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Lagoon amphipods as a new feed resource for aquaculture: A life history assessment of *Grandidierella halophila*

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ABSTRACT

Amphipods are emerging as a new feed resource in aquaculture. In an effort to provide an alternative feed for commercial nursery applications, the life history of an estuarine amphipod *Grandidierella halophila* was studied for the first time under laboratory conditions and reported herein. *G. halophila*, obtained from a lagoon in northern Kelantan, Malaysia was cultured in 500 l clear plastic containers with filtered water (at 28 °C and 7 ppt). Juveniles from a single brood were monitored in five replicates throughout the different phases of their lifetime. Data obtained included maturation time, number of broods per lifetime, number of juveniles per brood, growth rate, and productivity per lifetime. Results obtained suggest that the *G. halophila* exhibited a semiannual, multivoltine life history pattern, producing multiple broods in its short lifespan (72.3 vs 108.0 days for males and females respectively). Sex ratio was in favor of the females (1: 1.76) and the mean maximum size observed was 7.02 and 6.31 mm in length respectively for males and females within a lifespan. Female maturation time was 12.8 days at a mean total length size of 3.5 mm. The incubation period was 5.7 days with a mean of 20.8 juveniles produced per brood. Mean number of broods produced in a life span was 4.7. A strong positive correlation (R^2 = 0.95) was observed between the female size and the number of juveniles produced. With a mean of 97.5 juveniles produced by each female in a life span, *G. halophila* productivity stands at 0.90 juveniles per couple per day. The life history patterns described in this study serve as a baseline to jumpstart the commercial culture of this species for future use.

1. Introduction

Fry and larval management are crucial to the development of aquaculture ventures around the world (Solomon et al., 2015). The provision of nutritionally balanced live feeds for the early stages of finfish and shellfish species is pivotal for the successful rearing of most commercially important aquaculture species (Southgate, 2019). The most common starter diet used in hatcheries and fish farms is *Artemia*,

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which is imported, hence very expensive (Solomon et al., 2015; Okomoda, 2018). With the continuous increase in the price of *Artemia* and other conventional feedstuffs, the profit margin accruing to the aquaculture producers is significantly reduced (Amubode and Ogogo, 1994; Rana et al., 2009). Therefore, as sustainability is at the forefront of aquaculture research, the search for alternative feed resources has increased (Tacon and Metian, 2008). In recent years, marine amphipods have shown promising results as a new feed resource for cephalopod, shrimp and seahorse aquaculture as a replacement for adult *Artemia* or included in integrated multi-trophic aquaculture (IMTA) systems (Baeza-Rojano et al., 2010; Baeza-Rojano et al., 2013a; Herawati et al., 2020; Modesto et al., 2019; Vargas-Abúndez et al., 2021a; Xu and Mu, 2017; Xue et al., 2021).

Amphipods are an order of macroscopic crustaceans whose lifecycle is characterized by a direct development to adulthood (Baeza-Rojano et al., 2010). Simply put, the females carry embryos in a brood chamber and when the juveniles are released, they develop into adults after several molts without metamorphosis (Väinölä et al., 2008). Experimental studies under laboratory conditions have shown amphipods to be important natural prey to an array of marine species of commercial interest. This includes cephalopods (e.g. octopus, *Octopus vulgaris)* crustaceans (e.g. mud crab, *Scylla serrata*), marine fishes (e.g. sea bass, *Dicentrarchus labrax*, seabream, *Sparus aurata*) and ornamental fish (e.g. lined seahorse, *Hippocampus erectus*) (Jiménez-Prada et al., 2015, 2021; Khan et al., 2018; Olmos-Pérez et al., 2017; Teixeira and Musick, 2001). Nutritional studies of their partial replacement for fishmeal in formulated diets of fish have also given very promising results (Alberts-Hubatsch et al., 2019a; Ashour et al., 2021). In the wild, amphipods have been reported to play a critical role in aquatic food webs, because they act as conduits of nutrients and energy to higher trophic levels (Väinölä et al., 2008), hence, their use for aquaculture species under captivity and laboratory conditions is ecologically justifiable. Potential aquaculture uses for amphipod feeds are, as a replacement for adult *Artemia* used in various nursery feeding regimes, as a fishmeal replacement in aquafeeds and inclusion in IMTA systems. General knowledge about the culture techniques for amphipods used in aquaculture is still very limited. A deeper knowledge of reproductive biology at the species level is needed to potentiate the optimization of mass production.

