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**Original Article**

# Sinusoidal growth, recruitment, mortality, yield-per-recruit analysis of Buried fan scallop *Mimachlamys funebris* (Reeve, 1853) and their implications for mariculture

**Ian Cris R. Buban • Christian D. Cabiles • Renan U. Bobiles • Alex P. Camaya • Victor S. Soliman**

*Coastal Resource Management Section, Bicol University Tabaco Campus, 4511 Tabaco City, Philippines*

**Correspondence**
Victor S. Soliman; Coastal Resource Management Section, Bicol University Tabaco Campus, 4511 Tabaco City, Philippines.

vssoliman@bicol-u.edu.ph

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**Abstract**
This study described the growth, mortality, recruitment pattern and exploitation rate of the Buried fan scallop (*Mimachlamys funebris*) in Asid Gulf, Philippines. Monthly length-frequency data ($N$=3988) from April 2018 to March 2019 were used to examine population parameters using FISAT II. Two estimates of natural mortalities were used to compare variability of limit exploitation rates. Modelling through the oscillating von Bertalanffy growth function revealed that the species is fast growing ($K$=1.1 year$^{-1}$) attaining $SH_\infty$ of 10.5 cm. Adequacy in the use of the sinusoidal version of the growth formula hinges on the mean annual temperature difference reported in the gulf to be 2°C. Recruitment pattern was continuous and bimodal throughout the year with two high pulses in April–May and September consistent with the reproductive seasonality reported for congeneric species. Fishing mortality coefficients (4.26 and 4.82 year$^{-1}$) were higher than the natural mortality coefficients (0.543 and 1.1 year$^{-1}$). Yield and biomass-per-recruit analysis showed that the current exploitation rates are 112% ($E_{curr1}$ = 0.90) and 92% ($E_{curr2}$ = 0.80) higher than the biological reference points adopted for the study particularly $E_{50}$. These results demonstrate that *M. funebris* stock is overexploited, which necessitates effective management measures including mariculture.

**Keywords:** Length-frequency analysis; population parameters; stock assessment; sustainable management.

## 1 | INTRODUCTION

The scallops, family Pectinidae, constitute one of the most economically important commercial bivalve resources worldwide that support both commercial fisheries and mariculture efforts (Shumway and Parsons 2016). The commercial fisheries for pectinids have led to over-exploitation of some species especially in areas where resource management systems are not properly implemented or lacking. Notable species reportedly overexploited include *Argopecten purpuratus* in Peru (Stotz and Gonzales 1997), *A. ventricosus* in Panama (Medina *et al.* 2007) and *Euvola ziczac* in Brazil (Pezzuto and Borzone 2004). In the Philippines, the species *Amusium pleuronectes* (Linnaeus 1758) were heavily exploited in the Visayan Sea (Gabral-Llana 1988) and in Lingayen Gulf (Del Norte 1988).

Currently, Asid Gulf, located in southern Luzon in the province of Masbate, is one of the commercially major scallop fishing grounds in the Philippines Island. Multiple species of scallops are being harvested in the gulf of which at least five species are considered true scallops (Pectinids) and are harvested at commercial scales (Soliman and Dioneda 2004). The reported production of 11000 MT of whole scallops in 2003 (Soliman and Dioneda 2004) is higher than any annual yield of scallops reported for the period 1997 – 2014 in the Philippines (Bobiles and Soliman 2018). The Buried fan scallop *Mimachlamys funebris* (Reeve, 1853) constituted a considerable portion of this production (39%). Ironically, this high production is a result of unregulated harvesting that ultimately led to the decline of the scallop stock in the gulf (Soliman and Dioneda 2004; Bobiles and Soliman 2018). The situation is attributed to the open access characteristic of the fishery where the only limitation for harvesting the scallops is the capacity of the boat and adverse weather conditions. The only exception is the municipality of Cawayan where closed season for scallops harvesting from December to March in Municipal waters has been implemented since 2011 with the passage of a local ordinance.

Soliman and Dioneda (2004) conducted an assessment of the buried fan scallop based on length-frequency analysis using quick stock assessment techniques. After four years (in 2007), a follow-up scallop stock monitoring was conducted by Bobiles and Soliman (2018). However, these studies were based on a single estimate of natural mortality ($M$) computed as the average of $M$ from published literature. Direct estimate of $M$ can only be obtained from a completely unfished stock (Pauly 1980) whereas contemporary effort data for the species are not available, thus estimating the value of $M$ is very difficult. In order to ensure that a reliable $M$ of the Buried fan scallop was covered in the analysis, the present study considered different estimates of $M$. The first $M$ estimate is based on the previous studies (*i.e.* Soliman and Dioneda 2004; Bobiles and Soliman 2018) and the other estimate assumed $M = K$ (growth coefficient). The second estimate was grounded on the close relationship between the natural mortality and the growth constant (Pauly 1980) in the von Bertalanffy Growth Function (VBGF). The VBGF for *M. funebris* depicts an oscillating pattern, hence, the use of the sinusoidal VBGF form. Suitability on the use of the oscillating VBGF substantiates the idea that even for tropical species, detectable seasonal growth oscillation can be induced by seasonal temperature differences as small as 2°C (Pauly 1990).

