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Assessment of the commercial stock of Distant Scallop (*Bractechlamys vexillum*, Reeve 1853) in Asid Gulf, Philippines

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Abstract

The study investigated the growth, mortalities, recruitment, yield-per-recruit and exploitation rates of the commercially important Distant scallop (*Bractechlamys vexillum*) in Asid Gulf, Philippines as basis for interim management. The fishery is economically valuable because it produces the highest yield of scallop in the country on a per unit area basis. Optimum total monthly length frequency data (n=3,987) were collected from April 2018 to March 2019. Using an objective fishery software to analyze the data, the growth (K) was revealed to be 0.65/year attaining an asymptotic shell height (SH_∞) of 7.98 cm. Recruitment pattern was continuous and bimodal with minor and major peaks in April and August, respectively. The total instantaneous mortality (Z) is 3.18/year with fishing (F) and natural mortality (M) of 2.637 and 0.543, respectively. Current exploitation ratio (E_{curr}) of 0.83 is higher than the biological reference point (BRP) E_{10} (0.816) and E_{50} (0.428). However, E_{curr} is lower than the estimated exploitation at maximum sustainable yield (E_{max} = 0.907). Relative to the estimated E_{max}, the present result is a good indicator that the stock has the potential for recovery from an overexploited state. This may be due to the reduced fishing effort, increase in length at first capture (L_{50}), size restriction by traders and the existing close season ordinance in the Municipality of Cawayan. Nevertheless, strict management measures must be put in place to prevent future collapse of the stock. The fast growth and the availability of recruits encourage prospects for mariculture.

Keywords: Stock assessment; Biological reference points; Growth parameters.

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1. Introduction

The scallop fishery in Asid Gulf, Masbate in southern Luzon, Philippines is dominated by a five-species complex of commercially harvested true scallops, Family Pectinidae. The production of commercial scallop in the gulf has reached an all-time high of 11,000 tons in 2003 (Soliman and Dioneda, 2004), and since then, declined to 2,308 tons and 1,554 tons in 2007 and 2017, respectively (Bobiles and Soliman, 2018). The top contributor of the scallop production in the gulf is the Distant scallop (*Bractechlamys vexillum*), previously identified as *Decatopecten striatus*) that comprised the majority (57%) of scallop production (Soliman and Dioneda, 2004; Bobiles and Soliman, 2018). From mid-afternoon to night-time within the villages of Naro Island of Cawayan, Masbate, the processing of harvested scallops from the gulf is uniquely wasteful because only the adductor muscles are traded while the shells and the other soft parts are thrown away. The adductor muscles are being sold to local traders in Naro Island, who sell them to outlets in the nearby cities of Cebu and Iloilo which ultimately export them to other countries. Market channels and the value chain for scallops from the gulf are not well studied. World import for scallops from January to September 2018 was 104.5 thousand tons with China and the United States of America as the major destinations (FAO, 2019). Because of the high demand for the scallop's adductor muscle, the natural stock in the gulf has been reported to be depleted as early as 1999 (Soliman and Mendoza, 2005). In 2008, the reported very poor scallop harvest has displaced hundreds of scallop divers from their livelihood (Bobiles and Soliman, 2018). These events reflect vulnerability of natural scallop stock to overharvesting that is linked to its open-access system. For most of the gulf, fishers solely decide on the volume to be harvested, time and place of operation, and size at harvest of scallops. This free-for-all fishing regime exempts the coast of Cawayan where closed season for scallop harvesting from December to March has been implemented in 2011 through a local ordinance.

