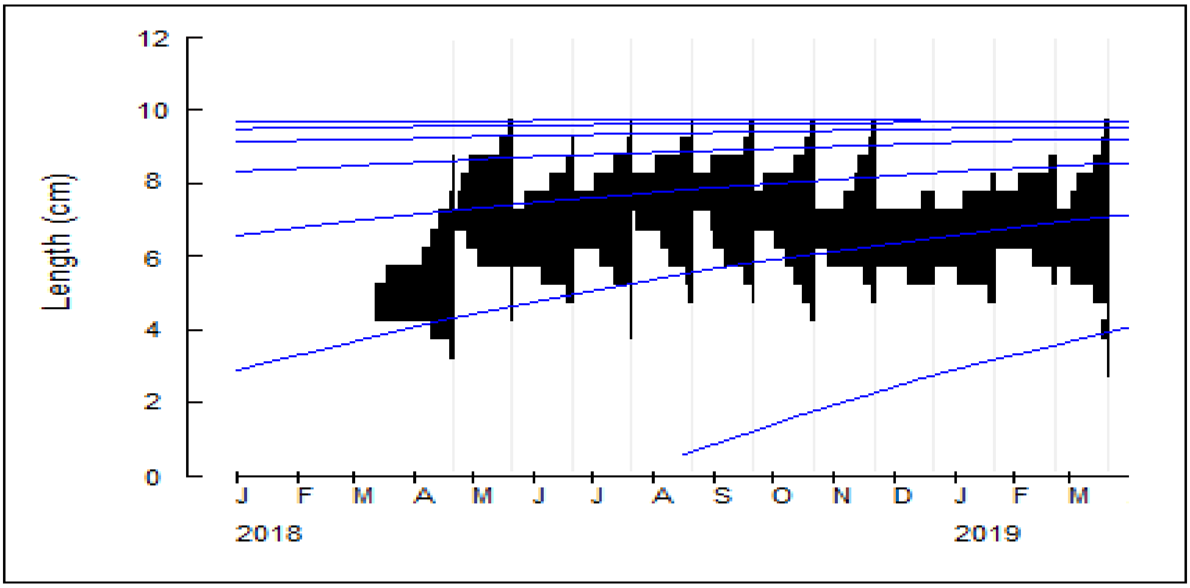

Fig. 3. Growth curve of *C. nobilis* using ELEFAN I method where L_∞ = 9.82 and K = 0.76 year^{-1} with Rn = 0.282 (goodness of fit) from Asid Gulf during April 2018-March 2019.

Yield per recruit

The relative yield-per-recruit (*Y'/R*) values as functions of exploitation rates of *C. nobilis* was shown in Fig. 8. The estimates of probabilities of capture and length-at-first-capture values were used as inputs for relative yield-per-recruit of Beverton and Holt (Y'/R). The L_c/L_∞ and M/K values used for Y'/R analysis were 0.63 and 0.72, respectively. The indices for sustainable yield were 0.40 for optimum sustainable yield (E_{50}), 0.76 for the maximum sustainable yield (E_{max}) and 0.70 for economic yield target (E_{10}). It may be noted that the present exploitation rate (E=0.76) is already at its maximum state.

Discussion

Growth parameters of C. nobilis

Despite of the utilization of scallop specifically *C. nobilis* as one of the prime commodities in Asid Gulf, it is confronted with a considerable dearth of information. However, its population parameters can be compared with other well-studied species in the Philippines as well as in some parts of the world. In the present study the length-frequency distribution data were used to analyse the VBGF growth parameters such as growth constant coefficient (K year^{-1}) and asymptotic length (L_∞ in cm). *C. nobilis* shows rapid growth rate (0.76 year^{-1}), and this value did not show much difference when compared to the K value estimated by authors using other Pectinid species. For instance, growth constant of *C. nobilis* was found to be similar to 0.76 year^{-1} in *Chlamys varia* (Conan and Shafee, 1978), but higher than 0.69 year^{-1} in *C. varia* by Burnell (1995); 0.45 year^{-1} in *C. funebris* and *C. nobilis* (Soliman and Dioneda, 2004) and 0.67 year^{-1} in *C. funebris* by Bobiles and Soliman (2018).