In accessing the reproductive potentials and planning culture strategies of amphipods, the life history traits influencing productivity are an important aspect to study. Some of these traits are important indexes for identifying potential new feed resources for aquaculture (Jiménez-Prada et al., 2018). These life cycle characteristics include a multiple brooding pattern (iteroparous and multivoltine pattern) and rapid growth rate which make them well suited for large-scale culture as they commonly form dense populations in natural and artificial environments (Baeza-Rojano et al., 2013b; Fernandez-Gonzalez et al., 2018; Navarro-Mayoral et al., 2020). In addition to their capability to reach high biomass when cultured, amphipods are also rich in valuable polyunsaturated fatty acids, protein, and amino acids and typically demonstrate high tolerances to environmental stresses (Baeza-Rojano et al., 2014; Fernandez-Gonzalez et al., 2018; Woods, 2009). Importantly, their potential for mass production is cost effective and environmentally sustainable (Alberts-Hubatsch et al., 2019b; Guerra-García et al., 2016; Harlıoğlu and Farhadi, 2018; Woods, 2009). Studies of several amphipods have shown iteroparous and multivoltine life history patterns which contribute to their high densities (Baeza-Rojano et al., 2011; Sainte-Marie, 1991). In addition, they present a large brood size, high fecundity and early maturation (Baeza-Rojano et al., 2013a; Grabowski et al., 2007; Xue et al., 2013). However, despite the encouraging characteristics of many amphipod species (Baeza-Rojano et al., 2011, 2013b; Vargas-Abúndez et al., 2021b), their productivity has been poorly reported in previous studies, especially under culture conditions.

First established by Coutière (1904), the amphipod genus *Grandidierella* has over 43 species described around the world (Horton et al., 2020, 2022; Wongkamhaeng et al., 2020). The genus is widespread in marine environments such as brackish, estuarine, and coastal waters (Azman and Othman, 2012; Bochert and Zettler, 2009; Myers, 1981; Myers and Desiderato, 2019; Myers et al., 2019). Aside from their potential use as aquaculture live food (Jourde et al., 2013; Lo Brutto et al., 2016), other species are used as a standard for sediment toxicity studies (Hindarti et al., 2015; Lee et al., 2005; Nipper et al., 1989). *G. halophila* is a species belonging to the Aoridae family described by Wongkamhaeng et al. (2012) as a new species from the Inner Gulf of Thailand, inhabiting hypersaline waters of salt flats from the Samut Sakorn district, Thailand. At present, the bulk of the works on Aoridae (including those of Southeast Asia) are taxonomic studies. Only a few papers exist on the life history parameters of species such as *Grandidierella japonica,* and *G. bonnieroides* (Collie, 1985; Kang, 2014; Nayar, 1956; Thoemke, 1979; Wang et al., 2009). *G. halophila* was selected for this study because it is naturally abundant in the lagoons at Pantai Sri Tujuh in Kelantan Malaysia, hence, was easily accessible to the researchers for the study. Also, to the knowledge of the researchers, the life history of *G. halophila* has not been scientifically reported to date. This study, therefore, intends to investigate several aspects of *G. halophila* life history traits under laboratory conditions with a focus on its productivity, as this research is part of an assessment of its potential use as a new feed resource for aquaculture.