The present study hinges on the necessity to provide up-to-date information on the current exploitation rate and the biological reference points (BRPs) for exploitation of the resource as vital inputs for rational management approaches and mariculture efforts. The BRPs will be used to set target limits for exploitation of the species. BRPs represent a trade-off between resource utilisation and the resources' life history traits and productivity (Smith and Rago 2004). Information generated on the species such as growth, recruitment and fishing mortality rates are necessary inputs for yield prediction which are basis to decisions on resource management. Furthermore, scallop mariculture requires data on proper timing for spat collection that can be indicated by the information from the temporal recruitment pattern of the species.

## 2 | METHODOLOGY

### 2.1 Description of the scallop fishery and the study area

Asid Gulf is located in Bicol region, south of mainland Masbate province, Philippines (Figure 1). The southern coast is composed of five municipalities bordering the gulf *viz* Balud, Milagros, Cawayan, Placer and Esperanza. It is one of the major fishing grounds for finfishes and invertebrates in the country. Scallops (Pectinids) are particularly harvested in this fishing ground in commercial quantities. Scallop divers are mostly concentrated in the Municipality of Cawayan specifically in Naro Island. Harvesting of scallops in the gulf makes use of a boat equipped with an air compressor that supplies the air requirement of the diver through plastic hose attached to the mouth of the diver as a breathing device (generally referred to as "hookah diving"). Using this method, the divers literally pick the scallops in the seabed. Harvested scallops are then transported to Naro Island where the pre-processing of the scallop's adductor muscles commences at around late in the afternoon until the evening. The muscles are sold direct to local buyers in the area who sell the pre-processed muscles to Iloilo and Cebu for foreign markets.

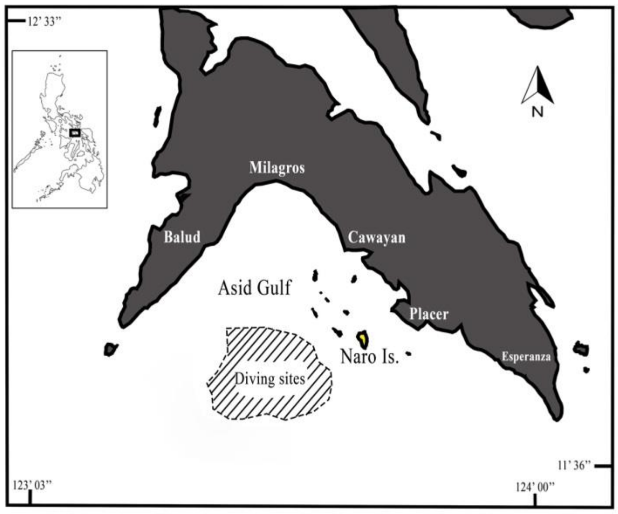


**FIGURE 1** Map of the study area (Philippine map inset) showing Asid Gulf and Naro Island as the collection site for *Mimachlamys funebris*; locations of scallop diving sites are approximated (hatched polygon).

### 2.2 Data collection

Representative monthly sample specimens ($n > 300$) of *M. funebris* were randomly collected from April 2018 to March 2019. These specimens ($N = 3988$) were obtained from the commercial landings of scallop in three Barangays namely Punta Batsan, Looc and Talisay of Naro Island, Cawayan, Masbate following the procedures of Soliman and Dioneda (2004). The scallops were cleaned and measured right after collection. Shell height (SH; maximum anterior-posterior axis) and shell width (SW; maximum dorso-ventral axis) were measured to the nearest 0.01 mm using a digital vernier caliper (Gross EDC/6). 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