The open-access, unregulated harvesting of scallops is a common concern for all scallop fishing grounds in the Philippines and elsewhere in the world. Results from other studies for major scallop resources in the Philippines, (e.g. Gabral-Llana, 1988; Del Norte, 1988; Soliman and Dioneda, 2004), represent the significance of generating up-to-date information of the status of the stocks. Length-based stock assessment studies have been undertaken for the species *Amusium pleuronectes* in the Visayan Sea (Gabral-Llana, 1988) and Lingayen Gulf (Del Norte, 1988) that reported overexploitation of this important resource. In Asid Gulf, key species of commercial scallops were assessed using similar method and were found to be overexploited as well (Soliman and Dioneda, 2004; Bobiles and Soliman, 2018). These previous studies underscore the usefulness of the length-based methods in assessing commercial scallop stocks and prospectively with this study in providing biological reference points (BRPs) for rationale exploitation. These biological reference points when used to set targets or limits, represents a tradeoff between mankind's utilization of a living resource and the resource's life history traits and productivity (Smith and Rago, 2004). This study is a full-blown stock assessment to determine the current exploitation ratio of *B. vexillum* on the premise that up-to-date information on exploitation level and biological reference points (BFPs) are critical in managing heavily exploited stocks for sustainable fisheries including prospect for increasing production through mariculture. Yield prediction offers basis to decisions pertaining to stock regulation, thus, requiring data on growth, recruitment, and natural and fishing mortality rates. Mariculture requires proper timing for spat collection that rely on information from the recruitment pattern of *B. vexillum* stock. Considering that *B. vexillum* constitutes more than half of the scallop production in the gulf, the current status of this dominant species will likely reflect the condition of the multi-species scallop industry in Asid Gulf and will set the basis and trend for the implementation of gulf-wide scallop management strategies.

2. Materials and methods

2.1. Description of the scallop fishery and the study area

The study was undertaken in Asid Gulf located in the southern coast of mainland Masbate province, Philippines. The southern coast is composed of five Municipalities bordering the gulf. One of which, the municipality of Cawayan, is known for scallop harvesting, specifically in Naro Island. Within Naro Island, the fisherfolk in the Barangays of Talisay, Punta Batsan, and Looc capture most of the scallop in Asid Gulf and they land the catches in their respective households for further processing of the adductor muscle. Scallops are being harvested through "hookah diving" using a boat equipped with a compressor that supplies the air through a plastic hose. The hose is attached to the mouth of the diver as a breathing device. The divers harvest wild scallops by

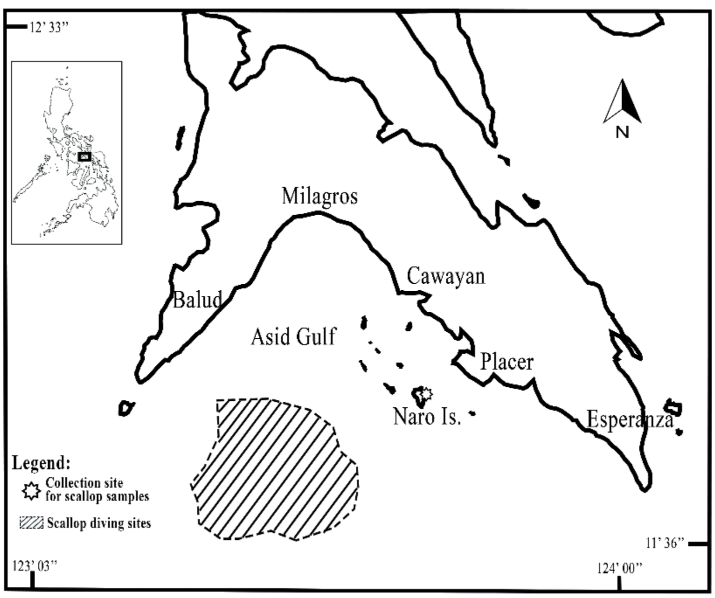

Figure 1. Map of the study area (Philippine map inset) showing the five Municipalities bordering Asid Gulf and Naro Island as the collection sites for *B. vexillum*; locations of scallop diving sites are approximated (hatched polygon)

handpicking the animals on the bottom. The map of Asid Gulf indicating Naro Island as the collection site for the Distant scallop samples is illustrated in Figure 1.

2.2. Collection of samples

The limitations of length-based methods for stock assessment were primarily taken into consideration. The requirements for the length-based stock assessment method such as optimum sample size, progression of modes from the monthly length frequencies and the coverage of wet and dry season have been complied. Representative monthly samples (n > 300) were randomly collected from April 2018 to March 2019. Samples were collected from the commercial catches of scallop compressor divers concentrated in the three Barangays. Samples were cleaned of any fouling organisms and measured right after collection. Shell height (SH) (i.e., maximum anterior-posterior axis) and shell width (SW) (i.e., maximum dorso-ventral axis) were measured to the nearest 0.01 mm using a digital vernier caliper. During sample collection, informal interviews were simultaneously conducted with the scallop divers to generate useful data from their observations and perceptions.

