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Endemic Muar, Malaysia Oyster *Crassostrea* (*Magallana*) *saidii* Wong & Sigwart, 2021 Approaches Optimal Harvest Despite Year-Round Multiple Recruitments

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ABSTRACT

Population dynamics provides insight into how the population changes in structure over time. The insight is especially paramount for species with limited distribution and of conservation concern, such as *Crassostrea* (*Magallana*) *saidii* Wong & Sigwart, 2021 (Sigwart et al., 2021). The species is a recently described oyster endemic to the Muar estuary, Malaysia. The species' size-weight relationship and population structure were assessed in 2019 to determine its population dynamic. Results indicated that the oyster showed a negative allometric growth with a coefficient of 2.5422 ($b < 3$). The observed asymptotic height ($SH\infty$) was 15.23 cm, with a growth coefficient (K) of 0.69 per year. The low coefficient value was indicative of a slow growth rate, where it sets within the range of typically long-lived species. The oyster's growth performance index (φ') was estimated at 2.204. The level of exploitation (E) index of the oyster (0.42) was lower than annual fishing mortality (1.27), indicating the *C.* (*M.*) *saidii* population was utilized close to the optimum yield. The oyster's recruitment pattern was continuous, peaking from April to June (18.46% to 13.82% oyster recruits) and September to November (10.68% to 12.37% recruits). The information of the current study is useful for sustainable management and proper utilization of the *C*. (*M*.) *saidii* oyster.

Keywords: *Crassostrea* (*Magallana*) *saidii*, mortality, optimal harvest, population dynamic, recruitment

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INTRODUCTION

Oysters are ecologically a keystone species in the marine ecosystems by providing ecological services as reef-builders, filter feeders, and clarifiers, and for this first reason, they are known as bioengineers (Smaal et al., 2019). There are a few species of oysters found in Malaysia. The oyster *Crassostrea* (*Magallana*) *saidii* Wong & Sigwart, 2021 is a species new to science. It is morphologically and genetically distinct, limited to Sungai Muar, Malaysia, the only known population in the scientific record (Sigwart et al., 2021). Because of its creamy white meat and excellent quality, the species is known as the white oyster among fisherfolk and locals and is more popular with oyster fans than the *Crassostrea belcheri* (Axe Oyster) species, which can also be found in the estuary of Muar (Sigwart et al., 2021). The oyster fishery in Muar estuary was first reported in 1858 by a British Captain, who described Muar oyster as a delicacy reserved for the royals and high officials (Macpherson, 1858). It was sold at the Singapore market, about 200 km away (Hanitsch, 1908). However, later Muar oyster fishery was reported as “anemic” in 1929, probably due to the decline in the oyster population (Dover, 1929). Muar oysters have been farmed through bottom ranching by returning empty oyster shells to certain points of the Sungai Muar estuary, which is still practiced today. However, the small population is threatened by urbanization, pollution, and habitat destruction (Sigwart et al., 2021). Therefore, a sound biological baseline is required to ensure sustainability, protection, and management.

The length-weight relationship (LWR) is an intensive and efficient tool for identifying parameters in bivalve resources in the fishing industry (Peters, 1983). The LWR is useful for fishery biologists to predict biomass from length data and monitor population health (Cone, 1989; Pouladi et al., 2020). Parameters such as an oyster’s body weight and height to calculate the length-weight relationship (Osei et al., 2021). In addition, the stock assessment is effective for sound fisheries management. It is normally practiced to predict future yields and determine the exploitation levels of fish stocks based on certain fishing mortalities (King, 2007). After interpreting growth patterns and evaluating the natural stocks, the new species can be managed more effectively. The species’ economic management also depends on detailed and comprehensive information on population dynamics. However, the current study commenced to assess the size-weight relationship and population characteristics of C. (*M.*) *saidii* for the first-time utilizing Food and Agriculture Organization-International Center for Living Aquatic Resources Management stock assessment tools II (FiSAT II).