2. Materials and methods

2.1. Amphipod sampling and culture conditions

G. halophila (Fig. 1) were collected from the lagoons at Pantai Sri Tujuh in Kelantan Malaysia (6.21928°N; 102.12819°E) by dragging scoop nets along the vegetation at the water's edge (with 7 ppt salinity). They were abundant as well as dominant in the vegetation surrounding the lagoons at high densities. The body color of *G. halophila* was brownish with tiny flashes of orange and green illuminating the midsection. Collected samples were transported back to the hatchery of the Institute of Tropical Aquaculture and Fisheries (AKUATROP) at Universiti Malaysia Terengganu. At the AKUATROP hatchery, they were acclimatized and maintained in 28 ± 1.0 °C water with a salinity of 7.0 ± 1.0 ppt (similar to the water quality in the lagoon where the amphipods were collected). The amphipods were fed daily with commercial tropical fish flake (Tetra® TetraMin) following the feeding procedure by Nipper et al. (1989) for *G. bonnieroides* cultured under laboratory conditions. Identification of *G. halophila* was done by two experts in amphipod taxonomy, namely Azman B.A.R. and Koraon Wongkamhaeng (Wongkamhaeng et al., 2012).

2.2. Determination of life span, growth rate and sex ratio

The life span of males and females was recorded by culturing all the offspring released from a single brood in a 500 ml clear plastic bowl for the entirety of their lives. Portions of 6 mm polypropylene rope were provided as artificial substrates. Water was exchanged bi-weekly and feed (Tetra® TetraMin) was provided every other day. A total of six brood replicates ($n = 6$ containing not <22 juveniles per brood) were reared throughout this study for the determination of the parameters reported herein. The total length of the species was taken as the length along the dorsal edge, from the tip of the rostrum to the telson tip. One individual of each sex per brood (male, n = 6 and female n = 6) was randomly sampled each week, euthanised with 70% ethanol and used for growth rate estimation. The amphipods were euthanised to ease the measurement of individuals. Also, only one sample was measured per sex, per brood per week because of the limited number of juveniles produced by the amphipod. Weekly measurements of the length were done for ten weeks using a Nikon Measuring Microscope MM-800. The growth rate was observed as the mean length increment in total length per day using the relation below.

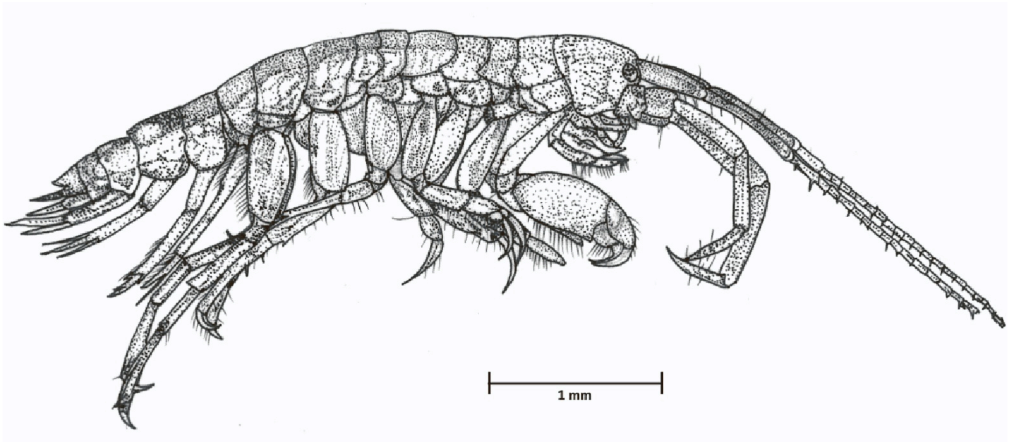

Fig. 1. Drawing of *Grandidierella halophila*, male.

$$\text{Growth rate (mm/d)} = \frac{L_2 - L_1}{t_{2-t_1.}}$$

where L_1 = initial length(mm)

L_2 = final length(mm)

t_2-t_1 = duration between L_2 and L_1 (days)

The growth rate for the different sexes was not obtained until the 14th day due to our inability to identify the sex of the species by appearance before the onset of sexual maturity. Thereafter, sex was determined by observation under dissecting microscope and confirmed by appearance of distinguishing characteristics (enlarged 1st gnathopod for males). Sex ratio was obtained by randomly sampling 500 adults from a larger stock culture (20*L*) being maintained for several months under the laboratory conditions. Sex was determined by observation under dissecting microscope as mentioned above.