2.3. Assessment of population parameters

The electronically recorded monthly length frequency data were grouped into length classes by 0.5 cm interval using a spreadsheet program. Subsequently, the spreadsheet data were initially analyzed to generate its length-frequency distribution (LFD). The LFD data were copied unto and analyzed using FISAT II Ver. 1.2.2 (Gayanilo *et al*., 2005) to generate estimates of growth, mortality, recruitment, biomass and yield-per-recruit and exploitation rates. The initial estimate of the asymptotic shell height (SH_∞) was generated using the Powell-Wetherall plot (Wetherall, 1986). The value of SH_∞ was further processed using the ELEFAN I function (Pauly and David, 1981) for the validation of the fit of SH_∞ and the growth coefficient (K) of the von Bertalanfy Growth Formula (VBGF):

$$SH_t = SH_\infty\,(1 - exp^{-k\,(t-t_0)})$$

where,
SH_t is shell height-at-age;
SH_∞ is the asymptotic shell height;
k is the growth coefficient;
t_0 is the age at which shell height is 0.

The growth curve was fitted to the monthly length frequency data by varying the values of K until a maximum value of the goodness of fit criterion (Rn) was achieved so that the curve passes through as many distribution modes as possible. From the estimates of K and $SH_{\infty,}$ the growth performance index (Ø) was computed using the formula Ø = 2 log10L_∞ + log10K (Pauly and David, 1981). Longevity was computed using the rearranged VBGF formula for the relative age (t) at maximum observed shell height (SH_{max}), and the relative age at optimum harvest (t_{L50}) was determined using the same process. The normal distribution of the monthly length frequency data was initially determined using Bhattacharya's method and further refined using NORMSEP (Pauly and Caddy, 1985).

The total mortality (Z) was estimated using the length-converted catch curve method (Pauly, 1984). The value of natural mortality (M) was taken as the average value of M from published literature (i.e., Orensanz *et al*., 1991) previously used in various studies in Asid Gulf (e.g. Soliman and Dioneda, 2004; Bobiles and Soliman, 2018; Buban *et al*., 2020). Upon the estimation of Z and M, the fishing mortality was calculated using the formula F=Z-M. The exploitation rate (E) was obtained from the equation E=F/Z (Gulland, 1971). The relative yield and biomass-per-recruit (*Y'/B'PR*) were estimated using the modified model of Pauly and Soriano (1986) assuming knife-edge selection. Using the recruitment analysis routine, the recruitment pattern was obtained by projecting the length frequency data backward onto the time axis (by means of the growth parameters) down to zero length (Pauly, 1982; Moreau and Cuende, 1991).

3. Results

3.1. Size frequency distribution

The large sample size (n=3,987) collected in the study allowed the inclusion of very large (7.51 cm) and very small (1.96 cm) *B. vexillum* that afforded the adequate representation of the exploited stock. Majority (52.45%) of the samples are within the size range of 52.5–62.6 cm SH (Figure 2). The highest vertical axis represents the class size with the highest number of individuals and the total number of individuals (n) for all length classes is 3987.

3.2. Growth and longevity

The asymptotic shell height (SH_{∞}) initially derived from the Powell-Wetherall plot was 7.78cm using the cut off length of 5.75cm. The growth constant (K) of the VBGF was 0.65/year and the fit of the growth curve plotted against the monthly length frequency distribution is shown in Figure 3. The final value of SH_{∞} that provided the optimum fit to the growth (K) is 7.98 cm (R_n = 0.233). The calculated growth performance index (Ø) is 1.78. The smallest individual (1.96 cm, SH) is estimated to be 0.43