Key requirements of length-based methods for stock assessment were primarily taken into consideration in the study. These were optimum sample size, progression of modes from the monthly length frequencies, capturing the species' reproductive spectrum and the coverage of wet and dry seasons in the gulf. Initially, the length-frequency data were encoded using a spreadsheet software to generate size frequency distribution with appropriate class interval and number of classes. The specimens for May and September were tested for normality using Shapiro-Wilk test at 0.01 alpha level. Normal distribution of samples for these months was necessary as they represent the peaks of recruitment. These months represent the dry and wet seasons that were considered in a recent study on the morpho-biometric relationships of scallop in Asid Gulf (Buban *et al.* 2019). The data were analysed using FISAT II (version 1.2.2) to generate estimates of growth, mortality, recruitment pattern, and exploitation rates (Gayanilo *et al.* 2005). Initial estimate of the asymptotic shell height ($SH_\infty$) was generated using the Powell-Wetherall plot (Wetherall 1986). This initial estimate was further processed using ELEFAN I function (Pauly and David 1981) for the validation of the fit of $SH_\infty$ and the growth coefficient ($K$) of the oscillating VBGF:

$$SH_t = SH_\infty * (1 - e^{-K_*(t-t0) + (CK/2\pi_* \sin(2\pi_*(t-ts))) - (CK/2\pi_* \sin(2\pi_*(t0-ts)))})$$

Where $SH_t$ is shell height-at-age, $SH_\infty$ is the asymptotic shell height, $K$ is the growth coefficient, $t_0$ is the age at which shell height is 0, $t_s$ is the onset of the first oscillation relative to t = 0 (or $t_s$ = winter point + 0.5), and $C$ is the intensity of the (sinusoid) growth oscillations.

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 ($R_n$) was achieved so that the curve passes through as many peaks as possible. From the estimates of $K$ and $SH_\infty$, the growth performance index (Ø) was computed using the formula:

$$Ø = 2 \log10 L_\infty + \log10 K \text{ (Pauly and David 1981)}$$

Longevity was computed using the rearranged oscillating VBGF formula for relative age ($t$) at maximum observed shell height ($SH_{max}$). 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). Using the recruitment analysis routine, the temporal pattern was obtained by projecting the length-frequency data backward onto the time axis (using the growth parameters) down to zero length (Pauly 1982; Moreau and Cuende 1991).

Mortalities in fishery biology research are typically expressed as instantaneous coefficient values. Natural mortality ($M$) is one of the most difficult population parameters to estimate. For scallops, various methods have been used to directly estimate $M$ including mark-recapture (tagging) experiments (Brand *et al.* 1991; Allison and Brand 1995), cluckers ratio (Ciocco 1996) and catch-at-age analysis (Gutiérrez and Defeo 2005). Direct estimates of $M$ for *M. funebris* using these methods are not available considering the relative difficulty and limitation of these methods. Thus, alternative methods for estimating $M$ was used such as $M_1$ (0.543) averaged from different species of pectinids from published literatures (Orensanz *et al.* 1991) and assuming $M_2 = K$. Total mortality ($Z$) was estimated using the length-converted catch curve method (Pauly 1984). Upon the estimation of $Z$ and $M$, the fishing mortality ($F$) was calculated ($F = Z – M$). Exploitation rate ($E$) was obtained from the equation $E = F / Z$. 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.

The biological reference points (BRPs) were generated from the $Y'/B'PR$ outputs of FISAT II. The $E_{50}$ suggests exploitation that will result in the reduction of the available unexploited ("virgin") biomass by 50% while $E_{10}$ suggests that 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 $E$. Gulland (1971) suggested that fishing mortality should be 50% of the total mortality to achieve optimum exploitation level ($E_{opt}$) from the relation $E = F / Z$ based on fish population dynamics principles. These BRPs particularly the $E_{50}$ which was adapted as $E_{opt}$ were used as basis for catch reduction recommendation for this study.

## 3 | RESULTS

### 3.1 Size frequency distribution

Large sample size ($N = 3988$) was collected that allowed the inclusion of a wide range of individual sizes (2.77–9.85 cm). Hence, the population of the exploited *M. funebris* was adequately represented. Fifty-five percent of the specimens are within the range of 6.20 – 7.50 cm. The

Shapiro-Wilk test revealed normal distributions of the samples collected during May ($p$ = 0.435) and September ($p$ = 0.043) necessarily complementing the analysis using FISAT II (Figure 2).