2.3. Determination of sexual maturity, incubation period, and productivity

For sexual maturity, the offspring from the single brood earlier cultured in the 500 ml clear bowl (with strands of 6 mm polypropylene rope as artificial substrate) were monitored closely for signs of reproduction. During this study, *G. halophila* was not observed engaging in precopulatory behaviors such as grasping or riding. Therefore, sexual maturity was measured by identifying the day on which the females were first observed with eggs. The ovigerous females (six replicates) were then placed in separate Petri dishes and observed until the juveniles were released. Incubation time was measured as the period from the oviposition of the eggs to the brood pouch until the juveniles were released. Female head length was recorded immediately after the release of juveniles and the spent female was placed in a new bowl with three mature males to continue breeding. The mean number of juveniles released per brood by a female in a lifespan was recorded. The total number of juveniles produced in a female lifespan was also recorded. The productivity of the *G. halophila* was then determined as juvenile produced per couple per day in a lifetime.

2.4. Analysis of data

Descriptive statistics of the data collected were done to present the range, means, and standard deviations of the different parameters using the software Minitab 16. In addition, the regression of the number of juveniles per brood vs the female head size was analyzed using the Minitab statistical software. Significant difference between the parameters of male and female were obtained using the student *t*-test ($P < 0.05$). The number of juveniles per brood was analyzed using analysis of variance and the means separated using Fisher's least significant difference (LSD).

3. Results

The life history parameters of *G. halophila* under laboratory conditions are shown in Table 1.

3.1. Life span

Total life span of males ranged from 66 to 77 days with a mean of 72.3 ± 4.5 days, while females lived significantly longer with life spans ranging from 89 to 127 days with a mean of 108.0 ± 16.1 days. Females lived on average, 1.5 times longer than males.

3.2. Growth rate

Newly released juveniles size ranged between 1.05 and 1.06 mm in length, with a mean length of 1.06 ± 0.01 mm. Growth was observed to

Table 1
Life history criteria of *Grandidierella halophila* (28 ± 1.0 °C and salinity 7 ± 1 ppt.).

Criteria	Male (M)/ Female (F)	Range	Mean*	*P*-value
Life span (days)	M	66–77	72.3 ± 4.5[b]	0.019
	F	89–127	108.0 ± 16.1[a]	
Max body length (mm)	M	6.72–7.28	7.02 ± 0.19[a]	0.001
	F	6.07–6.46	6.31 ± 0.15[b]	
The growth rate from 0 to 70 days (mm per day)	M	–	0.083 ± 0.002 [a]	0.0001
	F	–	0.068 ± 0.004 [b]	
Broods per female	F	3–5	4.7 ± 0.5	NA
No. of juveniles per brood	F	5–36	20.8 ± 9.2	NA
Juveniles per female (sum)	F	70–115	97.5 ± 20.3	NA
Incubation time (days)	F	5–7	5.7 ± 0.8	NA
Maturation time - female (days)	F	12–14	12.8 ± 0.8	NA
Maturation size- female (mm)	F	3.22–3.72	3.5 ± 0.2	NA
Productivity (couple $^{-1}$ day^{-1})	F	–	0.90 ± 0.17	NA

* Values are expressed as mean ± standard deviation from 6 brood replicates (n = 6). Means of sexes with different superscript under the same parameter differ significantly ($P < 0.05$). NA = Not applicable.

be more rapid for the first 14 days with a slope/growth rate of 0.21 mm day $^{-1}$ for males and 0.19 mm day $^{-1}$ for females. Overall daily growth rate after 70 days of laboratory culture was 0.08 mm day $^{-1}$ for males and 0.07 mm day $^{-1}$ for females (Fig. 2). Mean maximum size of male and female observed within a lifespan was 7.02 mm ± 0.19 and 6.31 mm ± 0.15 in length respectively.