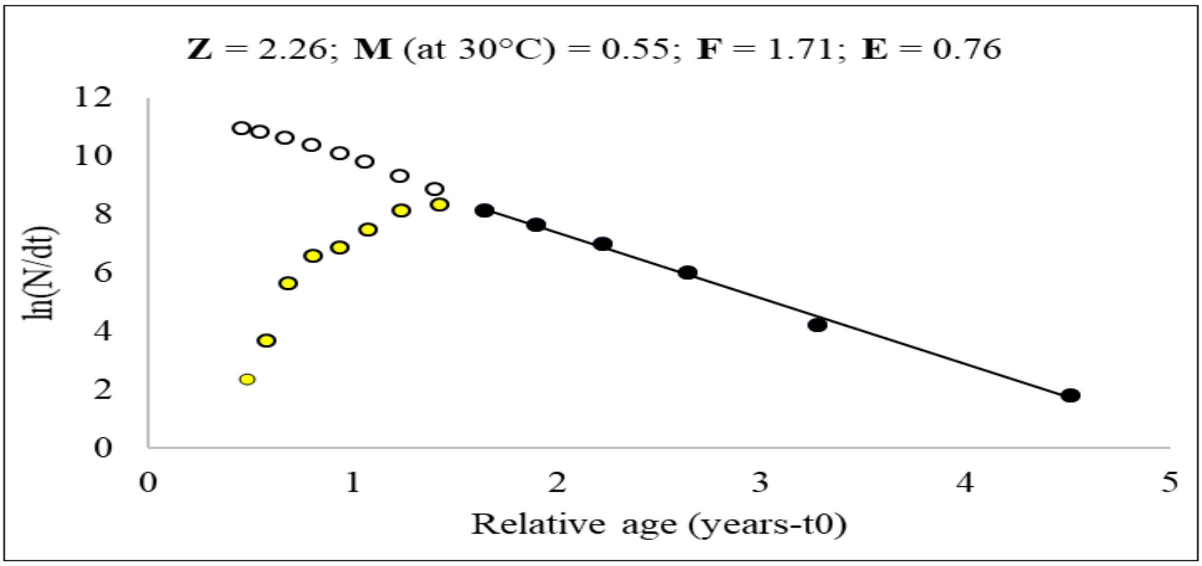

Fig. 4. Total mortality coefficient (Z) estimation using linearized catch-curve method; open circles are extrapolated points via the regression line and yellow circles represent scallop in size classes that are not fully recruited.

The variability between these values could be due to different factors such as physiological condition of the species, feeding variability, fishing pressure and sampling (Biswas, 1993). Similarly, growth also differs from stock to stock (Adam, 1980; Sparre *et al.*, 1992). On the other hand, the reported longevity of the species by Soliman and Dioneda (2004) with a life span of 6.55 years was observed to be close to the present value (5.9 years). Therefore, the high growth rate of *C. nobilis* generated in this study further justifies the excellent potential of this species as a candidate for mariculture or other aquaculture efforts and as basis for management.

