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RESEARCH ARTICLE

Morphometric characteristics of invasive species *Magallana gigas* (Thunberg, 1793) in Bandırma Bay, Marmara Sea

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ABSTRACT

Türkiye's seas are the scene of the spread of invasive species in the entire Mediterranean basin due to the marine transportation of alien species and intensive aquaculture activities. In order to protect the natural ecosystem and track invasive species' effects, these species must first be accurately identified and their distribution areas specified. The alien species, *Magallana gigas* (Pacific oyster), has introduced along the Turkish coasts. This study was carried out to determine the morphometric characteristics of *Magallana gigas* in the Bandırma Bay-Balıkesir between November 2013 and October 2014. Shell length varied between 68.08 mm (February) and 93.14 mm (April) during the year. Shell height was measured at the lowest 41.90 mm in February, and the highest 59.46 mm in June. Shell width was 35.80 mm in November when the study started, and it decreased gradually and reached its lowest value in February. W/L relationship of *M. gigas* was calculated as $W=0.411\times L^{2.653}$($R^2=0.064$) This study includes knowledges on morphometric relationships for the Pacific oyster which is crucial for the management of fisheries, aquaculture activities and native species (*Ostrea edulis*).

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Introduction

Pacific oyster or Japanese oyster *Magallana gigas* (Thunberg, 1793), which was previously named as *Crassostrea gigas* before molecular studies (Salvi & Mariottini, 2017), is found predominantly in the intertidal habitats and invasive, non-indigenous species. Invasive species share common characteristics such as the ability to settle, colonize, and expand their range. However, the spread of *M. gigas* has mainly occurred due to cultivation activities for growth purposes in open seas, such as lagoons and bays. Furthermore, this species has shown better growth and survival performance than native

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oyster species in the same population (Troost, 2010). The entry of this species into Europe and the Mediterranean coincides with the second half of the 20th century. In contrast, the native flat oyster (*Ostrea edulis*) fishery in France dates back centuries, to the Roman era. The production of oysters through cultivation has been continuously increasing for many years. However, due to the negative effects of disease and overfishing on populations, cultivation studies of *M. gigas* began. Small-scale trials were conducted between 1966 and 1970 (Grizel & Héral, 1991). *M. gigas* was imported from Canada and Japan and was planted in all production areas, including the Mediterranean coast of France (Grizel & Héral, 1991; Zibrowius, 1992). Later, it was found to be distributed in the Adriatic coast of Italy (Blundo et al., 1972), and larvae were collected from the Croatian coast (Hrs-Brenko, 1982). Subsequently, it was observed that the distribution area of this species in the Mediterranean extended from Cyprus to the Tunisian coast (Hrs-Brenko, 1982). While its presence in Black Sea was first detected in Sevastopol (Scarlato & Starobogatov, 1972), individuals were brought from Japan for cultivation purposes to the North Caucasian region in 1980 (Monina, 1987).

The native flat oyster commonly found in the subtidal habitat of Turkish seas is the European flat oyster, *O. edulis*. It is distributed intensively in the Marmara Sea, Aegean Sea, Mediterranean, and at the point where the Istanbul Strait meets the Black Sea. Despite the low world production of this species compared to *M. gigas*, it is preferred more due to its smooth shell shape, pleasant meat color, and taste, which makes it twice as expensive as *M. gigas* in markets. Özden et al. (1993) conducted the first cultivation studies of *M. gigas* in the SÜYO lagoon. In subsequent years, the presence of this species was determined in the Marmara (Albayrak et al., 2004) and Aegean Seas (Doğan et al., 2007) through field studies assessing their morphometric structures. Acarli et al. (2017) revealed the presence of the species in the Marmara Sea through genetic studies.