3.3. Maturation time and size

Females reached sexual maturity within a range of 12–14 days, at a mean of 12.8 ± 0.8 days. Female size at time of reaching maturation ranged from 3.2 to 3.7 mm in total length, at a mean of 3.5 ± 0.2 mm.

3.4. Incubation period

The eggs in the brood pouch were initially green in color and gradually turned yellowish to clear as the juveniles developed. Incubation time ranged from 5 to 7 days, at a mean of 5.7 ± 0.8 days. Juveniles resembled miniature adults as they were expelled from the brood pouch over several hours.

3.5. Fecundity, productivity rate and sex ratio

The total number of broods produced in the life span of a female ranged from 4 to 5, at a mean of 4.7 ± 0.5 broods. The mean number of juveniles produced per brood was 20.8 ± 9.2. The total number of juveniles produced in a single brood ranged from 5 to 36, wherein the number of juveniles produced during a life span gradually increased with each progressive brood (Fig. 3). A strong positive correlation (R^2 = 0.95) between female head size and number of juveniles produced was recorded (Fig. 4). The total number of juveniles produced in the life span of an individual female ranged from 68 to 114, at a mean of 97.0 ± 20.8 juveniles. This translated to a productivity rate of 0.90 ± 0.17 juveniles per couple per day. Sex ratio of stock culture was female-biased at 1.76: 1 (females: males).

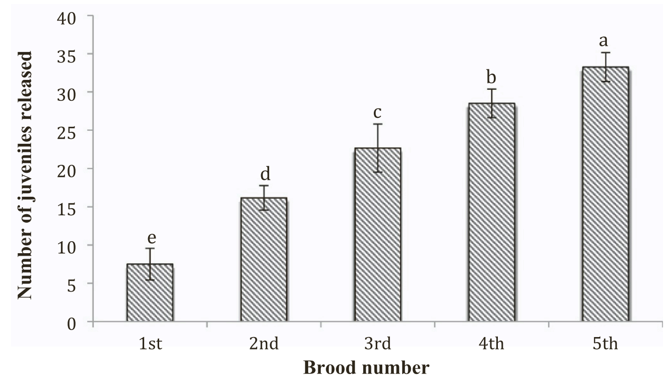

Fig. 3. Fecundity pattern of *Grandidierella halophila*. Values are expressed as mean ± standard deviation from six brood replicates (n = 6). Bars with different letters differ significantly.

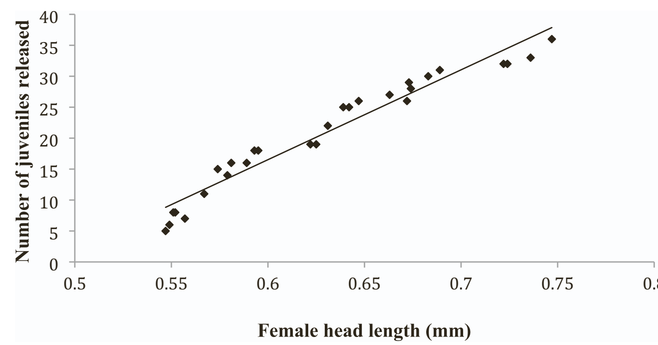

Fig. 4. Correlation between *Grandidierella halophila* female size and number of juveniles produced in a brood (y = 145.18× −70.59; R^2 = 0.94656).