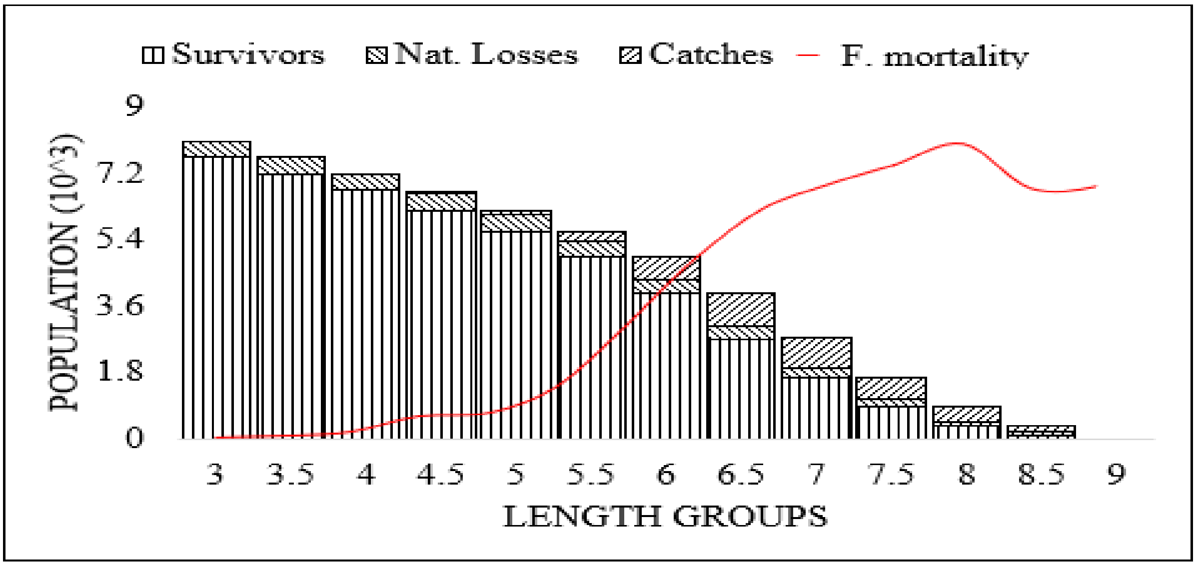

Fig. 5. Virtual population analysis showing the maximum fishing pressure on length class of 8.0-9.0 cm SH of *C. nobilis* fishery from Asid Gulf.

Mortality of C. nobilis

The mortality and exploitation rate of *C. nobilis* were estimated using length-converted catch curve using input values of VBGF growth parameters. Using the different values of M estimate (M_1=K, M_2=1, M_3=0.55) reveals varying fishing mortality (F_1=1.50,

F_2=1.26 and F_3=1.71), exploitation level (E_1=66, E_2=0.56, E_3=0.76) as well as maximum yield-per-recruit (E_{max1}=0.80; E_{max2}=0.87 and E_{max3}=0.76). All the computed values of fishing mortality reveal heavy fishing pressure implying higher exploitation level beyond the optimum (E=0.50) resulting to a heavily exploited resource. Such value of F (mean F for different size classes) generated from the length-converted catch curve did not show much difference to the F generated using virtual population analysis (F=2), particularly for 8.0-8.5 cm size group.

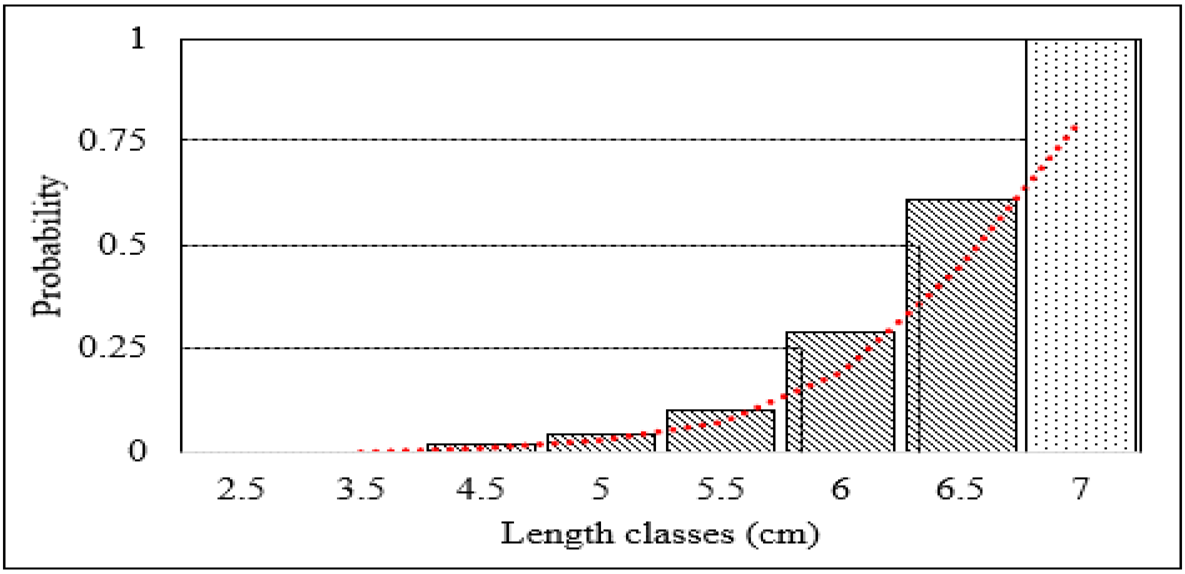

Fig. 6. Probabilities of capture pattern of *C. nobilis* population in Asid Gulf.