METHODS

Study Area

The river Sungai Muar flows through the states of Johor, Negeri Sembilan, and Pahang in Malaysia. The samples examined in this study were collected from the site where shells of the oysters are traditionally used as cultch to encourage spat fall. The location of the sampling site was the Sungai Muar estuary, Johor, southern Malaysia (02°03’36.8”N, 102°34’18.7”E; Figure 1), one of the most important oyster producer areas in the country. This oyster generally settles on the riverbed, at curves of the river in strong currents, probably due to the lower siltation at high speed. The oyster is buried under sediment during unusual high sedimentation fluxes and can survive, keeping the ventral margin gape exposed to the water column (Sigwart et al., 2021).

Samples Collection

Samples were collected between January 2019 and December 2019 from the traditional fishers. They have dived into the water after anchoring their boat to 20 feet on wooden poles erected at designated oyster cultivating points in the estuary during low tides to collect oysters from the muddy bottom by handpicking.

Oyster Measurement and Index

The biometric measurements of the oysters were taken after the removal of algal biomass, encrusting organisms, and other waste materials at the ecology laboratory in the aquaculture department, Universiti Putra Malaysia (UPM). Three hundred seventy-one (371) specimens of *C.* (*M.*) *saidii* ranging in size from 5.87 cm to 14.12 cm and in weight from 36.8 g to 342.89 g were collected for the study. Shell height, the longest distance of the oyster, was measured using a vernier caliper, placing the jaw of the caliper to the hinge-to-bill length of the oyster shell (Galtsoff, 1964). In contrast, the total individual weight was weighed using a digital balance. The shell height of the oyster was used for the length-based analysis since the body weight of an oyster is more influenced by the shell height than the shell length and breadth (Nair & Nair, 1986; Osei et al., 2021).

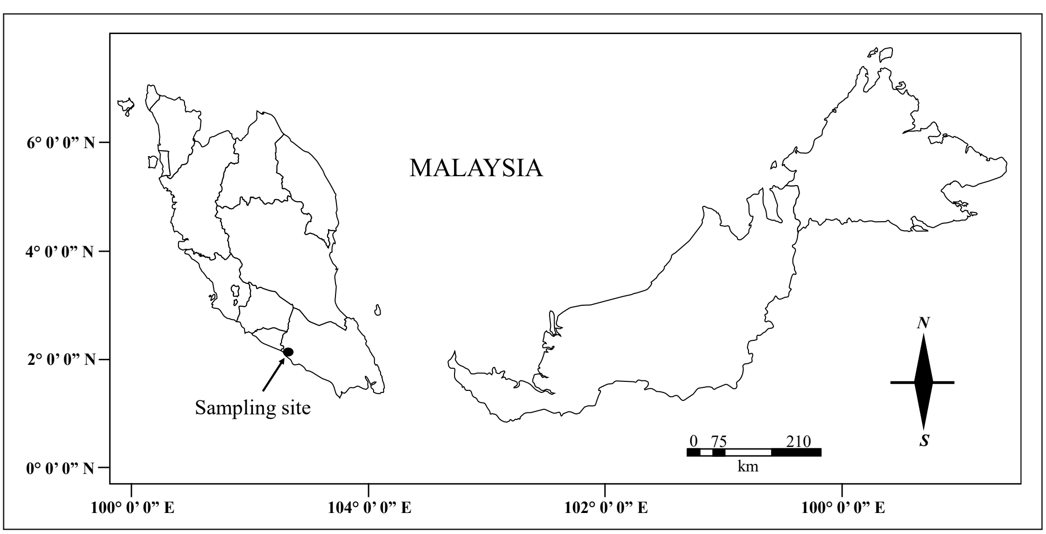

Figure 1. Location of the study site at Sungai Muar estuary, Johor, Malaysia (black circled)

