Length-weight relationship of the Pacific oyster (*Magallana gigas* (Thunberg, 1793)) in Sakoshi Bay, Japan

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Abstract. This quantitative descriptive research assessed the biological status of *Magallana gigas* in the waters of Sakoshi Bay, Hyogo Prefecture, Japan, based on field observations and surveys conducted from February to May 2025 at the Sakoshi Fishing Port. A total of 893 oyster samples were collected and their length and weight were recorded for analysis. The species exhibited a negative allometric growth pattern, expressed by the equation $W = 10.841\ L^{0.9217}$, where b = 0.9217 (b < 3), indicating that weight increases at a slower rate than length. The determination coefficient ($R^2 = 0.6102$) was relatively high, and the correlation coefficient (r = 0.7812) revealed a strong positive relationship between length and weight in *M. gigas*.

Key Words: allometric growth, bivalve, inland sea, Japan, *Magallana gigas*.

Introduction. Sakoshi Bay is located on Seto Inland Sea, in 319 Sakoshi, Ako, Hyogo Prefecture 678-0172, Japan, is a sheltered natural harbor characterized by calm, clear waters and surrounding hills. These environmental features create optimal conditions for the aquaculture of the Pacific oyster, *Magallana gigas* (syn. *Crassostrea gigas*) (Thunberg 1793; Bayne et al 2017; Fivash et al 2021). It also has forest on Ikushima Island (designated as a natural monument by the government), and Chikusagawa River which water is included in the Japan's top 100 mineral waters where plankton population is abundant (Hasegawa et al 2021; Herman et al 2025; Mustofa et al 2025). Such environment creates a prime habitat for diverse marine organisms. Sakoshi Bay has been a strategic port since the Edo period with strong environmental, cultural, and historical values as shown by well-preserved old sites and structures (Fajrin & Junianto 2025). The environmental conditions of Sakoshi Bay offer an optimal habitat for oysters. *Magaki*, *Sakoshikaki*, or *Kaki karatsuki* are local terms that refer to live oysters with shells intact (shell-on oysters), which reflect the physiological characteristics of *M. gigas* in the local waters. According to Hebert et al (2024), the nutrient-rich and sheltered waters support the growth of oysters, which growth rate is relatively fast to reach large shell sizes (up to approximately 25 cm), with a lifespan exceeding 20 years in natural conditions.

M. gigas is an important bivalve oyster that also has roles in the aquatic ecosystems across regions, including Japan (Grose et al 2020; Shinji et al 2022). Taxonomically, *M. gigas* belongs to the phylum Mollusca, class Bivalvia, order Ostreida, family Ostreidae, and genus *Magallana* (synonym *Crassostrea*). The most well-known species in this group is *Magallana* (syn. *Crassostrea*) *gigas* (Thunberg, 1793), commonly called the Pacific oyster/Japanesse oyster or globally referred to as the Pacific cupped oyster. *M. gigas* has shells that are asymmetrical, rough-textured, and tend to attach firmly to hard substrates (Thunberg 1793; Ruesink et al 2023; Dellong et al 2024; Wolfe et al 2024; Mrowicki & Uhl 2025). *M. gigas* is found in East Asia coastal waters, especially around Japan, Korea, and China. Due to its high economic value and adaptability to diverse environmental conditions, *M. gigas* has been exported to other parts of the world for aquaculture, including the coasts of North America (Pacific and Atlantic), Europe (France, England, Spain), Australia, and New Zealand (Des et al 2022; FAO 2022; Wolfe et al 2024; Calla et al 2025). Japanese oyster aquaculture is conducted in sheltered bays or calm coastal waters. In 2017, production of Japanese oysters reached approximately 600,000 tons within global aquaculture operations, positioning Japan as the third-largest oyster-producing country in 2016 (Botta et al 2020; Treviño et al 2020). Besides cultivated populations, *M. gigas* populations can thrive naturally in new habitats that are suitable for their growth. Their tolerance to salinity ranges between 10 and 35 ppt, temperatures from 7.4 to 22.6°C, and preference for available substrates supports their wide distribution. Consequently, they are regarded invasive in some ecosystems, although they contribute ecologically by enhancing microhabitat diversity and ecosystem services such as natural biofiltration (Schulte et al 2009; King et al 2021; McAfee & Connell 2020; Martin et al 2025). According to Yulianda & Atmadipura (2020), *M. gigas* exhibits a biphasic life cycle typical of many bivalves, comprising a planktonic larval stage, during which larvae swim freely in the water column, followed by a benthic stage in which they settle and permanently attach to suitable substrates. This pattern commences with external fertilization, yielding trochophore and veliger that drift planktotrophically, feeding on phytoplankton before developing a foot as pediveligers for settlement. Settlement typically occurs after 11-30 days at 16-30°C, after which juveniles (spat) cement permanently to hard substrates such as rocks or shells (Shumway & Parsons 2016; Corrochano-Fraile et al 2022; Zhang et al 2026). Once attached, oysters grow shell and body mass over time as sessile organisms. In estuarine or coastal waters such as Sakoshi Bay, oysters attach to hard surfaces (e.g., aquaculture racks, coral, poles, or other oyster shells) and feed by filter feeding.