The higher fishing mortality (F=1.71-2.0) toward the 6.0-8.5 cm group for *C. nobilis* vis-à-vis its natural mortality (M=0.5-1.0) suggests that fishing is the major cause of death among clams. Increase of fishing mortality and catches was observed among larger individuals which is an outcome of the size limit applied by the local traders in the area. In addition, the higher F generated for *C. nobilis* in this study supports the idea of continuous increase in fishing intensity resulting to excessive and unregulated harvesting of scallop species in the gulf. The swelling population in coastal communities as well as the constant demand of fishery products specifically adductor muscle in both the local and export markets favored by the open access fishery in the gulf are the major factors contributing to the depletion of this vulnerable resource.

Probability of capture

In order to maintain a population in equilibrium, it is of great importance to give each species the chance of reproducing at least once in its lifetime to recruit the stock, and therefore the length-at-first-capture (L_{50}) should be larger than length-at-first-maturity. For *C. nobilis*, various authors reported length-at-first-maturity of 5.89 cm in Asid Gulf (Soliman and Dioneda, 2004), 5.71 (Male) and 5.95 (Female) cm in Gigantes Island (Morillo-Manalo *et al.,* 2016). The current L_{50} (6.28) for *C. nobilis* population in Asid Gulf was higher than the reported length-at-first-maturity of the species. This is attributed to larger individuals dominating the samples resulting to a higher L_{50}. From the collected samples, 76.71% of *C. nobilis* were beyond the size-at-first-maturity indicating a good size of harvest. It indicates that *C. nobilis* were able to spawn at least once before they are subject to fishery capture. However, this could be an indication of recruitment overfishing suggesting that the adult population was fished heavily that the number and size of the spawning biomass could been reduced to a point that it might not have adequate reproductive capacity to replenish the fishery. Unregulated fishing effort in such a situation could result in the collapse of the fishery. Furthermore, large-sized individuals could be the first to be exterminated since they are preferred catch by scallop divers. On the other hand, about 23.29% of the total catch falls below the size where the species are capable of reproduction (assumed juveniles). It is expected that such percentage of juveniles in the catch will increase with time as large individuals are becoming scarce due to recruitment overfishing. Exploitation of juveniles is detrimental to population growth as it does not allow the stock to propagate at least once in its lifetime. This situation, removal of spawning as well as pre-spawning individuals may cause a greater reduction in the catch in the near future. Therefore, in order to promote the sustainable utilization of *C. nobilis* in the gulf, there is a need to regulate its exploitation within sustainable yield level.

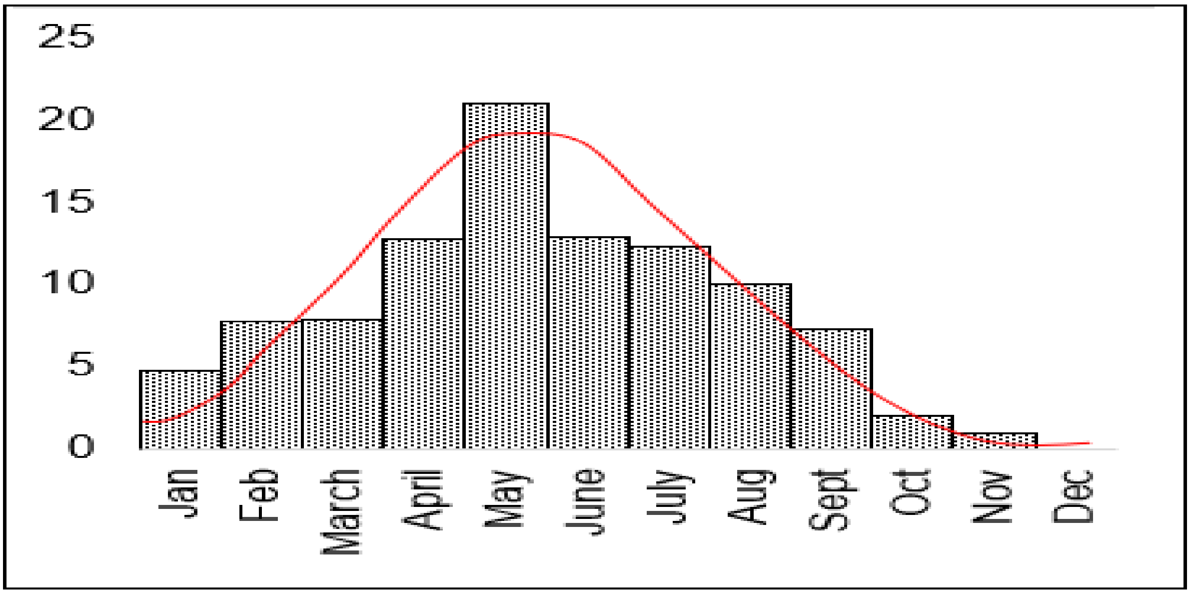

Fig. 7. Temporal recruitment pattern of *C. nobilis* in Asid Gulf during April 2018 to March 2019.