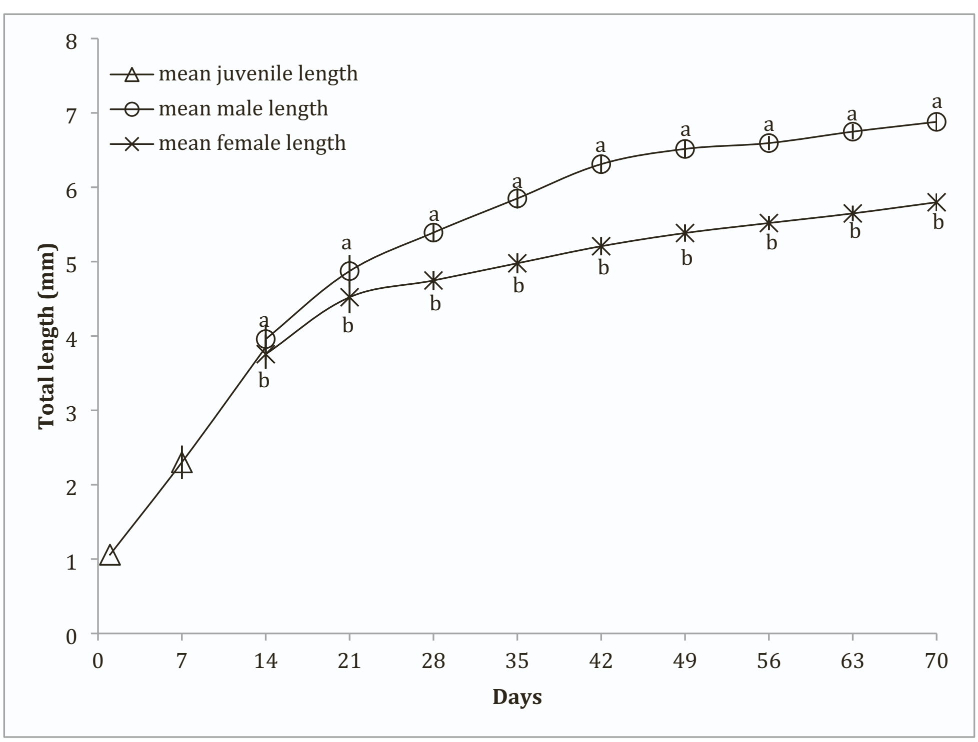

Fig. 2. Cumulative length (mm) increase of *Grandidierella halophila* (juvenile, n = 6; male, n = 6; female, n = 6). The markers at each time point with different letters differ significantly (P < 0.05).

4. Discussion

G. halophila exhibited a semiannual, multivoltine life history pattern, producing multiple broods in a short lifespan as observed in this study. This is consistent with the lifecycle of several marine amphipods such as *Caprella grandimana*, *Gammarus palustris*, *Orchestia mediterranea,* and *Pontoporeia affinis* which are reported to be iteroparous and multivoltine, hence, contributing to their high biomass production (Baeza-Rojano et al., 2011; Sainte-Marie, 1991). Steele and Steele (1991) also highlighted characteristics such as small size, short brood intervals, and multivoltinism when they were describing tropical amphipod life history traits. Similar also to our findings, gammarid amphipods are also characterized by early maturation, large brood size, high fecundity, and the release of juveniles that develop directly into adults without any metamorphosis during larval stages (Baeza-Rojano et al., 2013b; Cunha et al., 2000; Grabowski et al., 2007; Xue et al., 2013).

In a foundational study by Zimmerman et al. (1979) on the feeding ecology of gammaridean amphipods, *G. bonnieroides* was described as microphagous, feeding mostly on epiphytic diatoms and unidentified detritus accumulated on vegetation. Under laboratory conditions, numerous amphipods including the genus *Grandidierella* have been successfully reared on commercial fish flake feed (Hyne et al., 2005; Nipper et al., 1989; Vargas-Abúndez et al., 2021b) hence, our adoption of the same for the current study. Aside from *G. halophila* readily feeding on the flaked fish food provided, they used portions of the food, along with waste and debris to construct tube-like burrows to shelter themselves. This tube-building activity was observed from the juvenile's earliest days. Consistent with our finding, Barnard et al. (1991) describe a similar behavior in *G. bonnieroides,* and named the species a “detritus-blanket tube-builder”. This tube-building behavior could be relevant for future development of mass-culture and harvesting techniques of *G. halophila* for aquaculture purposes.