Statistical Analysis

Size-Weight Relationship. The equation $TW = a(SH)^b$ (Quinn & Deriso, 1999; Ricker, 1975) was used to estimate the relationship between shell height (SH, cm) and total weight (TW, g), where *a* is the condition factor, and *b* is the relative growth rate. The least-squares linear regression on a log–log-transformed data, $Log_{10}\ TW = Log\ a + b(Log\ SH)$, was used to assess the parameters *a* and *b*. A *t*-test was applied to analyze the deviation of the relative growth rate of the Muar Oyster from the isometric value using the equation: $Ts = (b - bi)$ / SE (Kandeel et al., 2013), where *Ts* = value of the *t*-test, *b* = relative growth rate of *C.* (*M.*) *saidii*, *bi* = isometric value (3), and SE = standard error of the relative growth. The coefficient of regression (R^2) at 95% confidence limits was calculated as a determinative of the characteristics of the linear regression.

Growth Parameters. The collected data were assembled into height groups at intervals of 1 cm. The FiSAT II computer package was used to scrutinize the recorded height-frequency data, according to Gayanilo et al. (1996). Electronic Length Frequency Analysis-1 (ELEFAN-1) was applied to assess the asymptotic height ($SH\infty$) and growth coefficient (K) of the von Bertalanffy growth function (VBGF) (Pauly & David, 1981). A routine *K*-scan was used to determine the *K* value. Finally, the equation: $\varphi' = 2Log_{10}SH\infty + Log_{10}K$ was applied to estimate the growth performance index of *C.* (*M.*) *saidii*, where φ' = growth performance index, $SH\infty$ = asymptotic height, and K = growth coefficient (Pauly & Munro, 1984).

The height-at-age curve was estimated by applying a non-linear least squares estimation procedure by fitting the VBGF using the equation: $SH_t = SH\infty\ [1 - e^{-k\,(t - to)}]$ (Pauly et al., 1992). In the equation, SH_t = height at age t; $SH\infty$ = asymptotic height; K = growth coefficient; t = age of the oyster, and t_0 = the theoretical age when the oyster show null height (Newman, 2002). The hypothetical age at which the *C.* (*M.*) *saidii* reaches null height (t_0) was assessed using the equation: $Log\ (-t_0) = -0.3922 - 0.2752Log_{10}\ SH\infty - 1.038Log_{10}\ K$ (Pauly, 1979), where $SH\infty$ = asymptotic height and K = growth curvature of the VBGF curve.

Mortality Pattern and Exploitation Rate. The total mortality coefficient (Z) value of the oyster fishery was determined by applying the length-converted catch curve method (Pauly, 1987). The empirical equation assessed the annual natural mortality coefficient (M) of the oyster: $Log_{10}\ M = -0.0066 - 0.279Log_{10}\ SH\infty + 0.6543Log_{10}\ K + 0.4634Log_{10}\ T$ (Pauly, 1980); where M = annual natural mortality, $SH\infty$ = asymptotic height, K = VBGF growth coefficient, and T = annual environmental mean water temperature of the Muar estuary. The water temperature was recorded using an Honest Observer by Onset (HOBO) data logger, and the annual mean (± SE) was recorded at 30.1 ± 0.6 °C. The equation: $F = Z - M$ was used to estimate the fishing mortality of the oyster, where F = fishing mortality, M = natural mortality, and Z = total mortality coefficient. The level of exploitation (E) was determined by the ratio of the fishing mortality to the total mortality, i.e., $E = F / Z = F / (F + M)$.

Recruitment Pattern. The recruitment pattern of the fishery was ascertained in FiSAT II software, inputting the growth parameters, namely growth coefficient (K), asymptotic length ($L\infty$), and theoretical age (t_0) at which the oyster reaches zero height. Then, the composite length-frequency distributions were decomposed by using a modified analytical method for mixtures of normal distributions (NORMally Separation [NORMSEP]) (Pauly & Caddy, 1985) in FiSAT II software.