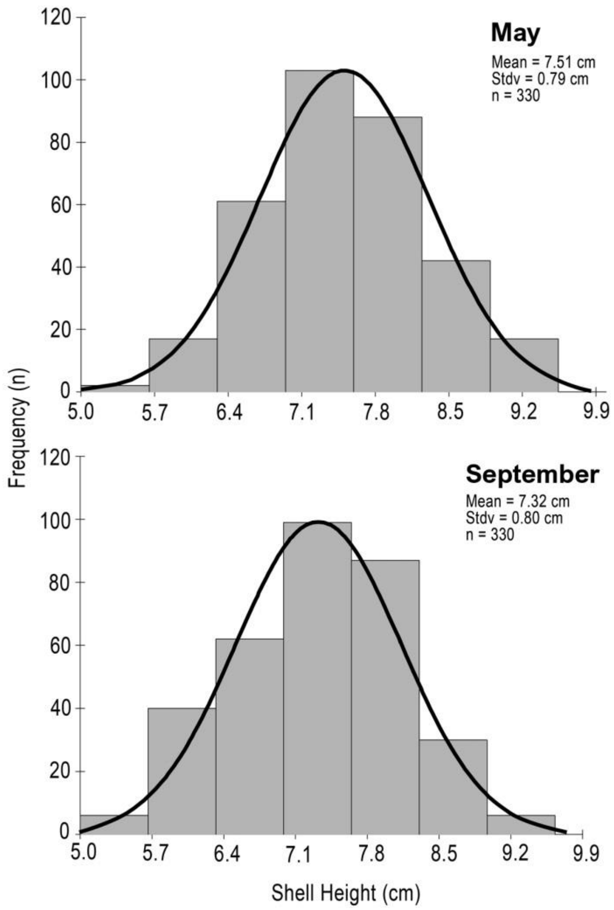


**FIGURE 2** Length-frequency distributions of *Mimachlamys funebris* superimposed with the normal curve for May and September.

### 3.2 Growth and longevity

For initial growth analysis, the Powell-Wetherall plot yielded a shell height infinity ($SH_\infty$) value of 10.14 cm using a cut-off length of 6.85 cm. Growth constant ($K$) of the oscillating VBGF was 1.1 year$^{-1}$. Optimum fit of the growth curve fitted over the monthly *LF* data resulted to a final $SH_\infty$ value of 10.5 cm ($R_n$ = 0.243) with growth performance index of 2.08. The growth demonstrated by *M. funebris* had a slight sinusoidal pattern with inflexions observable during January to February. Two cohorts were evident (Figure 3). The discernible secondary growth line indicates the presence of the second cohort. The modal progression analysis obtained a separation index of 6.09 and 4.22 for the two cohorts appearing in December and March respectively. Longevity of *M. funebris* was estimated 3.46 years.

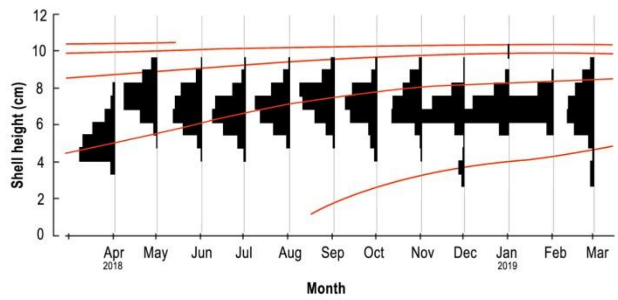


**FIGURE 3** Growth curve of the oscillating VBGF form for *Mimachlamys funebris* fitted over the monthly length-frequency distribution showing discernible second cohort appearing in December and March; graphic output based from FISAT II where longevity of three and half years can be estimated visually by counting the full length and fraction of superimposed growth curves.

### 3.3 Recruitment pattern

The occurrence of the second cohort initially observed in Figure 3 was further validated by the analysis of the temporal recruitment pattern of the species. *Mimachlamys funebris* spawns continuously throughout the year with a bimodal pattern. The major recruitment pulse started to manifest in March until May. Two peak pulses were revealed in May and September that contributed 13.54% and 14.99%, respectively, to the total recruitment for the year. The Gaussian distribution fitted with the recruitment pattern indicated significant separation between the two components (Figure 4).

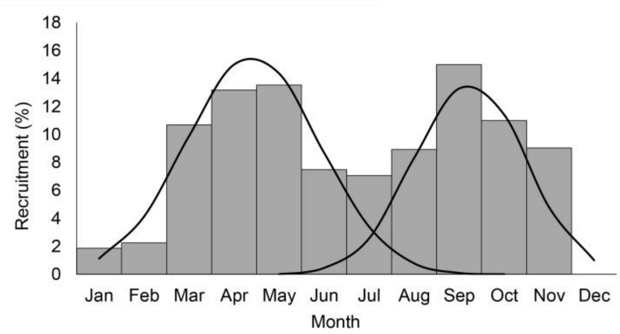


**FIGURE 4** Temporal recruitment pattern of *Mimachlamys funebris* superimposed with the normal distribution showing two pulses of recruitment occurring in May and September; a finding that generally concurs with the spawning of many tropical and subtropical scallop species.