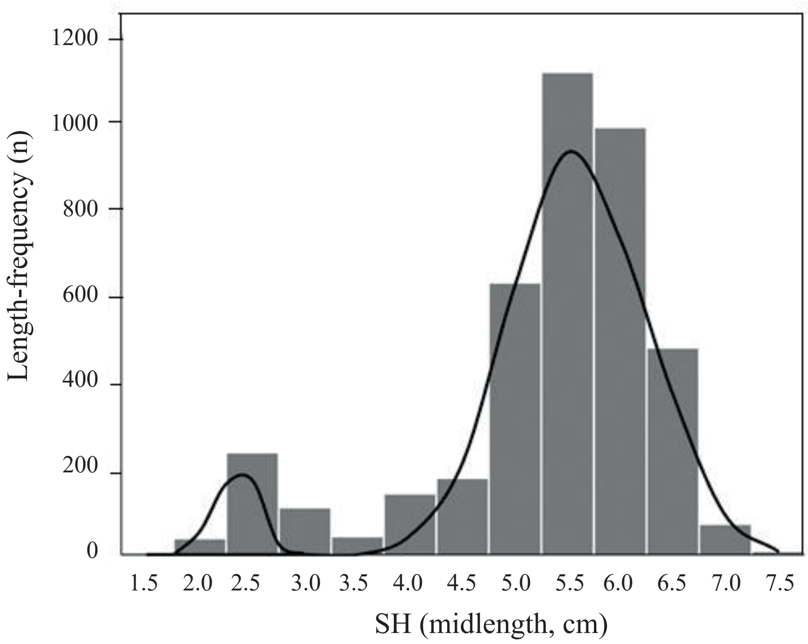

Figure 2. Length-frequency distribution of *B. vexillum* superimposed with the normal curve, total number of individuals, n =3987

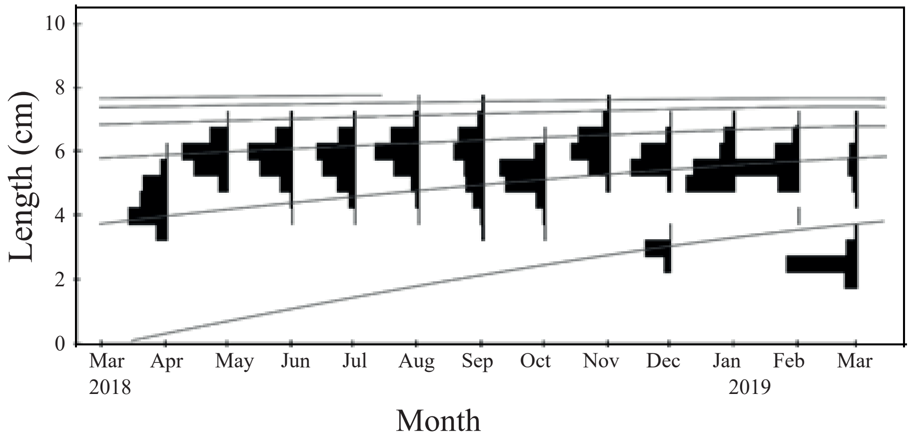

Figure 3. Growth curve of the non-oscillating VBGF form for *B. vexillum* fitted over the monthly length-frequency data as a graphic output based from FISAT II

years while the largest (7.51 cm, SH) is 4.37 years with the latter representing the estimated longevity of the species. The relative age at optimum harvest (t_{L50}) was estimated at 2 years.

3.3. Recruitment pattern

Recruitment pattern of *B. vexillum* was continuous and bimodal throughout the year (Figure 4). Two peak pulses were observed, a minor recruitment peak in April and a major peak from August to September. The two pulses contributed 18.71% and 19.74% to the total recruitment for the year.

3.4. Mortality parameters and relative yield/-biomass-per-recruit analysis

The length-converted catch curve analysis produced a total mortality (Z) of 3.18/year (Figure 5). The estimated fishing mortality

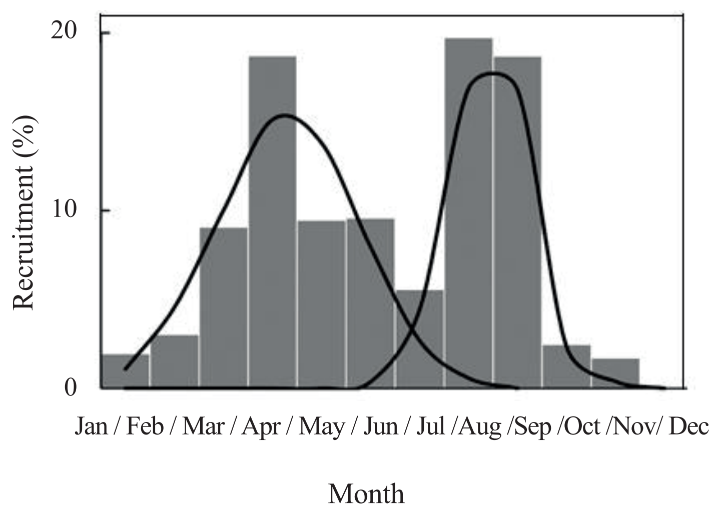

Figure 4. Temporal recruitment pattern of *B. vexillum* superimposed with the normal distribution (two pulses of recruitment in April and September)

(F) is 2.637/year with natural mortality (M) estimate of 0.543. The yield-per-recruit (Y′/R) and biomass-per-recruit (B′/R) analyses (Figure 6) revealed that the current exploitation ratio (E_{curr}) of 0.83 exceeded the biological reference points (BRPs) E_{10} (0.816) and E_{50} (0.428) by 1.7% and 93.9%, respectively.