RESULTS

Height-Weight Relationship

The height-weight relationship of the oyster was determined from the height and weight of the individuals, which was linear with high significant linearity (Figure 2; $R^2 = 0.9937$, $p < 0.01$). The slope of the relationship ($b = 2.5422$; SE = 0.012) is significantly different from 3 ($t = 38.93$, $p < 0.01$), which indicates a negative allometry growth of the *C.* (*M.*) *saidii* in the estuary. The linear regression revealed the average b value was 2.5422 ± 0.012 (SE), and the growth coefficient (b) varied between 2.5190 and 2.5653 at a 95% confidence level.

Growth Parameters

The observed extreme height of the oyster was 14.50 cm, whereas the predicted extreme height of the oyster was 14.72 cm (Figure 3a). The range of extreme values was 13.73 cm to 15.72 cm at a 95% confidence interval. The Electronic Length Frequency Analysis 1 (ELEFAN 1) program reckoned growth coefficient (K) and asymptotic height ($SH\infty$) of VBGF for the oyster were 0.69 per year and 15.23 cm, respectively. The ELEFAN-1 analysis determined the hypothetical age

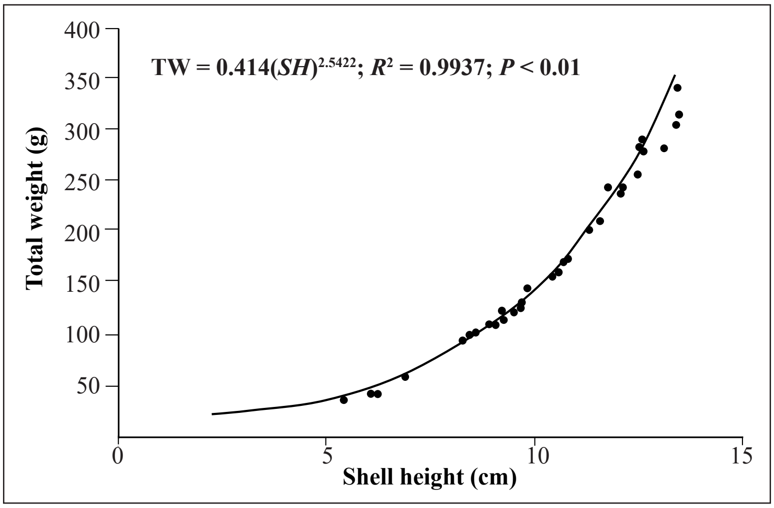

Figure 2. Height-weight relationship of *C.* (*M.*) *saidii* collected from the estuary of Sungai Muar, Johor, Malaysia

(t_o) at which the oyster's null height was -0.28 years. However, the sizes attained by the oyster from Sungai Muar estuary, Johor were 4.68 cm, 6.35 cm, 8.94 cm, 12.07 cm, 13.65 cm, 14.43 cm, and 14.85 cm at the end of 0.25, 0.5, 1, 2, 3, 4, and 5 years of age, respectively (Figure 3b). The computed growth curve was superimposed with the growth parameters over the restricted height distribution (Figure 3c). The black bars in Figure 3c indicated higher frequencies, whereas the white bars indicated lower frequencies of the collected oyster during the study period in the Sungai Muar estuary. The oyster's growth performance index (φ') was determined at 2.204 (Figure 3d).

Mortality Pattern and Exploitation Rate

The total mortality rate (*Z*) was determined at 3.02 per year, while the natural mortality coefficient (*M*) and fishing mortality coefficient (*F*) were 1.75 and 1.27 per year, respectively (Figure 4). Therefore, the oyster's exploitation level (*E*) was obtained at 0.42, which appeared to be lower than