### 3.4 Mortality parameters and relative yield-per-recruit ($Y'/R$) and biomass-per-recruit

Total mortality ($Z$) was 5.36 year$^{-1}$ (Figure 5). Fishing mortalities (4.82 and 4.26 year$^{-1}$) were relatively higher than the natural mortalities (0.543 and 1.1 year$^{-1}$ respectively, for averaged $M = M_1$ and $M_2 = K$) which indicate overharvesting. Current exploitation rates ($E_{curr}$) were 0.90 ($E_{curr1}$) and 0.80 ($E_{curr2}$) corresponding to the two $M$ estimates. Shell-height-at-first-capture ($L_{50}$) estimated using $M_1$ was

7.18 cm (Figure 6) and 7.16 cm using $M_2$. Values for 25% capture probabilities using both $M$ were similar (*i.e.* 6.57 cm) while for 75% capture probability, the values were very close (7.79 cm and 7.76 cm estimated from $M_1$ and $M_2$ respectively).

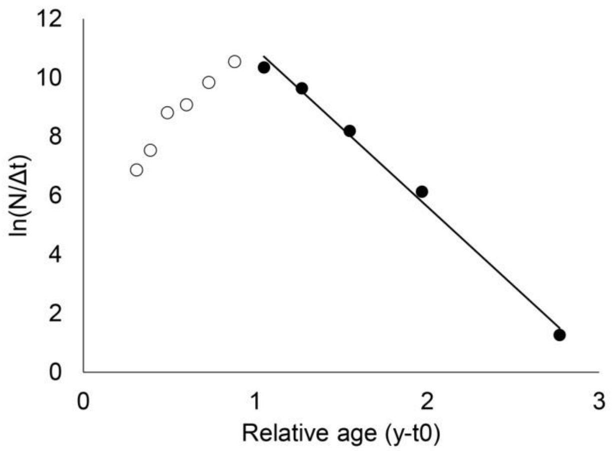


**FIGURE 5** Length-converted catch curve for the estimation of total mortality ($Z$) of *Mimachlamys funebris*. Note the open dots on the left represent scallops not fully recruited and/or selected and the black dots represent the selected length classes where the first and last points are chosen for the analysis, and the slope of the regression line multiplied by –1 provide an estimate of $Z$.

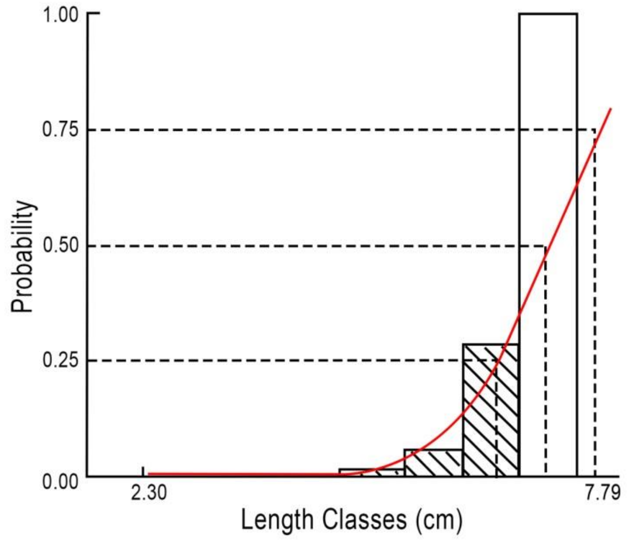


**FIGURE 6** Probabilities of capture by length for *Mimachlamys funebris* showing the corresponding estimated length at capture using $M_1$ (25% = 6.57 cm, 50% = 7.18 cm and 75% = 7.79 cm).

The $Y'/R$ and $B'/R$ analyses revealed that the values of $E_{curr1}$ has exceeded the biological reference point $E_{50a}$ by 112%. $E_{curr1}$ is also beyond $E_{10a}$ and the maximum sustainable yield ($E_{max\text{-}a}$) by 25% and 15% respectively. $E_{curr2}$ is higher than $E_{50b}$ (by 92%) and $E_{opt\text{-}b}$ (by 59%). However, $E_{curr2}$ was within the limit of $E_{10b}$ and $E_{max\text{-}b}$ (Table 1). $E_{50}$ resulting from the averaged $M$ (*i.e.* $M_1$) and $M_2$ (*i.e.* $M = K$) are very close to each other despite the great difference in the values of $M_1$ and $M_2$. On the contrary, the values of $E_{max}$ are highly variable. Results in Figure 7 are shown for both estimates of $M$.