Bivalve shell parts are defined in terms of dimensions such as shell length, shell thickness, and shell width, and these three parameters show continuous variation (Malathi & Thippeswamy, 2011; Lucas et al., 2019). Changes in the shell ratios of bivalves during growth are generally associated with the preservation of the area/volume ratio, which is an applicable physiological ratio according to environmental conditions (Rhoads & Pannella, 1970). Due to the population density and increasing depth gradient, irregular shell thickness and shorter forms of *C. madrasensis* were observed (Santhi et al., 2021). It is known that in some bivalve species, shells become higher and wider during growth to resist involuntary displacement caused by turbulence and currents (Eagar, 1978; Hinch & Bailey, 1988). When environmental conditions deteriorate, oyster growth is negatively affected because oysters spend most of their energy adapting to the environment (Dame et al., 2001). Oysters in environments with high-quality and abundant food are larger and thicker (Kasmini et al., 2018). Oysters are irregular in shape and live densely attached to a hard substrate (rock) (Singh, 2019; Arja et al., 2020). Understanding the ecological variations and productivity of oyster populations requires defining the relationship between shell and soft body characteristics (Nagi et al., 2011). The length-weight relationship is essential in generating useful information for the assessment of the growth and production of bivalve species (Chatterji et al., 1985; Acarli et al., 2011, 2012, 2023; Idris et al., 2012; Vasconcelos et al., 2018; Derbali et al., 2019). The allometric relationship based on shell measurements is a simple way to estimate biomass and total meat production (Powell et al., 2016; Acarli et al., 2023).

The objective of this study was to assess the morphometric characteristics of *M. gigas*, a Pacific oyster species that is not indigenous to the Marmara Sea. Therefore, these statistics offer important information for understanding the development of bivalves as well as for sustainable fisheries and aquaculture.

Material and Method

Total 365 specimens of *M. gigas* were collected from Bandırma Bay, Balıkesir (Marmara Sea, Türkiye) (N 40°22'03.43" E 27°55'29.47") during the period from November 2013 to October 2013 (Figure 1). Diving was conducted to collect *M. gigas* individuals from depths ranging from 1 to 6 meters on a monthly basis.

Figure 1. Location of sampling area in from Balıkesir-Bandırma (Marmara Sea, Türkiye)

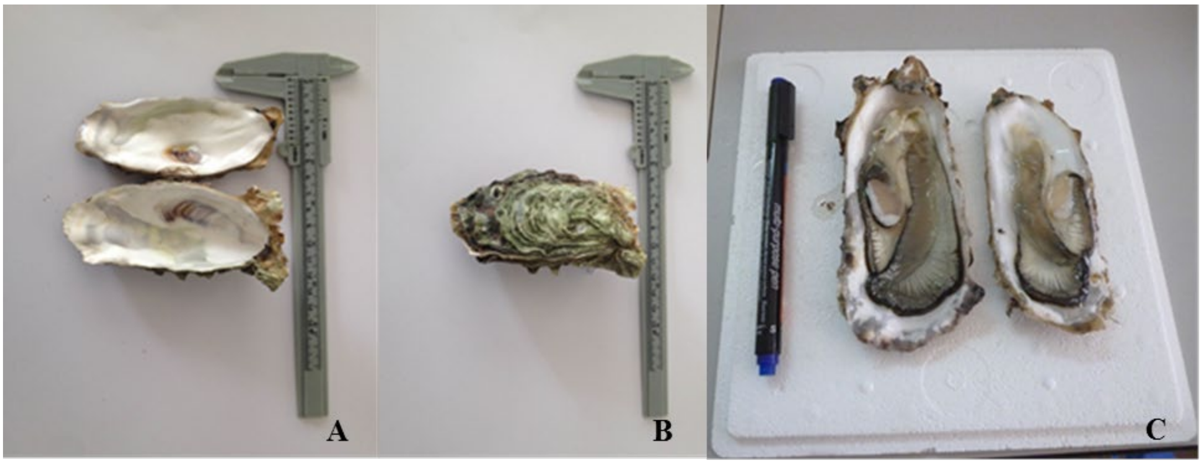

Figure 2. Inner shell (A), outer shell (B) and internal organs of *M. gigas* (C)

To prepare the *M. gigas* for analysis, they were thoroughly cleaned to remove any biofouling organisms (Figure 2). The shell length (L) (anterior-posterior axis), shell height (H) (dorsal-ventral axis), and shell width (Wi) (axis of the two thickest shell valves) were measured using an electronic caliper (Mitutoyo CD-15PK). Additionally, the total weight, wet shell weight, wet tissue weight, and dry tissue weight were determined using an electronic scale (0.01 g, Sartorius GE 412). The meat of *M. gigas* was separated from the shells and weighed separately. The shells were then dried at 60°C for 48-72 hours until a constant weight was achieved, while the soft tissues were dried using freeze-drying.