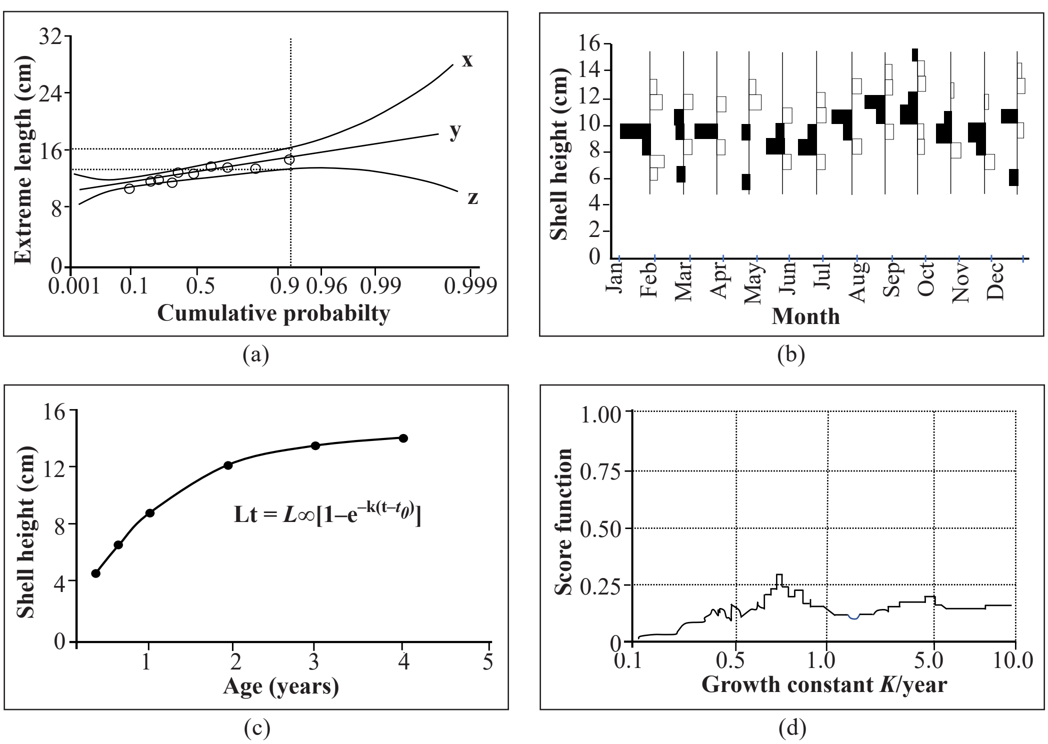

Figure 3. Growth parameters of the oyster *C.* (*M.*) *saidii*: (a) The predicted maximum height for the *C.* (*M.*) *saidii* according to the extreme value theory (Formacion et al., 1991). The overall asymptotic height was incised from the x and y, as well as y and z lines, respectively, to get the predicted asymptotic height and the extreme height at a 95% confidence level; (b) Plot of age and shell height relationship for the *C.* (*M.*) *saidii* in the estuary of Sungai Muar, Johor based on the von Bertalanffy growth function; (c) Restructured height-frequency distribution of *C.* (*M.*) *saidii* from the estuary of Sungai Muar Johor, Malaysia ($L\infty$ =15.23 cm and K = 0.69 per year); (d) *K*-scan routine for the determination of the growth coefficients (*K*) and asymptotic height ($SH\infty$) of *C.* (*M.*) *saidii* using ELEFAN-1

the established expected minimum level of exploitation (E = 0.50).

Recruitment Pattern

The recruitment pattern of the oyster was continuous over the study period (Figure 5). At the beginning of the study in January, 5.47% oysters were recruited into the population. Two major recruitment pulses were observed from April to June (18.46% to 13.82%) and September to November (10.68% to 12.37%). The peak pulse of recruitment was observed in April, with 18.46% recruitment, whereas the minimum recruitment was produced in August, with 2.09% recruitment.