**TABLE 1** Biological parameters and indices generated from the two estimates of natural mortality ($M$). a, estimates based from $M_1$; b, estimates based from $M_2$.

| *M* | Biological parameters and indices | | | | | |
|---|---|---|---|---|---|---|
| | $E_{curr}$ | $E_{50}$ | $E_{10}$ | $E_{max}$ | $L_{50}/L_\infty$ | $M/K$ |
| $M_1$ (0.543) | 0.899[1] | 0.425[a] | 0.719[a] | 0.784[a] | 0.684[a] | 0.494[a] |
| $M_2$ (1.1) | 0.795[2] | 0.415[b] | 0.80[b] | 0.881[b] | 0.682[b] | 1.0[b] |

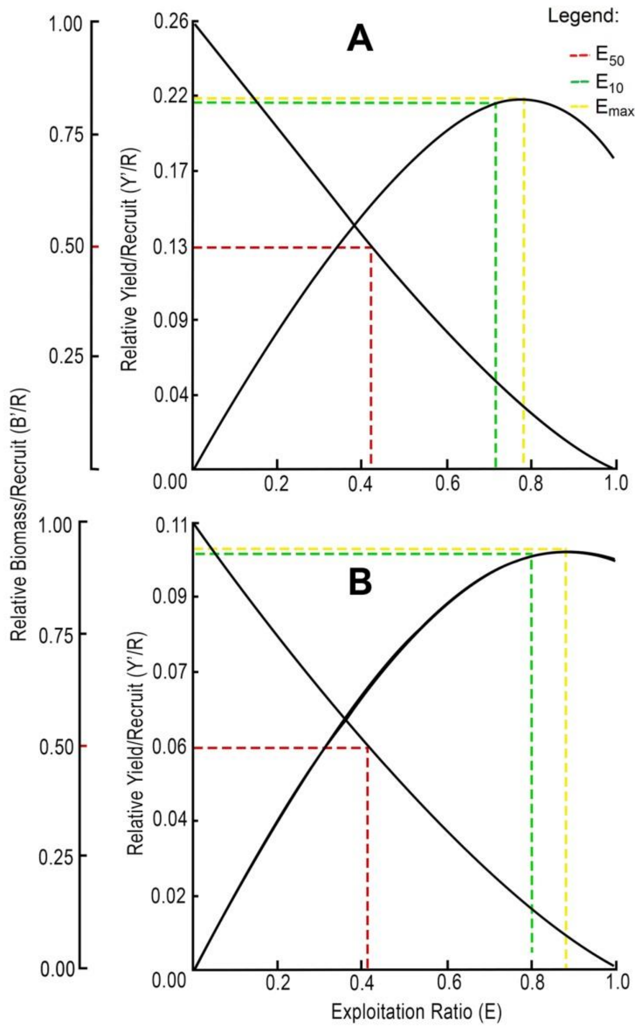


**FIGURE 7** Relative yield-per-recruit ($Y'/R$) and biomass-per-recruit ($B'/R$) of *Mimachlamys funebris* showing estimates of the biological reference points in relation to one another for (A) $M_1$ = 0.543 and (B) $M_2$ = 1.1; Note the *Y'PR* curve has a singular peak suggesting its amenable use for management.

## 4 | DISCUSSION

High fishing mortalities and exploitation rate generally exceeding the limit reference points showed an overexploited stock of *M. funebris* in Asid Gulf. Overexploitation of the species has been reported as early as 2003 (Soliman and Dioneda 2004) although the data for the study were limited by the context of a quick stock assessment conducted over a period of three months. Similar results were reported in 2007 (Bobiles and Soliman 2018). Over a decade has passed yet uncontrolled harvesting of scallops in Asid Gulf is persistently occurring that leads to the declining trend in scallop harvest. The highest recorded scallop production from the gulf was 11000 tons in 2003 and since then dropped to 1554 tons in 2017 (Bobiles and Soliman 2018). This shows a devastating decline of about 86% that negatively affected the livelihood of close to 3500 fishers. The continuous demand for the scallop's adductor muscle coupled with the free-for-all open access fisheries regime is the root cause of the stock depletion. Unregulated harvesting driven by the high demand for scallops has brought about the overexploitation of some notable scallop species like *Chlamys islandica* in West Iceland (Jonasson *et al.* 2007), *A. purpuratus* in Peru (Stotz and González 1997), *A. ventricosus* in Panama (Medina *et al.* 2007), *A. irradians* in Florida (Arnold *et al.* 2005) and *E. ziczac* in Brazil (Pezzuto and Borzone 2004).