Recruitment pattern of C. nobilis

The frequencies of the different SH classes differed in various months, which support the concept of several recruitment per year. In the present study, recruitment was observed almost whole-year round due to the continuous spawning of the species throughout the year with a major peak from December to February and a minor peak in August (Morillo-Manalo *et al.,* 2016). Recruitment pattern suggests that annual recruitment consist of one seasonal pulse; the highest peak occurs in May with 21.01% of total annual recruitment. The peak recruitment from April to May detected in the present study corresponds to the major spawning season reported for this species. In other words, *C. nobilis* in Asid Gulf starts migrating seaward to spawn in December to February and the juvenile individuals enter the fishing ground to complete their life cycle in March to August. Therefore, to maximize the collection of scallop spats for stock enhancement or grow-out mariculture should consider the warm months in summer (April and May) in the Philippines when aquaculture planning and associated activities are afforded with many advantages.

Exploitation rate of C. nobilis

The exploitation rate "*E*" corresponding to permissible level of obtaining maximum yield-per-recruit "E_{max}" values for *C. nobilis* was 0.76. According to Gulland (1971), a stock is optimally exploited when fishing mortality (F) equals natural mortality (M). In the latter work, current exploitation rate (E = 0.76) is higher than the optimum exploitation rate (E_{50} = 0.40) as well as to economic yield target (E_{10}=0.70) by 90% and 8.5%, respectively, which means *C. nobilis* are being overexploited.

In addition, E_{max} value at 0.76 indicated that the species under study has reached full exploitation in Asid Gulf. This finding agrees with Bourne (2000) stating that most of all scallop fisheries worldwide has collapsed whereby no large unexploited scallop stocks are known at present, most of the fisheries are currently harvesting stocks at maximum yield. This collapse of scallop fishery is primarily attributed to heavy fishing pressure (Gould and Fowler, 1991; Orensanz *et al.*, 1991; Bull, 1994; Lu and Blake, 1997; Strand and Vosltad, 1997; Stotz and Mendo, 2001).