The length-weight analysis of *M. gigas* Sakoshi Bay waters serves as the fundamental basis for fisheries biology studies and the scientific utilization of oyster resources. The population of the oyster in the wild should be assessed to analyze the ecosystem balance. One form of morphometric evaluation is the analysis of the length-weight relationship. To date, only few research had been performed on the the length-weight relationship of edible oysters (Ostreidae) conducted in Japan. No research on the length-weight relationship has been performed in Sakoshi Bay, Ako City. Therefore, the present research was intended to close the gap and to propose evidence-based recommendations to the oyster conservation and aquaculture based on the length-weight relationship of *M. gigas* in Sakoshi Bay, Ako City.

Material and Method

Location and time. This research was conducted in Sakoshi Bay, Ako City, Hyogo Prefecture, Japan. The Sakoshi district serves as one of the central hubs for fisheries and economic activity in Ako City. Field surveys and interviews were carried out from February to April 2025 at Sakoshi Port (Figure 1).

Research materials. The samples of this research were 893 individuals of *M. gigas* (Figure 2) landed by oyster fishermen using the suspended raft aquaculture method. The fishermen used workboats ship made of FRP with 450 horsepower engines. Oyster length (total length – TL) was measured systematically and structurally from different suspended rafts in each sampling period. All samples were measured with a cutting mat of 0.1 mm precision and weighed using digital scales with 0.1 gram precision to ensure the representativeness of different age groups. The primary data collected included total length (cm) and body weight (g).

Analysis method. This quantitative descriptive research examined the length-weight relationship to describe the growth patterns and the biological conditions of oyster population based on morphometric parameters using the following equations (King 1995; Sparre & Venema 1998; Froese 2006):

$$Wt = a.Lt^b \quad (1)$$

$$Ln\ Wt = Lna+b.LnLt \quad (2)$$

where: Wt = oyster weight at age *t* (g); Lt = oyster length at age *t* (cm); a, b = constant.