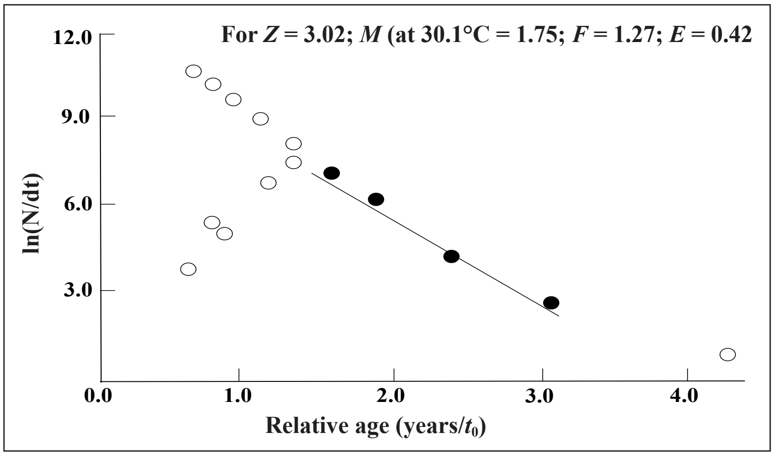

Figure 4. The size converted catch curve of the *C.* (*M.*) *saidii*, where 'N' is the population size and 'dt' is the time required to reach the population size. The least-square linear regression was applied to establish the catch curve. The solids dots points were used in the estimation, while the open dots reflect the relative ages that were either not fully recruited or close to asymptotic height (*SH*∞)

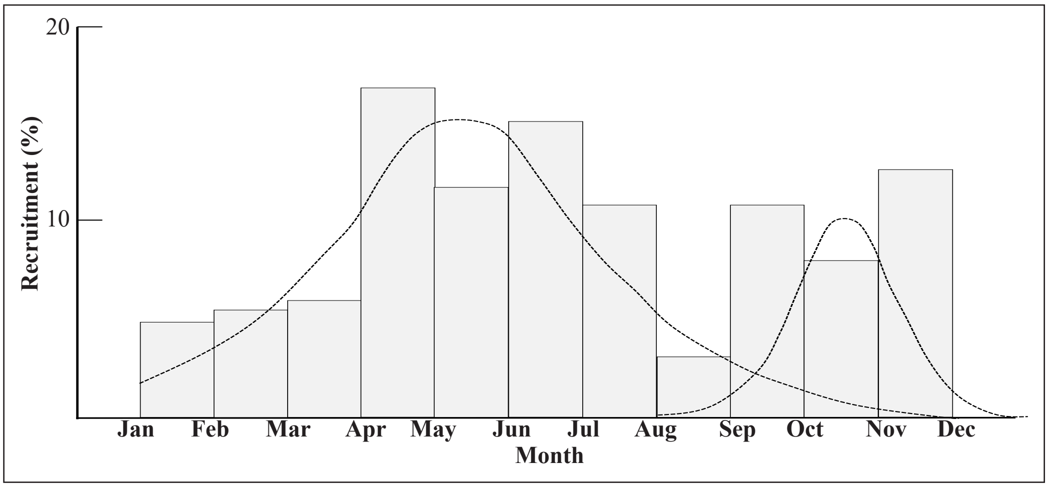

Figure 5. Bimodal distribution of recruitment pattern of *C.* (*M.*) *saidii* from the estuary of Sungai Muar, Johor Malaysia. The backward projection of the restricted height-frequency data was explored to get the pattern of the recruitment basis on a one-year timescale

DISCUSSION

It is the first study on the size-weight relationship and population dynamics of the oyster *C.* (*M.*) *saidii.* Our study recorded the value of growth coefficients (*b*) for *C* (*M.*) *saidii* at 2.5422. Carlander (1977) reported that the value of *b* usually lies between 2.5 to 3.5 for aquatic animals. The growth of an aquatic animal is isometric when the relative growth rate (*b*) value is equal to 3 (Quinn & Deriso, 1999). This result implies that the weight gain of the oyster *C.* (*M.*) *saidii* was lower than the height increment in the Sungai Muar, Johor, Malaysia estuary. The growth of the oyster could be impacted by the influences of many anthropogenic activities, including effluent and industrial discharges, due to urbanization and pollution in the studied area.