4. Discussion

Generating an exploitation index relative to biological reference points are vital in monitoring fisheries stock status, especially for an overexploited species. The Distant scallop (*B. vexillum,* previously identified

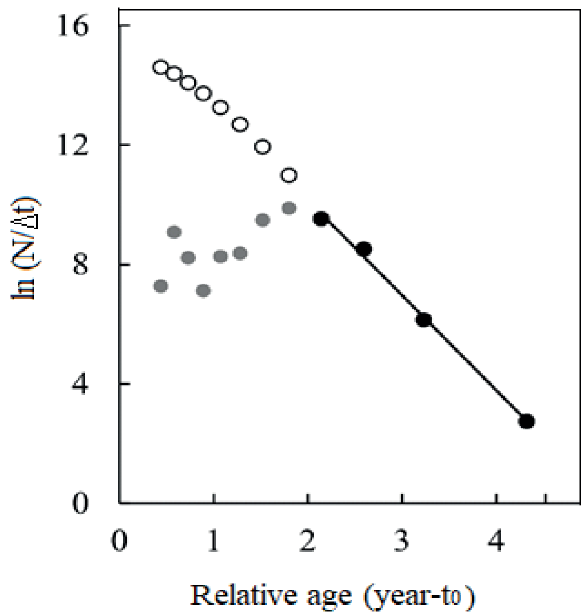

Figure 5. Length-converted catch curve for the estimation of total mortality (Z) of *B. vexillum*

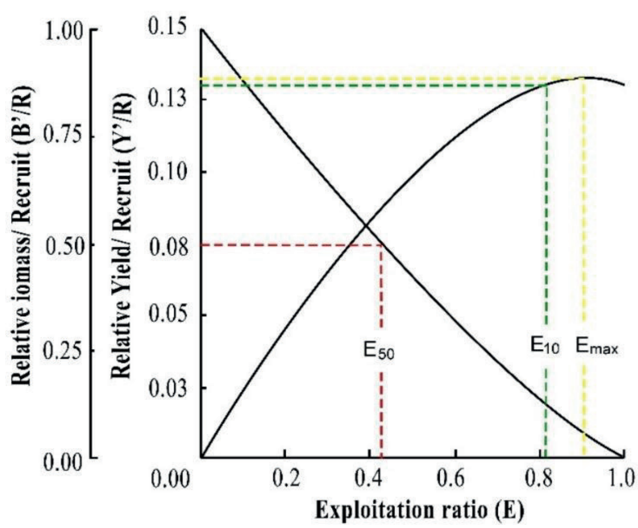

Figure 6. Relative yield-per-recruit (Y’/R) and biomass-per-recruit (B’/R) of *B. vexillum* to estimate the biological reference points (E_{max}, E_{10}, and E_{50}) in relation to one another

as *Decatopecten striatus*) in Asid gulf were reportedly overexploited in 2003 (Soliman and Dioneda, 2004) and 2007 (Bobiles and Soliman, 2018). The result of the present study shows positive signs of recovery. The estimated current exploitation ratio (E_{curr} = 0.83) is lower than the estimated exploitation at maximum sustainable yield (E_{max} = 0.907). However, the E_{curr} ratio still exceeds the BRPs E_{10} and E_{50} by 1.7% and 93.9%, respectively. The BRP E_{10} suggests a level of exploitation at which the marginal increase in yield-per-recruit reaches 10% of the marginal increase computed at a very low value of E while E_{50} suggests 50% exploitation of the available virgin biomass (Gayanilo *et al*., 2005). Buban *et al*. (2020) suggested the use of the BRP E_{50} to be adopted for the Buried fan scallop (*Mimachlamys funebris*) in Asid Gulf considering the very low variability of values despite high variation of natural mortalities used is the analysis. Thus, despite the positive sign of recovery for *B. vexillum*, reduction in exploitation level is still recommended with reference to BRP E_{50} as a safeguard measure to prevent future collapse of scallop stocks. In this case, E_{curr} should be reduced by 48%. This suggestion is based on several concerns that were observed during the study. First, the fact that the E_{curr} is very close to the biological limit (E_{max}), an increase in fishing effort originating from the free-for-all open access regime in Asid Gulf may eventually cause the collapse of the natural scallop stocks. Second, scallop divers are persistently pursuing larger scallops that lead them to desperately dive into deeper areas in the Gulf. The deeper areas in Asid Gulf is believed to be the natural sanctuary for the spawning stock population of *B. vexillum* (Buban *et al.,* 2020). For very long years these areas were exempted from scallop harvesting due to high risk of the deep-water diving. But at present, these areas are the new harvesting grounds as demand for larger scallops' increase which may lead to recruitment overfishing. The persistence of the scallop divers' poses danger not only to the resource, but also to the resource-dependents (scallop divers).