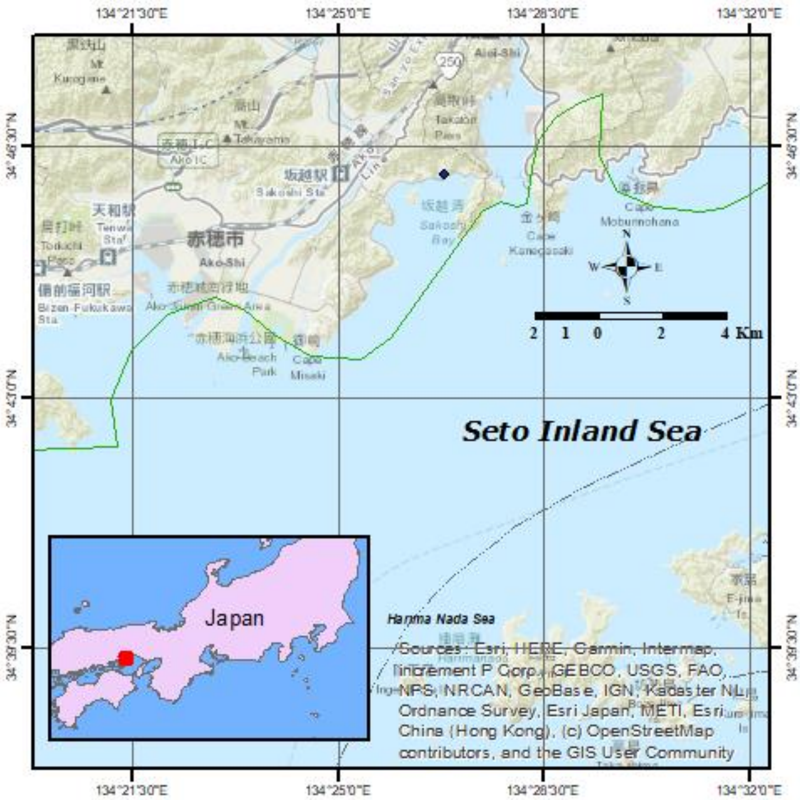

Figure 1. Sakoshi Bay (research location).

Figure 2. *Magallana gigas*.

Results. *M. gigas* is a benthic sessile mollusk in seabed that permanently attaches to substrates (Gosling 2003; Shumway & Parsons 2016; Charifi et al 2023; Mercer et al 2024). Unlike fish, oysters do not swim or migrate in their adult phase, as they remain permanently attached to hard surfaces. *M. gigas* lives in colonies, often forming 'oyster banks' in coastal and bay areas (Bergström et al 2025). According to Beck et al (2024), its natural habitat includes estuarine waters, shallow bays, and intertidal to subtidal zones. *M. gigas* can be found from intertidal depths to approximately 40 m, but is most dominant in shallow intertidal-subtidal zones (0-15 m) (Ruesink et al 2023). The abundance of the oysters' prey depends on water quality and substrate. *M. gigas* is a filter feeder that feeds on phytoplankton, detritus, and dissolved organic particles in the water column. Its preferred substrate is muddy sand or mud mixed with gravel with adequate water circulation. Phytoplankton and marine aggregates constitute food sources because oysters can filter and ingest phytoplankton cells and suspended organic aggregates (Doni et al 2023). The size of *M. gigas* varies, with average standard length for 2-3-year-old adults ranging from 80 to 150 mm, with maximum length reaching 300-450 mm (Shatkin et al 1997; Helm et al 2004). Based on the data of this research, the length-weight relationship of *M. gigas* follows the equation $W = 10.841\ L^{0.9217}$ (Figure 3). The coefficient $y = 0.9217$ is lesser than 3 ($b < 3$), indicating negative allometric growth, where shell length increases more significantly than body weight (Sotelo-González et al 2020; Hira et al 2025). The determination coefficient $R^2 = 0.6102$ for the LnW–LnTL relationship curve indicates a relatively strong fit of the model which can be an effective predictive tool. The correlation coefficient $r = 0.7812$ shows a very strong positive correlation between the length and weight of *M. gigas* (King 1995; Sparre & Venema 1998).

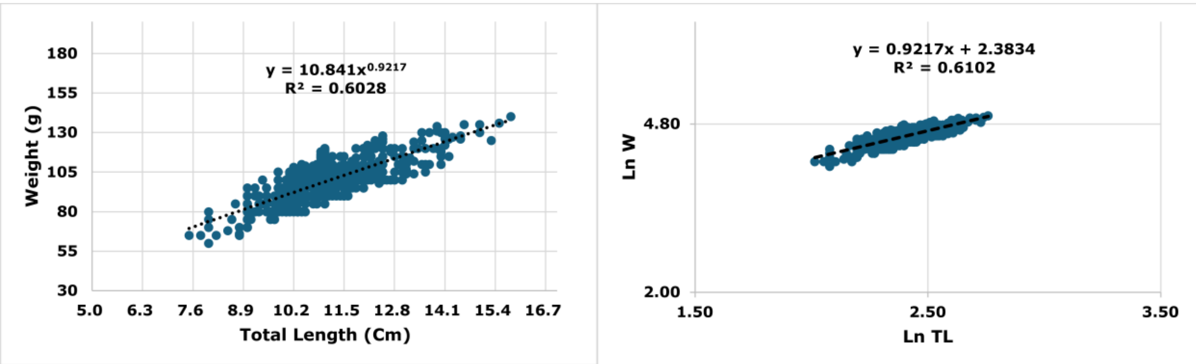

Figure 3. Length-weight relationship of *M. gigas*.