Using the two estimates of natural mortalities, the variability of the BRPs ranged from 1% for $E_{50}$ and 10% for $E_{max}$. It indicates $E_{50}$ as a stable limit reference point even with $M$ varying twice as much. With $E_{50}$ as the target limit, current exploitation ratios ($E_{curr1}$ and $E_{curr2}$) must be reduced by 48% and 53% respectively to achieve this target of exploiting 50% of the unexploitable stock. Gulland (1971) also suggested that optimum exploitation level can be achieved when the fishing mortality is 50% of the total mortality (*i.e.* natural mortality and fishing mortality rate is equal). At this level, the $E_{curr1}$ and $E_{curr2}$ should be reduced by 37% and 44% respectively. Overall, this shows a range of 37 – 53% reduction in exploitation rate that could be translated into catch quota, then number of scallop divers and boats inferred from basic catch and effort statistics. The greater challenge rests on the options that a management body presents to decision makers to avert fishery collapse which could be evident for the scallop stock in the gulf.

In Asid Gulf, scallop harvest is generally limited by the capacity of the boat and the occurrence of intense weather condition. As a consequence, the scallop stocks within the shallower area of the gulf have been depleted and catch consists mainly of small immature scallops. Fishers wanting to gain larger catch desperately forced themselves to dive into deeper areas of the gulf that is about 20 – 30 m deep exposing them to high risk of diving accidents or even death. This situation also poses the risk of overexploiting the breeding scallop stocks. Divers reveal that most large scallops in the gulf can only be found in deeper areas (>20 m) where such population potentially represents the bulk of their spawning stock biomass responsible for sustaining the 'bust and boom' fishery of scallops in the gulf and off the adjacent Gigantes Islands. The high exploitation of the spawning stock would exacerbate stock depletion through recruitment overfishing. Similarly, a case of fishery regime in San Jose Gulf, Argentina was described for the small-scale dive fishery for *Aequipecten tehuelchus* (Orensanz *et al.* 2006). The fishery for *A. tehuelchus* has been sustained for 20 years with minimal effective regulation, but eventually collapsed when a new market developed for small immature scallops whereby hard economic crisis pushed fishers to risk fishing in deeper waters which lowered the density threshold at which time they voluntarily abandoned the fishing bed (Orensanz *et al.* 2006).

The growth demonstrated by *M. funebris* has a slight sinusoidal pattern with inflexions observable during January to February. According to Pauly (1990), temperature difference as small as 2°C can cause oscillation in the growth curve in tropical fishes. The period from December to February represents the coldest months in the Philippines due to the influence by the cold wind of the northeast monsoon. In a study by Morillo-Manalo *et al.* (2016), the recorded mean monthly bottom temperature in the adjacent Gigantes Island in December to February was 25°C that is at least 2 degrees lower than during the warm months with 27°C and higher in April to July. Although the bottom water temperature in the gulf was not recorded in the present study, the close proximity of Gigantes Island to the gulf would reasonably substantiate such assumption that similar temperature condition would exist between the sites. Both sites belong to the Visayan Sea; fed with rich waters from Sibuyan Sea, Guimaras Strait and Tanon Strait. Furthermore, the months of December to February is the major spawning season for the scallop in Gigantes Island (see Morillo-Manalo *et al.* 2016), thus, the slower growth of *M. funebris* during this period may be due to the reallocation of energy for gametogenesis and reproduction (see Macdonald 1986; Macdonald and Bourne 1987). On growth dynamics, the growth constant and asymptotic shell height observed for *M. funebris* is slightly higher than with pectinids reported from various scallop grounds in the Philippines (Table 1). A direct comparison of the parameters is not possible because there are no studies on the same species available. But the values of the growth performance index (Pauly and David 1981) provided a more universal comparison. The growth performance index of *M. funebris* generated in the present study is very high relative to the other Philippine pectinids. Moreover, a significant implication of the high growth and short life span revolves around the mariculture potential of *M. funebris*. If the species is cultured from the recommended stocking size of 3.5 cm (Buban and Soliman 2019) it could reach a harvestable size of 8.8 cm after a year.

The recruitment pattern of the species potentially assures an annual supply of scallop spat. Two peaks in May and September contributed 13.54% and 14.99% respectively to the total recruitment for the year. The continuous recruitment with two high recruitment pulses can correspond to the larval settlements of *M. funebris*. In fact, the preponderance of large spawners every month can be observed in the modal progression of samples (Figure 2) indicating the presence of spawners. In December and March, the association of large and small scallops could reflect recruitment activity of the species. This recruitment pattern is consistent with other pectinids in the Philippines. For example, the species *Chlamys 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). The recruits (<4 cm) of *M. funebris* measured in March – May and September in this study could have been spawned a month earlier or thereabouts. Investigations on spawning season of *M. funebris* through reproductive biology studies can be explored in the future for further validation. Information on the temporal recruitment pattern for *M. funebris* is vital to guide the timely collection of scallop spats for mariculture purposes and since artificial spawning induction for the species is yet to be developed.