Linear regression analysis was employed to establish the relationships between length and height, length and width, as described by Ricker (1973), using the following equation:

$$LogY = loga + blogX \qquad (1)$$

Where Y is either the height or the width, X is the length, a is a constant, and b is the regression coefficient.

The length and total weight, length and wet tissue weight, length and dry tissue weight, and length and dry shell weight relationship were calculated using the formula given below (Pauly, 1983):

$$Y = a * X^b \qquad (2)$$

Where Y represents the total weight, wet tissue weight, dry tissue weight, or dry shell weight, while X represents the length, a is a constant, and b is the regression coefficient.

Regression analyses were used to investigate the morphometric relationships between weight and length, width and length, height and length, and width and length measurements of 365 individual Pacific oysters. Morphometric relationships were categorized as isometric growth (b=1 or b=3), positive allometry ($b > 1$ or $b > 3$), or negative allometry ($b < 1$ or $b < 3$) based on the estimated regression coefficients. t-test was performed at a 95% confidence level to test the hypothesis (H_0) that the regression coefficients were equal to 1 or 3. The statistical software SPSS 20 was used for all data analyses and calculations.

Results

M. gigas shell length, obtained monthly from natural sources, generally exhibited small sizes during winter and larger sizes in spring and summer. Throughout the year, shell length ranged from 68.08±28.69 mm in February to 93.14±14.25 mm in April. Shell height was measured at its minimum, 41.90±8.53 mm, in February, and reached its maximum, 59.46±11.20 mm, in June. Shell width varied from 26.74±7.59 mm in September to 36.17±7.47 mm in July. Total weight ranged between 44.51±43.36 g and 110.75±57.58 g (Table 1). The size-frequency graph of *M. gigas* is presented in Figure 3. During the study, the shell length of the oyster varied between 33.05 mm and 140.10 mm. Individuals with shell lengths ranging from 80 to 100 mm constituted 38.4% of the total population.

The relationships between length and total weight, length and dry shell weight, length and wet tissue weight, and length and dry tissue weight were calculated (Figure 4). The results indicated a negative allometric relationship between total weight and body length, with an increase in length leading to a disproportionate decrease in total weight. The weight/length (W/L), height/length (H/L), and width/length (Wi/L) ratios of *M. gigas* were determined as: $W=0.0083\times L^{2.021}$ (R^2=0.7237), $\log H = 0.4925 + 0.6227 \log L$ (R^2=0.5096) and $\log W = 0.2547 + 0.6531 \log L$ (R^2=0.6014), respectively. It was observed that there was a negative allometric relationship between *M. gigas* shell length and the other parameters ($P \leq 0.05$) (Figure 5).

Table 1. Monthly variation of shell length, shell height, shell width and total weight of *M. gigas*

Months	Mean Shell Length± SE	Mean Shell Height± SE	Mean Shell Width± SE	Mean Total Weight± SE
November	80.78±14.12	53.39±10.87	35.80±8.38	49.48±23.50
December	82.02±22.25	46.97±11.70	34.20±7.53	76.32±53.37
January	74.50±17.28	46.83±9.60	33.93±17.81	50.47±33.20
February	68.08±28.69	41.90±8.53	26.74±7.59	44.51±43.36
March	74.16±18.38	47.45±10.82	30.81±8.53	53.04±34.83
April	93.14±14.25	58.60±14.35	35.71±4.99	91.98±37.50
May	88.03±30.69	51.93±7.53	35.02±10.32	75.18±44.13
June	93.29±21.99	59.46±11.20	34.68±7.85	81.67±26.28
July	92.99±21.87	51.97±12.05	36.17±7.47	110.75±57.58
August	92.62±16.58	53.30±8.05	34.36±7.89	92.32±43.37
September	68.80±14.38	42.97±6.90	27.71±6.19	48.92±21.71
October	83.50±22.44	48.91±8.94	30.77±6.39	71.22±33.73±