The length-weight relationship parameters of *M. gigas* obtained in this research were compared to the ones of previous research conducted in several aquatic locations. As seen in Table 1, the results of prior research consistently show negative allometric growth with growth constant (b) values lesser than 3. The increase in shell length occurs at a faster rate than the increase in body weight, thereby the weight of the oyster does not increase proportionally to the length growth. As the results, the oyster tends to have relatively thinner shell or slower weight gain relative to length. This pattern has been an important biological characteristic to consider for growth modeling and resource management.

Table 1

Comparison of length-weight relationship parameters of *Magallana gigas* from various research locations

Length-weight equation	*b*	*R^2*	*n*	*Types of growth*	*Area*	*Reference*
$W = 0.0143.L^{1.6662}$	1.6662	0.6589	235	Negative allometric	Southern Black Sea, Türkiye	Aydin et al (2021)
$W = 0.411.L^{2.653}$	2.653	0.6014	365	Negative allometric	Bandırma Bay, Marmara Sea, Türkiye	Acarli et al (2023)
$W = 2.2067.L^{0.3457}$	0.3457	0.4706	-	Negative allometric	Krueng Cut, Province of Aceh, Indonesia	Octavina & Afriana (2024)
$W = 10.841.L^{0.9217}$	0.9217	0.6102	893	Negative allometric	Sakoshi Bay Water, Hyogo, Japan.	This study

The growth constant b in this research was 0.9217, with a coefficient of determination (R^2) of 0.6102 and a sample size of 893 individuals, indicating a fairly strong relationship between length and weight. Similar values were also obtained by Aydin et al (2021) and

Acarli et al (2023), with slight variation across different regions. These variations are influenced by different environmental conditions, such as temperature, salinity, food availability, as well as biotic and physiological factors of the organism (Stechele et al 2022; Acarli et al 2023; Octavina & Afriana 2024; Pang et al 2024). The comparative results provide a general overview that the growth pattern of *M. gigas* across various locations consistently exhibits negative allometric growth, despite variability in growth constants between populations.

Discussion. Sakoshi Bay in Hyogo Prefecture, Japan, is a coastal area known for its environmental conditions that support diverse marine organisms, including *M. gigas*. The area hosts high biodiversity, comprising phytoplankton, macroalgae, seagrass, as well as various fish and marine invertebrates that play critical roles in maintaining the coastal ecosystem balance. The estuarine ecosystem shows high biodiversity that is affected by interactions between terrestrial and marine components such as forests, rivers, and coastal morphology (Itsukushima 2023). *M. gigas* is a natural biofilter that improves water quality through filtration activities and holds high economic value as a premium aquaculture commodity (Hargrave et al 2021; Anwar & Maulina 2022; Mustofa et al 2025).

Successful management and conservation of *M. gigas* in Sakoshi Bay rely heavily on the support of local communities, especially oyster fishermen and cultivators who have resided in the area for generations (Adams et al 2021; Ridlon et al 2021; Shinji et al 2022; Hamelin et al 2024; Howie et al 2024). Without sustainable livelihoods, communities may engage in activities that disrupt the coastal ecosystem balance, such as overexploitation or unmanaged waste disposal. Therefore, sustainable management of *M. gigas* is crucial to preserve the oyster population viability and ecological functions as well as in supporting the socio-economic aspects of the local communities. Balanced and sustainable marine ecosystem conservation contribute to the welfare of the community in the short and long terms (Jentoft & Chuenpagdee 2009; Hamelin et al 2024; Howie et al 2024).