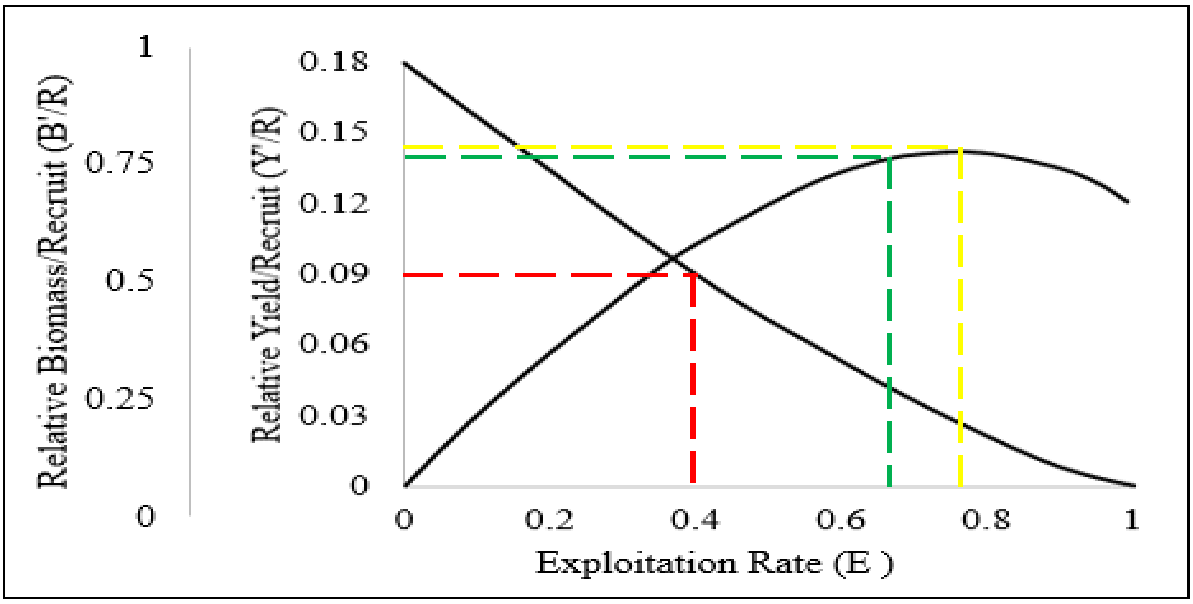

Fig. 8. Relative yield per recruit of *C. nobilis* in Asid Gulf (L_c/L_∞ = 0.63; M/K = 0.72; E_{10} (Green line) = 0.70; E_{50} (red) = 0.40; E_{max} (yellow) = 0.76).

In fact, residence scallop divers of Naro Island revealed the shortage of larger scallops in their area and catches have been declining for years, so they now tend to expand their activities into deeper waters as well as explore far areas just to get a good catch. These results however not only confirm the previous findings that the scallop stock in Asid Gulf is overexploited (Soliman and Dioneda, 2004) but even further emphasizes that the situation has become far more serious at the present. So, if this trend continues, there is a high probability for *C. nobilis* population to collapse.

Conclusions

Results of the present study provided sufficient evidence to justify a substantial reduction in the fishing effort with a view of obtaining optimum yields. Though current exploitation does not exceed E_{max} (i.e., E_{cur}=E_{max}), keeping *C. nobilis* exploitation at the present level will permit harvest of the sustainable yield and avoid overfishing problems. On the other hand, using the E_{10} and E_{50} values as basis for economic and optimum yield limitations, a reduction of 8.6% and 90% from the current exploitation should be made to ensure sustainability of the stock. Although this seems to be a justifiable effort to ensure sustainability, a reduction in the effort would leave a substantial portion of the fishing community to be unemployed. Therefore, fishery managers should take some serious steps to save this commercially important species so that stakeholders can get more benefit from the stocks such as establishment of certain reserves or protected areas in the gulf to protect the spawning stock resources. Similarly, closed season during the time of spawning should be implemented to ensure sustainable supply and increase recruitment in the area. This will form part of the long-term strategy for the sustainable development of aquatic fisheries in the region in the future.

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References

Adam P. 1980. Life history pattern in marine fishes and their consequences for fisheries management. Fishery Bulletin-National Oceanic and Atmospheric Administration **78,** 1- 12.

Belda CA, Del Norte AGC. 1988. Notes on the induces spawning and larval rearing of the Asian moon scallop *Amusium pleuronectes* (Linne) in the laboratory. Aquaculture **72,** 173-179. https://doi.org/10.1016/0044-8486(88)90157-3

Beverton RJH, Holt SJ. 1966. Manual of methods for fish stock assessment, Part II. FAO Fisheries Technical Paper No. 38 (Rev. 1), Rome: FAO, p 67.

Bobiles RU, Soliman VS. 2018. Fishery of commercial scallops in Asid Gulf, Philippines. Aquaculture Aquarium Conservation and Legislation Bioflux **11(4),** 1265-1273.

Bourne NF. 2000. The potential for scallop culture – the next millennium. Aquaculture International **8,** 113-122.

Brand AR. 1991. Scallop ecology: distribution and behavior. In: Scallops: Biology, Ecology and Aquaculture (ed. S.E. Shumway), p 517-84. Elsevier Science Publisher B.V., Amsterdam.

Brand AR. 2006. Scallop ecology: distributions and behavior. In: Shumway, S. E. & G. J. Parsons, editors. Scallops: biology, ecology and aquaculture. Amsterdam, The Netherlands: Elsevier, p 651–744.

Bull MF. 1994. Enhancement and management of New Zealand's "southern scallop" fishery. In: Bourne, N.F., Bunting, B.L., Townsend, L.D. (eds.). proceedings of the 9th International Pectinid Workshop, Nanaimo, B.C., Canada, April 22-27, 1993. Volume 2. Canadian Technical Report of Fisheries and Aquatic Sciences 1994, p 131-136.

Burnell GM. 1995. Age-related protandry in the scallop *Chlamys varia* (L.) on the west coast of Ireland. International Council for the Exploration of the Sea (ICES) Marine Science Symposia **199,** 26-30.