In the current study, the asymptotic height was computed at 15.23 cm, and the growth coefficient *K* was calculated at 0.69 per year for the oyster *C.* (*M.*) *saidii*. These values did not differ much from some other *Crassostrea* species (Table 1). The asymptotic length ($L\infty$) of *Crassostrea madrasensis* was recorded at 20.88 cm in Bangladesh (Amin et al., 2008) and 14.90 cm for *Crassostrea rhizophorae* in Colombia (Mancera & Mendo, 1996). The annual growth rate (*K*) was recorded at 0.30 for the oyster *C. tulipa* (Osei et al., 2021) in Densu Delta, Ghana, and the value was observed at 3.96 for the oyster *C. rhizophorae* in the waters of Venezuela (Angell, 1986). These variations in the growth parameters can be explained by the different species or the environmental factors present in various study areas (Derbali et al., 2020).

The overall average first-year growth rate of the oyster was estimated at 0.48 (± 0.03) cm per month, and thus the oyster attained 8.94 cm in height in 12 months. The oyster's growth performance index (φ') was calculated at 2.204, suggesting that the oyster's culture could be feasible in the region due to its high growth performance.

A stock's yield is said to be optimized when the value of fishing and natural mortality are equal (Gulland, 1971). In the study, the natural mortality (M = 1.75) was greater than the fishing mortality (F = 1.27), suggesting an unequal position of the oyster stock as well as predation in the study area. Quayle (1980) noted that predators of oysters are crabs, snails, fish, flatworms, and starfish in the marine environment, while crabs may be the main predators in

Table 1
Growth parameters of some Crassostrea *species from different studies*

Location	Species	$L\infty$ (cm)	K yr-1	φ'	Source
Bangladesh	*Crassostrea madrasensis*	20.88	0.35	2.18	Amin et al. (2008)
Venezuela	*Crassostrea rhizophorae*	7.60	3.96	4.34	Angell (1986)
Colombia	*Crassostrea rhizophorae*	14.90	0.90	4.30	Mancera and Mendo (1996)
Ghana	*Crassostrea tulipa*	16.97	0.30	-	Osei et al. (2021)
Malaysia	*Crassostrea* (*Magallana*) *saidii*	15.23	0.69	2.204	Present study

Note. $L\infty$ = Asymptotic length; K = Annual growth coefficient; φ' = Growth performance index the estuary. The young oyster will survive if it grows rapidly to a size that exceeds the range where predation is effective. This number appeared to be small for the *C.* (*M.*) *saidii* in the Sungai Muar estuary due to high natural mortality. The higher natural mortality contrasted with fishing mortality might also be attributed to habitat degradation and habitat modification in the estuary for C. (*M.*) *saidii*. The exploitation rate (0.42) was close to the optimum level of exploitation (0.5) (Gulland, 1971), which indicates that the stock was harvested close to the optimum level.

The recruitment pattern obtained in the present study indicates that the continuous recruitment consisted of two seasonal peaks, the first between April to June and the second between September and November. This recruitment pattern is typical in tropical regions for the short-lived and fast-growing bivalved species (Mohammed & Yassien, 2003). In Malaysia, there is a lack of published reports on the recruitment pattern of *C.* (*M.*) *saidii*. Nevertheless, few studies have been conducted with different bivalved species in Malaysia to observe the recruitment pattern using the FiSAT II computer software package. For example, Al-Barwani et al. (2007) studied *Perna viridis* in Malacca, Malaysia found that the major recruitment was in July-August. The variations may be explained by Nair and Nair (1986), who reported that spawning and recruitment patterns could vary from species to species.

CONCLUSION

The recruitment pattern of the *C.* (*M.*) *saidii* oyster was continuous and peaked twice throughout the year. The pattern predictably ensures year-round multiple recruitments in the Muar estuary. The natural mortality higher than the fishing mortality measures showed that predation affected the oyster population more than the harvest. Therefore, the dynamics of the *C.* (*M.*) *saidii* oyster population in the Muar estuary can currently sustain exploitation, such as from artisanal fishing practices.

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