M. gigas is a filter-feeding bivalve with significant roles in the coastal ecosystems, especially in estuarine and bay waters, by improving water quality through filtration of phytoplankton and suspended particles (Cognie et al 2001; Newell 2004; Smith & Pruett 2025). In Japan, *M. gigas* is one of the main fisheries commodities, which production distributes across several coastal prefectures, including Hiroshima, Miyagi, and Hyogo (FAO 2022). In Sakoshi Bay, Hyogo Prefecture, local communities have long sustainably cultivated *M. gigas* using floating raft aquaculture system. Adult *M. gigas* typically attach to hard substrates in shallow waters with high salinity and good water circulation. Octavina & Afriana (2024) found the maximum shell length of *M. gigas* found in Krueng Cut, Banda Aceh was or 5.02 cm. In this research, the cultivated *M. gigas* in Sakoshi Bay showed a maximum shell size of 15.8 cm, larger than the average sizes reported by Octavina & Afriana (2024). Hermawati et al (2017) found higher sizes of oysters in brackish water ponds and estuaries compared to coastal plain areas, with exhibiting *M. gigas* various stages of gonadal maturity and with length at first gonad maturity ($Lm_{50\%}$) ranging from 4.746 to 4.843 cm in males and 7.527 to 7.550 cm in females.

Size structure is an important information for population analysis. Length measurements yield critical data for estimating growth, mortality, and recruitment parameters in bivalve populations. In this research, *M. gigas* ranged from a minimum length of 7.5 cm to a maximum of 15.8 cm, with weights ranging from 60 g to 140 g. Length distribution of oysters landed from Sakoshi Bay waters was dominant in the 10.2-11 cm total length range, with weight distribution dominant between 98 g and 105.5 g. *M. gigas* holds high economic value in the domestic Japanese market and it is also an export commodity (Hasegawa et al 2021; Herman et al 2025). The length-weight relationship analysis yielded a growth coefficient b = 0.9217 (less than 3) that indicates negative allometric growth, in which shell length increases more significantly than body weight (Mazumder et al 2016; Aydin et al 2021; Marquardt et al 2024). The coefficient of determination (R^2) was 0.6102, showing that 61.02% of weight increase can be attributed to length increase, while 38.98% is due to other factors such as environment and age. A strong positive correlation (r = 0.781) between length and weight indicates that increases in length substantially contribute to weight gain, though environmental factors remain influential. Water quality parameters (temperature, salinity, pH, dissolved oxygen) significantly influence growth and survival of oysters. Seasonal changes (monsoons) affected temperature and salinity that influence the physiological conditions of oysters (Barraza-Guardado et al 2009; Gosling 2015; Hossain et al 2025). The length-weight relationship serves as a key indicator of the biological, physiological, and ecological characteristics of oysters, providing a robust foundation for stock assessment and inter-regional comparisons of *M. gigas* population dynamics.

Aydin et al (2021), Acarli et al (2023), and Octavina & Afriana (2024) showed in their studies that growth constant values (b) were lesser than 3 (negative allometric growth), where shell length increases at a faster rate than body weight. The b values varied across studies: Aydin et al (2021) reported b = 1.6662, Acarli et al (2023) reported b = 2.653, and Octavina & Afriana (2024) reported b = 0.3457. This range (0.34-2.65) indicated significant physiological and environmental differences among research sites. Coefficients of determination (R^2) varied across studies, ranging from 0.47 to 0.66: Aydin et al (2021) = 0.6589, Acarli et al (2023) = 0.6014, and Octavina & Afriana (2024) = 0.4706. These values indicate a moderate to strong relationship between length and weight, although not entirely deterministic. This means that the length variable can explain the majority of variations in body weight, but other factors also contribute to individual growth. Variations in b values are influenced by factors that include food and phytoplankton availability, water temperature and salinity, substrate type (sand, mud, rock), population growth stage and age structure, population density and spatial competition, as well as seasonal and sampling period effects. These ecological factors critically determine growth efficiency and biomass accumulation per population (Nurfadilah et al 2023; Li et al 2024).