Biswas SP. 1993. Manual of Methods in Fish Biology. South Asia Publishers. Pvt. Ltd, New Delhi, p 195.

Cabiles CD, Soliman VS. 2019. Reproduction temperature-nexus influencing spawning of pectinids in tropical and temperate waters. Aquaculture Aquarium Conservation and Legislation Bioflux **12(1),** 63-72. http://www.bioflux.com.ro/docs/2019.63-72.pdf

Cadrin SX, Collas MD. 2015. Stock assessment methods for sustainable fisheries. International Council for the Exploration of the Sea Journal of Marine Science **72(1),** 1-6. https://doi.org/10.1093/icesjms/fsu228

Conan G, Shafee MS. 1978. Growth and biannual recruitment of the black scallop *Chlamys varia* (L.) in Lanveoc area, Bay of Brest. Journal of Experimental Marine Biology and Ecology **35(1)**, 59-71. https://doi.org/10.1016/0022-0981(78)90090-4

del Norte AGC. 1988. Aspect of the growth, recruitment, mortality and reproduction of the bay scallop *Amusium pleuronectes* (Linne) in Lingayen Gulf, Philippines. Ophelia **29(2),** 1533-168. http://dx.doi.org/10.1080/00785326.1988.10430826

del Norte-Campus A, Villarta KA. 2010. Use of population parameters in examining changes in the status of the Short-Necked Clam *Paphia undulata* Born, 1778 (Mollusca, Pelecypoda: Veneridae) in coastal waters of Southern Negros occidental. Science Diliman **22,** 53-60.

Gayanilo FC, Sparre P, Pauly D. 1996. FAO-

ICLARM Stock Assessment Tools (FiSAT) user's manual. FAO Computerized Information Series (Fisheries) **8,** p 266.

Gayanilo FC, Pauly D. 1997. The FAO-ICLARM stock Assessment Tools (FiSAT) Reference Manual FAO Computerized information Series (Fisheries). No.8, FAO, Rome, p 262.

Gayanilo FC, Sparre P, Pauly D. 2005. FAO-ICLARM stock assessment tools II (FiSAT-II). Revised version. Users guide. FAO Computerized Information Series (Fisheries) **8,** revised version. FAO, Rome.

Gosling EM. 2003. Bivalve molluscs; Biology, Ecology and Culture. Oxford, OX_2OEL, Fishing News Books, p 443.

Gould E, Fowler BA. 1991. Scallops and pollution. In: Shumway, S.E. (ed). Scallops: biology, ecology and aquaculture. Elsevier, Amsterdam, p 495-515.

Gulland JA. 1971. Fish resources of the ocean. FAO Fisheries Technical Paper (97). West Byfleet, Survey, Fishing News Books Ltd., p 425.

Hardy D. 2006. Scallop Farming 2nd Edition. Oxford: Blackwell Publishing, p 59-65.

Laureta LV. 2008. Compendium of the economically important seashells in Panay, Philippines. Quezon City, Philippines. The University of the Philippines Press, 162 p.

Llana MEG. 1979. Notes on the occurrence of pea crab (*Pinnotheres* sp.) in the Asian moon scallop (*Amusium pleuronectes* Linne.). Fisheries Research Journal of the Philippines **4(2),** 41-43.

Llana MEG. 1983. Size composition, occurrence, distribution and abundance of scallops in the Visayan Sea. Philippine Journal of Fisheries **16(2),** 75.94.

Llana MEG. 1988. Growth, mortality, and recruitment in the Asian moon scallop, *Amusium pleuronectes* in the Visayan Sea, Philippines. In Contr. Trop. Fish. Biol.: Papers by the participants at the FAO/DANIDA Follow-up Training Courses on Fish Stock Assessment in the Tropics, edited by Venema S. C., Christensen J. M., Pauly D., pp 16-24. Manila Philippines, 12 January-6 February 1987. FAO Fisheries Report **389,** 519, p Rome 1988.

Llana MEG, Aprieto VL. 1983. Reproductive biology of the Asian moon scallop *Amusium pleuronectes*. Fisheries Research Journal of the Philippines **5(2),** 1-10.

Lu YT, Blake NJ. 1997. Clearance and ingestion rates of *Isochrysis galbana* by larval and juvenile bay scallops, *Argopecten irradians concentricus* (Say). Journal of Shellfish Research **16,** 47-54.