**Table 2** Comparison of asymptotic shell height ($SH_\infty$), growth ($K$ year$^{-1}$) and growth performance index for the different scallop species in the Philippines.

| Location | Species | $SH_\infty$ (cm) | $K$ year$^{-1}$ | Growth performance Index (Ø) | Reference |
|---|---|---|---|---|---|
| Asid Gulf | *Mimachlamys funebris* | 10.50 | 1.10 | 2.08 | Present study |
| Asid Gulf | *Decatopecten striatus* (now *Decatopecten plica*) | 7.88 | 1.11 | 1.84 | Bobiles and Soliman (2018) |
| Asid Gulf | *Decatopecten striatus* (now *Decatopecten plica*) | 7.70 | 0.51 | 1.48 | Soliman and Dioneda (2004) |
| Asid Gulf | *Chlamys senatoria nobilis* | 7.90 | 0.46 | 1.46 | Soliman and Dioneda (2004) |
| Asid Gulf | *Chlamys nobilis* | 9.82 | 0.76 | 1.87 | Cabiles *et al.* (2019) |
| Asid Gulf | *Chlamys funebris* | 8.22 | 0.46 | 1.49 | Soliman and Dioneda (2004) |
| Asid Gulf | *Chlamys funebris* | 11.29 | 0.67 | 1.93 | Bobiles and Soliman (2018) |
| Lingayen Gulf | *Amusium pleuronectes* | 10.60 | 0.92 | 2.01 | Del Norte (1988) |
| Visayan Sea | *Amusium pleuronectes* | 10.00 | 0.94 | 1.97 | Gabral-Llana (1988) |

Current situation in the gulf highlights the potential role of scallop mariculture in boosting production while at the same time decreasing the pressure on the natural scallop stocks. Biological criteria for mariculture are supported by the fast growth, bigger size and the availability of natural scallop spat evidenced by the recruitment pattern of the species. *Mimachlamys funebris* is short-lived (about 3.5 years) and fast-growing ($K$ = 1.1 year$^{-1}$), typical traits of scallops inhabiting shallower waters. Short-lived, fast growing species that are restricted to shallow coastal waters (<10 m) with reported longevities were *Amusium pleuronectes* (2 years; Del Norte 1988), *Argopecten irradians* (1.9 years; Bricelj *et al.* 1987), *Chlamys varia* (7 – 8 years; Conan and Shafee 1978) and *C. tehuelcha* (6 years; Orensanz 1984). In contrast, long-lived, slow-growing scallops are those found in deep waters (100 – 200 m) living up to 20 – 23 years including *Placopecten magellanicus* (MacDonald 1986), *C. islandica* (Vahl 1981), *Patinopecten caurinus* (Macdonald and Bourne 1987); and those found at moderate depths (50 – 60 m) including *Pecten maximus* (Mason 1957) and *Crassadoma gigantea* (MacDonald and Bourne 1989).

## 5 | CONCLUSIONS

The uncontrolled and unregulated harvesting of *M. funebris* in Asid Gulf has led to the overexploitation of the stock. Despite using varying estimates of natural mortality, the current investigation resulted in an exploitation level that is past the BRP adopted for the study ($E_{50}$). Therefore, there is a need to reduce exploitation level by 48% to 53% to prevent further stock depletion. In addition, the results of the present study implied a necessity for a suite of management interventions to be utilised such as the strict implementation of the existing closed season policy, setting aside a no-take zone and recruit-replenishment area for scallop and improving marketability and market opportunities for the harvested scallop. Furthermore, the present study shed light to the potential of *M. funebris* for mariculture considering the fast growth and the availability of natural scallop spat throughout the year. Together with the suite of interim management interventions, mariculture is the highly well-thought-out option in reducing the impact of wild harvesting and increasing production potential for the resource.

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**CONFLICT OF INTEREST**

The author declares no conflict of interest.

**DATA AVAILABILITY STATEMENT**

The data that support the findings of this study are available on request from the corresponding author.

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**CONTRIBUTION OF THE AUTHORS**

**ICRB** sampling, data analysis and manuscript preparation;
**CDC, RUB & APC** sampling;
**VSS** data analysis and manuscript preparation.

***ICR Buban*** https://orcid.org/0000-0001-8916-501X
***CD Cabiles*** https://orcid.org/0000-0001-6493-8709
***RU Bobiles*** http://orcid.org/0000-0002-7670-5598
***AP Camaya*** https://orcid.org/0000-0002-5085-6232
***VS Soliman*** http://orcid.org/0000-0002-5627-2860