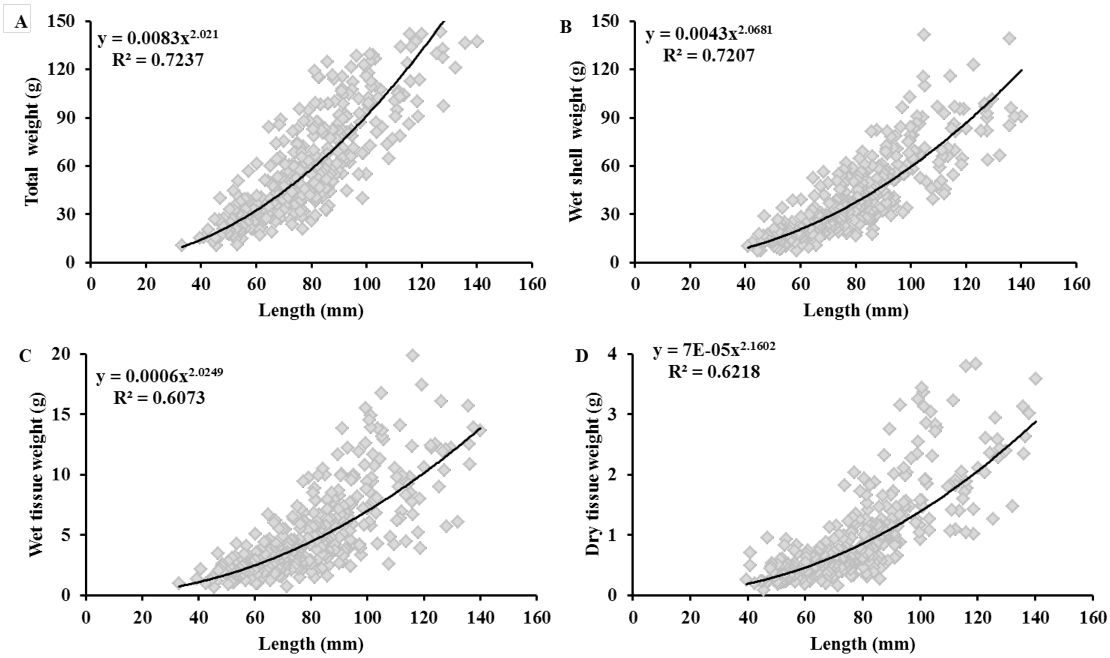

Figure 4. Relationship between length and total weight (A), length and wet shell weight (B), length and wet tissue weight, length and dry tissue weight (C) in *M. gigas*.

Although there was variation in the b value of the length-total weight relationship throughout the months, it was observed that it ranged from 2.32 to 1.91 between November and February. The highest *b* value (2.46) was recorded in March. Subsequently, it gradually decreased until July, reaching *a* value of 1.42. The *b* value then fluctuated between 1.94 and 1.74 from July to October (Figure 5).

Discussion

The growth, shape, total weight, and length-weight relationships in bivalves are influenced by physiological factors such as genetics (Hajoovsky et al., 2021) and environmental factors including temperature, salinity, turbidity, and chlorophyll-a (Acarli & Vural, 2018; Morán et al., 2022; Vural, 2022), as well as depth (Claxton et al., 1998), food availability (Dang et al., 2010), tidal currents (Fuiman et al., 1999; Akester & Martel, 2000; Dame et al., 2001), geographical variation (Beukema & Meehan, 1985), and habitat type (hanging or bottom) (Elamin & Elamin, 2014).

The relationships between length-weight, length-height, and length-width are crucial when examining the biology of molluscs since they provide insights into the environmental conditions that bivalves inhabit (Agboola & Anetekhai, 2008). In this study, the weight/length (W/L) relationship of *C. gigas* was determined as $W=0.0083\times L^{2.021}$($R^2=0.7237$), and the b value was found to be less than three. This indicates a negative allometric relationship ($b = 2.653$, $b < 3$) for W/L. Additionally, negative allometry was observed between length-height (H/L) and length-width (Wi/L). Similar findings have been reported by Unnikrishnan Nair & Balakrishnan Nair (1986), Yapi et al. (2016), and Aydın et al. (2021) (Table 2). In contrast, Góngora-Gómez et al. (2018) found a positive allometry for W/L in *C. cortezienzis*. The negative allometric growth in *C. gigas* suggests that the shells become thinner as they increase in length (Farías-Tafolla et al., 2015), indicating that shell length increases more rapidly relative to weight.