Mendoza AB, Soliman VS. 2017. Coastal habitats of Asid Gulf, Masbate, Philippines: assessment and role of marine protected areas for management development. Aquaculture Aquarium Conservation and Legislation Bioflux **10(5),** 1351-1359.

Mendo J, Jurado E. 1993. Length-based growth parameter estimates of the Peruvian scallop (*Argopecten purpuratus*). Fisheries Research **15,** 357-367.
https://doi.org/10.1016/0165-7836(93)90086-M

Minchin D. 2003. Introductions: some biological and ecological characteristics of scallops. Aquatic Living Resources **16,** 521-532.
https://doi.org/10.1016/j.aquliv.2003.07.004

Morillo-Manalo L, Quinitio GF, Laureta LV, Anasco NC, Monteclaro HM. 2016. Ecology and reproductive biology of the senatorial scallop *Chlamys senatoria* (Gmelin 1791) in Gigantes Islands, Carles, Central, Philippines. Journal of Shellfish Research **35(1),** 17-25.
https://doi.org/10.2983/035.035.0103

Nurul-Amin SM, Zafar M, Barua M. 2009.

Population dynamics of Venus Clam *Meretrix meretrix* from the Moheshkali Island in the Cox's Baxar Coast of Bangladesh. Asian Fisheries Science **22,** 1031-1043.

Orensanz JM, Parma AM, Iribarne OO. 1991. Population dynamics and management of natural stocks. In: Shumway, S.E. (ed). Scallops: biology, ecology and aquaculture. Elsevier, Amsterdam, p 625-713.

Pauly D, Gaschuetz, G. 1979. A simple method for fitting oscillating length growth data, with a program for pocket calculators. ICES CM 1979/G:24. Demersal Fish. Cttee., 26 p (mimeo).

Pauly D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal of de Conseil, Conseil International Pour L'Explorat de la Mer **39,** 175-192.

Pauly D. 1983. Some simple methods for the assessment of tropical fish stocks. FAO Fisheries Technical Paper **234,** 1-52.

Pauly D. 1984. Length-converted catch curve: A powerful tools for fisheries research in the tropics (part II). ICLARM Fishbyte **2,** 17-19.

Pauly D, Munro J. 1984. Once more on growth comparisons in fish and invertebrates. Fishbyte **2(1),** p 21.

Peña JB. 2001. Taxonomía, morfología, distribución y hábitat de los pectínidos Iberoamericanos. In: A.N. Maeda-Martínez (ed.). Los moluscos pectínidos de Iberoamérica: ciencia y acuicultura, Editorial Limusa, México, p 1-25.

Poutiers JM. 1998. Bivalves (Acephala, Lamellibranchia, Pelecypoda). In: Carpenter, K. E. & V. H. Niem, editors. FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific **1,** Seaweeds, corals, bivalves and gastropods. Rome, Italy: FAO., p 123–362.

Soliman VS, Dioneda RR. 2004. Quick stock assessment of commercial scallops (Bivalvia: Pectinidae) in Asid Gulf, Masbate. University of the Philippines in the Visayas Journal of Natural Science **9(1),** 165-176.

Sparre P, Ursin E, Venema SC. 1992. Introduction of tropical fish stock assessment, Part 1 Manual, FAO Fisheries Technical Paper **306(1),** Italy, Rome. FAO, p 337.

Stotz W, Mendo J. 2001. Pesquerías, repoblamiento y manejo de bancos naturales de pectínidos en Iberoamerica: su interacción con la acuicultura. In: A.N. Maeda- Martínez (ed.). Los moluscos pectínidos de Iberoamérica: ciencia y acuicultura, Editorial Limusa, México, p 357-374.

Strand O, Volstad JH. 1997. The molluscan fisheries culture of Norway. NOAA Technical Report NMFS 129. US Department of Commerce, p 7-24.

Telahigue K, Hajji T, Cafsi M, Saavedra C. 2018. Genetic structure and demographic history of the endemic Mediterranean scallop *Pecten jacobaeus* inferred from mitochondrial 16s DNA sequence analysis. Animal and Biodiversity Conservation **41(1),** 61-73.

Waller TR. 1991. Evolutionary relationships among commercial scallops (Mollusca:Bivalvia:Pectinidae). In: Shumway, S.E. (ed). Scallops: biology, ecology and aquaculture. Elsevier, Amsterdam, p 1-73.