On a positive note, the implication of stock recovery can be explained by several reasons. First, there has been an observed decrease in the level of exploitation (E_{curr}) for *B. vexillum* (previously *D. striatus*) relative to that of 2007 (Table 1). This decadal decrease in exploitation level from 2007 to 2017 is the result of the decrease in fishing effort in the gulf through the years. The average number of fishing boats operating for a whole year varies from 200-250 in 2003 and declined to 100-250 in 2017 (Bobiles and Soliman, 2018). Second, the estimated SH at first capture (L_{50}) increased from 3.09 cm in 2007 (Bobiles and Soliman, 2018) to 5.81 cm in 2017. The present L_{50} estimate is close to the estimated length-at-first maturity (L_{mat}) of 6.01 cm (Soliman and Dioneda, 2004). For a closely related species *Chlamys senatoria* in the adjacent Visayan Sea, the estimates of L_{mat} were 5.71cm and 5.95 cm for male and female, respectively (Morillo-Manalo *et al.,* 2016). Therefore, the current scallop fishery exploited more mature individuals as compared to the immature scallop harvesting in 2007. The change in the sizes of the currently harvested scallop is influenced by the size restriction imposed by the local traders that is positively affecting the recovery of the stock. Only the large adductor muscle from large scallop is being bought from the scallop diver, but this is not always consistent as few smaller adductor muscles from small scallops are still accepted at times, and only for local distribution. This has been reflected in the varying sizes of catches ranging from size as small as 1.96 cm to as large as 7.51 cm. Finally, the existence of a close season ordinance in the municipal water of Cawayan Masbate may have contributed to the positive recovery of the stock.

The growth, large size and temporal recruitment of *B. vexillum* highlights a positive implication to mariculture. A study on the morpho-biometric characters of *B. vexillum* initially highlighted its mariculture potential (Buban *et al*., 2019). The current estimate of the asymptotic shell height (SH_{∞} = 7.98 cm) for *B. vexillum* was very close to SH_{∞} values previously estimated in the studies of Bobiles and Soliman (2018) and Soliman and Dioneda (2004) (Table 1). Interestingly, the estimated SH_{∞} in the present study is relatively bigger than the reported SH_{∞} of less than 4.2 cm (Wantiez and Thollot, 2004) and 4.74 cm (Lefort and Clavier, 1992) for *B. vexillum* in New Caledonia. In comparison to other Philippine Pectinids, SH_{∞} of *B. vexillum* is similar with *Chlamys senatoria nobilis* (Soliman and Dioneda, 2004), but smaller as compared to *Chlamys funebris* (Soliman and Dioneda, 2004; Bobiles and Soliman, 2018; Buban *et al.,* 2020;) and *Amusium pleuronectes*. The growth coefficient (K) in the present study is higher than the estimated value in 2003 (Soliman and Dioneda, 2004), but is relatively lower than that of 2007 (Bobiles and Soliman, 2018). The value of K estimated for *B. vexillum* is higher as compared to *C. senatoria nobilis* (Soliman and Dioneda, 2004), nearly similar with that of *C. funebris* (Bobiles and Soliman, 2018), but relatively lower than *A. pleuronectes* (Del Norte, 1988; Gabral-Llana, 1988). The big size and high growth rate of *B. vexillum* is a good indicator for future mariculture prospect for the species. If *B. vexillum* will be cultured