Aydin et al (2021) conducted a research in Black Sea waters, Turkey, and found that *M. gigas* inhabited waters at the depth of 0-5 m on rocky coastal substrates. While the specific season was not specified, the temperature data correspond to August, which is the warmest month, with an average sea temperature of 26.2°C and salinity approximately 18%. In this Black Sea region, food availability for *M. gigas* is shaped by the anoxic basin, which may reduce phytoplankton productivity in the oxic layers. The negative allometric growth observed in Aydin et al's research indicates that the oysters become slimmer as they grow longer, likely influenced by the unique environmental combination of the Black Sea (low salinity, hard substrate, and population density).

Acarli et al (2023) in Bandirma Bay, Marmara Sea, Turkey, found that *M. gigas* densely attached to hard substrates (rocks). The research reported that the length-to-width ratio varied with substrate type, with coastal oysters having longer and narrower shells, while oysters in intertidal areas have wider shells. Shell length significantly varied throughout the year, with the smallest measurement at 68.08 mm (February) and the largest at 93.14 mm (April). The mean shell length measured 46 mm after one year, 70 mm after two years, and 91 mm after three years. Size data and population density indicated that the species had been established in the study area for a minimum of two years. Morphometric parameters, including length-to-width and length-to-thickness ratios, exhibited substantial variability, with low coefficients of determination (R^2) for these allometric relationships, attributable to variations in population density and substrate characteristics. Acarli et al (2023) also noted that variation in the growth constant (b) from length-weight relationships might be related to various metabolic processes, especially reproductive cycles in bivalves. The spawning period of *M. gigas* in Bandirma Bay occurs during spring and summer. However, the parameter most influencing variability in weight is the number of juveniles found during certain months. The reproductive cycle has no primary effect on b variation. Growth, shape, total weight, and length-weight relationships in bivalves are influenced by physiological factors such as genetics and environmental factors including temperature, salinity, turbidity, and chlorophyll-a. Despite the lack of temperature and salinity data for the sampling site, these factors are recognized as major drivers of oyster morphometric variation. The main factors affecting the b value are combinations of population density, individual size variability (especially juvenile presence), substrate type, and environmental conditions, rather than the reproductive cycle itself.

Octavina & Afriana (2024) identified morphological factors as the primary determinant influencing negative allometric growth in *M. gigas* in Krueng Cut, Banda Aceh, Indonesia. The species exhibits a flattened and elongated shell shape, resulting in a growth pattern where shell length increases faster than weight (b = 0.3457; b < 3). The research did not specifically address food and phytoplankton availability at the site and it showed that the water quality parameters did not significantly affect variations in the growth constant b. Temperature ranged between 33 and 34°C (species tolerance 5-35°C), salinity from 10 to 13 ppt (tolerance 10-30 ppt), pH from 8.09 to 8.13 (tolerance 6.80-9.25), and dissolved oxygen levels ranged from 6.96 to 7.2 mg L^{-1} (minimum requirement > 1 mg L^{-1}), all remaining relatively constant and conducive to *M. gigas* survival. The substrate conditions comprising mud, sand, gravel, and rocks with warm and wave-protected waters are appropriate habitats for oysters. Among 172 individuals observed, the average size was small with shell length ranging from 20 to 50.2 mm and dominant weights between 7.4 and 8.4 g (28 individuals), indicating gonadal maturity with accumulation of body mass in preparation for spawning. The research did not specifically analyze population density or spatial competition. Single-period sampling in October 2020 prevented seasonal analysis. The negative allometric growth pattern was chiefly driven by morphology and substrate adaptation, with water quality remaining stable and optimal.