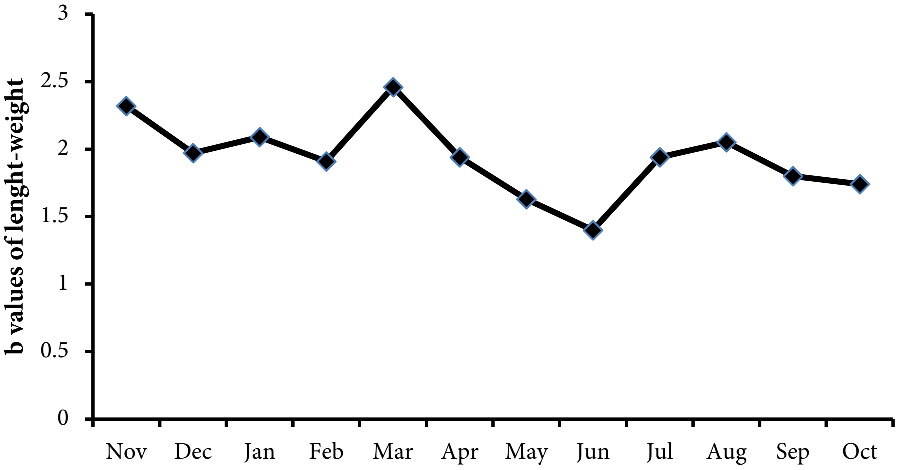

Figure 5. Changes in b value of length- total weight of relationship in *M. gigas*

Table 2. Parameters of the morphometric relationship for family species obtained from this study and available literature

Species	N	L mean ± SD (L min-L max)	Allometric relation	*a*	*b*	Determination confident (r^2)	SE of b (%95 CI of *b*)	Relationship (t-test)	Area	Reference
O. edulis			W/L	0.127	3.148	0.924			Mersin Bay, Aegean Sea, Türkiye	Acarli et al. (2011)
C. corteziensis	650	54.29±22.31 (4.31-105.06)	W/L	-3.8585	3.2023	0.98	0.015	+ allometry	Gulf of California, Mexico	Góngora-Gómez et al. (2018)
C. madrasensis	135	≥3.5	H/L	0.013	0.9866	0.931	0.332		Cochin Harbour, India	Unnikrishnan Nair & Balakrishnan Nair (1986)
C. madrasensis	291	3.5-8	H/L	0.402	0.5712	0.693	0.023		Cochin Harbour, India	Unnikrishnan Nair & Balakrishnan Nair (1986)
C. madrasensis	766	≤8	H/L	0.867	0.1669	0.096	0.062	-allometry	Cochin Harbour, India	Unnikrishnan Nair & Balakrishnan Nair (1986)
C. gasar	360	4.4-10.1	W/L	2.20	1.77	0.85		-allometry	Ebrié and Aby Lagoons, Ivory Coast, Ghana	Yapi et al. (2016)
C. gasar	360	4.1-11.2	W/L	0.2	2.82	0.85		-allometry	Ebrié and Aby Lagoons, Ivory Coast, Ghana	Yapi et al. (2016)
C. gasar	360	5.3-10.9	W/L	0.406	2.47	0.5		-allometry	Ebrié and Aby Lagoons, Ivory Coast, Ghana	Yapi et al. (2016)
C. gigas	235	59.57±13.65 (24.09-98.17)	W/L	0.0143	1.6662	0.6589		-allometry	Black Sea, Türkiye	Aydın et al. (2021)
C. gigas	235	59.57±13.65 (24.09-98.17)	Wi/L	2.6516	0.5736	0.3177		-allometry	Black Sea, Türkiye	Aydın et al. (2021)
C. gigas	235	59.57±13.65 (24.09-98.17)	H/L	1.7971	0.5228	0.1447		-allometry	Black Sea, Türkiye	Aydın et al. (2021)
C. madrasensis		25-60	W/L	-2.22269	2.0670	0.7828	0.111	-allometry	Mandovi Estuary, India	Nagi et al. (2011)
C. madrasensis		25-60	W/L	1.6477	1.7236	0.7295	0.113	-allometry	Mandovi Estuary, India	Nagi et al. (2011)
C. gryphoides		51-55	W/L	1.2468	1.4655	0.6340	0.197	-allometry	Mandovi Estuary, India	Nagi et al. (2011)
C. gryphoides		51-55	W/L	2.1179	1.9946	0.7436	0.167	-allometry	Mandovi Estuary, India	Nagi et al. (2011)
M. gigas	365	81.26±21.84 (33.05-140.1)	W/L	0.0083	2.021	0.7237	0.064	-allometry	Marmara Sea, Türkiye	This study
M. gigas	365	81.26±21.84 (33.05-140.1)	H/L	0.4925	0.6227	0.6014	0.030	-allometry	Marmara Sea, Türkiye	This study
M. gigas	365	81.26±21.84 (33.05-140.1)	Wi/L	0.2547	0.6531	0.5096	0.037	-allometry	Marmara Sea, Türkiye	This study