Table 1. Comparison of growth parameters (asymptotic shell height, SH_{∞} and growth, K/year) and exploitation ratio (E) for the different scallop species in the Philippines

Location	Species	Year of study	SH_{∞} (cm)	K/year	E	Studies
Asid Gulf	*Bractechlamys vexillum*	2018-19	7.98	0.65	0.83	Present study
Asid Gulf	*Decatopecten striatus* (now *B. vexillum*)	2007	7.88	1.11	0.90	Bobiles and Soliman (2018)
Asid Gulf	*Decatopecten striatus* (now *B. vexillum*)	2003	7.70	0.51	0.60 & 0.63	Soliman and Dioneda (2004)
Asid Gulf	*Mimachlamys funebris*	2020	10.1	1.1	0.80 & 0.90	Buban *et al*. (2020)
Asid Gulf	*Chlamys senatoria nobilis*	2003	7.90	0.46	0.58 & 0.60	Soliman and Dioneda (2004)
Asid Gulf	*Chlamys funebris*	2003	8.22	0.46	0.70 & 0.75	Soliman and Dioneda (2004)
Asid Gulf	*Chlamys funebris*	2007	11.29	0.67	0.89	Bobiles and Soliman (2018)
Lingayen Gulf	*Amusium pleuronectes*	1985-86	10.60	0.92	0.74	Del Norte (1988)
Visayan Sea	*Amusium pleuronectes*	1976-77	10.0	0.94	0.69	Gabral-Llana (1988)

from the recommended initial stocking size of 3.5 cm (Buban and Soliman, 2019) it could reach about 5.6 cm after a year. The result showed that *B. vexillum* is a fast growing and short-lived scallop. This characteristic is similar with the scallop *A. pleuronectes* in Lingayen Gulf, Philippines (Del Norte, 1988). Short-lived and fast growing species include scallops that are restricted to shallow coastal water (<10 m) with reported longevity for species like *Argopecten irradians* (1.9 years, Bricelj *et al.*, 1987), *Chlamys varia* (7-8 years, Conan and Shafee, 1978) and *Chlamys tehuelcha* (6 years, Orensanz, 1984).

The continuous recruitments with two high recruitment pulses are corresponded to the larval settlement of *B. vexillum* and are similar to other pectinids in the Philippines. For example, the species *C. senatoria* (Morillo-Manalo *et al.,* 2016) and *A. pleuronectes* (Del Norte, 1988) spawn continuously throughout the year with two peaks observed in August (minor peak) and December to February (major peak). Considering the pattern of spawning in these scallop species, the recruits in the months of April and August to September observed in this study may correspond to the spawning seasons of *B. vexillum*. The peak recruitment observed from August to September corroborates with the result of the study conducted by Chauvet (2000) for *B. vexillum* in New Caledonia Lagoon. At present, there have been no studies undertaken to directly determine the spawning and spat settlement season of *B. vexillum* in Asid Gulf which could be explored for validation in the near future. Knowledge of the recruitment pattern for this species is vital for the mariculture initiative in Asid Gulf, especially in guiding the proper timing of setting-up of spat collectors. The result of the present study provided up-to-date information on the status of the *B. vexillum* commercial stock that is currently recovering. However, to prevent the collapse of scallop stock in the future, the present result can be used as the basis for the implementation of interim management approaches. The suggestions of Buban *et al*. (2020) which included strict implementation of the close season policy, was setting aside a no-take zone and recruit-replenishment area for scallop, improving marketability and market opportunities for the harvested scallop and, exploring mariculture potential. Most importantly, it is imperative to have sustained and continuous support from the Local Government Units bordering the gulf, the scallop fishers, and traders.

Conclusion

The current study shows positive sign of recovery for the Distant scallop (*Bractechlamys vexillum*). However, the current exploitation level is very close to the biological limit of the maximum sustainable yield, thus the BRP E_{50} is suggested to be adopted as basis for interim management necessary to improve the scallop fishery at the same time protect the natural scallop beds. The situation necessitates improvement of enforcement in the current management approaches vis-à-vis provision of livelihood opportunities. Together with the suite of technical management measures, mariculture is a viable option in reducing exploitation on the natural stock, which at the same time would increase production potential given the high growth rate of the species. This option is further supported by the availability of the recruits throughout the year with peak pulses as guide in collecting spat for grow-out culture.

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