The research conducted in Sakoshi Bay, Hyogo, Japan, revealed a growth coefficient (b) of 0.9217 (very low). In this research, *M. gigas* elongate in faster rate than the increase in body mass. This phenomenon is likely influenced by local environmental factors such as relatively low water temperatures (10-20°C), high but fluctuating salinity, and high individual density in the aquaculture raft system, causing competition for space and food. The samples were likely dominated by individuals in the juvenile or post-spawning phase, when energy is directed toward tissue repair and shell growth instead of weight accumulation. The correlation coefficient (r = 0.7812) reflects a strong positive relationship between length and weight in *M. gigas*. Although growth is not fully proportional (isometric), the biological pattern remains consistent with characteristics observed in this species across other regions. Overall, b values for *M. gigas* are influenced by a combination of environmental factors (temperature, salinity, substrate), food availability, population age and size structure, density, and sampling season. The largest impact on b variation among the research by Aydin et al (2021), Acarli et al (2023), and Octavina & Afriana (2024) is attributed to substrate conditions and the oyster's adaptive morphology to its habitat, followed by population density and individual size variation.

The reproductive biology of *M. gigas* is a critical aspect to consider in resource and fisheries activities. This species exhibits protandric hermaphroditism, wherein young individuals function as males and subsequently transition to females as they grow and increase in size (Guo et al 1998; Yasuoka & Yusa 2016). Large female broodstock is essential for successful natural spawning since females produce significantly more eggs than males. The commercial potential of *M. gigas* in Japan encompasses both aquaculture and capture fisheries within its production cycle. Exploitation activities include harvesting adult wild oysters using scallop shells in Miyagi Prefecture and collecting wild spat with natural (scallop shells) and artificial collectors (bamboo, hanging ropes) in Mushiage Bay (Okayama Prefecture), Hiroshima Bay (Hiroshima Prefecture), and Osaka Bay to support intensive floating raft aquaculture (Yasuoka et al 2024). In Sakoshi Bay, aquaculture relies on spat supplied from Mushiage and Hiroshima Bays. The spawning and harvest sites lie within the semi-enclosed Seto Inland Sea, which features depths of 2-15 m, salinity of 30-34 PSU, and surface water temperatures between 6 and 27°C throughout the year (Kamiyama et al 2005; Southgate & Lucas 2008; Yasuoka et al 2024). The combination of coarse gravel and sandy mud substrates, together with high phytoplankton productivity, promotes natural reproduction and larval settlement (Morelle et al 2020; Nishizaki & Ackerman 2019).

The price of fresh *M. gigas* in Sakoshi Bay ranges from ¥700 to ¥1,200 per kilogram, depending on size, season, and meat quality. According to Mustofa et al (2025), the total weight of oysters sold with shells is approximately 20,000 kg and sells at a price of ¥1,100/kg, while the total net weight sold without shells (meat only) during the same period is about 2,700 kg, priced at ¥3,200/kg. Mustofa et al (2025) also reported average daily weights of *M. gigas* individuals as 666.7 kg/day (with shells) and 90 kg/day (without shells). The integration of capture fisheries (wild spat collection) and intensive aquaculture reflects a sustainable resource management strategy in Japan, with natural recruitment from wild waters forming the primary basis of national aquaculture stocks (Shumway & Parson 2016; Wijsman et al 2019; FAO 2024; Padin et al 2024).

The morphometric information obtained from the length-weight relationship research can contribute to optimizing stock management, estimating commercial biomass, and predicting oyster meat yield for both cultured and wild populations in the research area and surrounding regions. A balanced sex ratio is an important factor for sustaining populations and ensuring optimal regeneration of *M. gigas* in natural environments (Broquard et al 2020; Sun et al 2023). Environmental factors that include water temperature, salinity, and food availability also influence gonadal cycles and spawning timing of oyster. Therefore, sustainable reproductive management practices regarding the aforementioned factors should be promoted.

Conclusions. The length-weight relationship of *Magallana gigas* follows the equation $W=10.841\ L^{0.9217}$ with negative allometric growth pattern, where increases in length are more pronounced than increases in weight. This phenomenon is attributed to the flattened body shape of *M. gigas* and its benthic habitat, leading to a faster increase in shell length relative to weight as an adaptation to its environment. Further research concerning the physicochemical factors of the aquatic environment is necessary to provide threshold quality data and support the sustainability of *M. gigas* in Sakoshi Bay, Ako City, Hyogo, Japan.

Conflict of interest. The authors declare that there is no conflict of interest.

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