Note: *N*: number of individuals; *L*: shell length (mm); *H*: shell height (mm); *Wi*: shell width (mm); *W*: total weight (g); *SD*: standard deviation; *SE*: standard error; *CI*: confidence interval.

Singh (2017) and Lim et al. (2020) have indicated that the health condition or general condition of bivalves can be predicted from variations in their weight. The variations in the b values (equilibrium constant) of the length-weight relationship can be related to a wide range of metabolic processes, mainly the reproductive cycle in bivalves (Chávez-Villalba et al., 2008; Ramesha & Thippeswamy et al., 2009; Thejasvi et al., 2013; Thippeswamy et al., 2014). In this study, the monthly *b* value of the length-total weight relationship changed from 1.42 (June) to 2.46 (March). Acarli et al. (2019) reported that the spawning period of *C. gigas* in the same study area was in the spring and summer seasons. While an increase in gonad weight during periods of high maturation would be expected to result in higher *b* values, the actual influential parameter is the variability in the number of young individuals encountered during the months and, consequently, the variability in flesh or shell weight. The shapes of oyster species depend on the habitat they adhere to and the density, which differs from clams that live buried in the sand. Tanita & Kikuchi (1957) reported that the length-width ratio decreases with increasing density in *Pinctada martensii* (now revised to *Pinctada fucata*). Orton (1936) observed that the length-width ratio in *Ostrea angulata* varies with the type of substrate, with coastal *O. angulata* having longer and narrower shells, while those in tidal areas have broader shells. Consequently, in this study, parameters such as length-width and length-thickness were found to be more variable, and the determination coefficient (r^2) values of the relationships were low. The reproductive cycle of *M. gigas* does not have a primary-level effect on the variations in the b values.

Oysters are classified into two size categories: 76 mm ('petite' or 'cocktail') and 76 to 102 mm ('regular') (Grizzle et al., 2017). The average length of *C. gigas* is 46 mm at age one, 70 mm at age two, and 91 mm at age three (Diederich, 2006; Wang et al., 2007). Aydin & Gül (2021) observed that in July, the majority of the *C. gigas* population in the Black Sea consisted of young individuals with an average length of 3.3 cm. In this study, it was found that the shell length of *M. gigas* ranged from 68 mm in September and February to 70-90 mm in November, December, January, March, May, and October, and 90-100 mm in April, June, July, and August. Based on the obtained size data and population density, it can be concluded that the species has been present in this area for at least two years. The observation of newly settled Japanese oysters in the laboratory samples indicates that the species has completed its adaptation process in this area.

Conclusion

Based on the obtained size data and population density, it is believed that the invasive species *M. gigas* has been present in this area for at least two years or longer. The observation of newly settled Japanese oysters in the laboratory samples indicates that the species has completed its adaptation process in this area. This study represents the first determination of the morphometric characteristics of this species in the Marmara Sea. According to the results, a negative allometric relationship was found between *M. gigas* shell length and other parameters. Despite being an invasive species, *M. gigas* is also widely cultivated. However, it is necessary to protect the stocks of the native species *O. edulis*, which are present in Turkish waters, against invasive species. Considering the distribution history of *M. gigas* worldwide, it is understood that preventing its introduction and distribution in our waters is challenging. Therefore, the detection, monitoring, and assessment of the distribution of *M. gigas* in Turkish waters are crucial for developing action plans to sustainably conserve the ecosystem and ensure economic significance.

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Compliance With Ethical Standards

Authors' Contributions

HY: Manuscript design, Laboratory experiments.
SA: Drafting, Editing, Laboratory experiments, Data analysis.
PV: Writing, Editing, Data analysis.
All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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