Commonly, females outnumber males in benthic amphipod populations (Costello and Myers, 1989). Previous studies on *G. japonica* revealed the sex ratio of the amphipod was female-biased just after juveniles were released (Kang, 2014; Wang et al., 2009). Differences in growth rate, maturation rate, longevity, and competition between males have been demonstrated to affect the population of males, hence influencing the sex ratio among amphipods (Dick and Elwood, 1996; Moore, 1981). Similarly, in our study, *G. halophila* was observed to be female-biased in culture (1.76: 1). A recent study by Vargas-Abúndez et al. (2021b) suggested that sex ratio is a key factor for amphipod culture optimization. This was because the fecundity of *Parhyale hawaiensis* increased nearly 5-fold per tank by increasing the sex ratio towards females. Hence, future studies can focus on manipulating the sex ratio of amphipods to enhance aquaculture production. The increasing bias of the sex ratio towards females as the culture aged in our study may also be linked to the longer lifespan of the females compared to the males. Nevertheless, the males grew to a larger size than females, despite having a shorter lifespan. In this study, the males maintained a daily growth rate that was approximately 1.4 times that of females. Sainte-Marie (1991) reported that around 97% of gammarid species have larger males compared to females. However, contrary to the finding of our study, *G. japonica* males were reported to have reached a lesser maximum size of 10.2 mm when compared to the females (11.10 mm) reared at a euryhaline tidal creek area in South Korea (Kang, 2014). Individual species differences and environmental-specific influence may explain this departure of the reference study from the norm of the trend.

Several different aspects of the reproductive biology of amphipods are crucial to the understanding of their potential productivity (Wang et al., 2009). High productivity in amphipods is influenced by factors such as fecundity, incubation time, generation time, and juvenile survival (Grabowski et al., 2007). In the present study, juvenile production per brood increased as female size increased with a strong positive correlation between female head size and the number of juveniles released. A similar relationship has also been established among Amphipoda species in previous studies (Cunha et al., 2000; Nelson, 1980; Sainte-Marie, 1991). Comparatively, *G. japonica* females have been reported to produce up to four broods in a lifespan, with the release of 13–71 juveniles under culture conditions (Wang et al., 2009). The varied number of embryos per brood has been reported under culture conditions for different amphipod species. These include *Cymadusa filosa,* with 20.0 juveniles at 28–30 °C; *P. hawaiensis*, with 12.8 juveniles at 26 °C; *Elasmopus pectenicrus,* with 6.5 juveniles at 26 °C; *Elasmopus levis* with 22.3; and *Eogammarus possjeticus*, with juveniles ranging between 48.1 at 18 °C and 16.4 at 27 °C to mention a few (Aravind et al., 2007; Borowsky, 1986; El Sayed et al., 2016; Vargas-Abúndez et al., 2021b; Xue et al., 2018).

Maturation time is an important factor contributing to species productivity as faster maturation time typically translates into higher productivity. Only a handful of studies have reported the maturation times of amphipods under culture conditions. According to Nayar (1956), *G. bonnieroides* females reached sexual maturity within 28–34 days of culture under laboratory conditions. Also, gammarids such as *E. possjeticus* and *P hawaiensis* females,have been reported to reach maturation in 38.2 days at 21 °C and 50.9 days at 26.0 °C respectively (Vargas-Abúndez et al., 2021b; Xue et al., 2018). Ampithoid, *C. filosa* matured within 30–37 days of culture at a size of 5.0–5.5 mm under a temperature of 29 °C (El Sayed et al., 2016). Females of caprellid, *C. grandimana,* also matured in 38.4 days at 17 °C (Baeza-Rojano et al., 2011). This is far above the observation made for *G. halophila* in this study with a maturation time of 12–14 days. Our study used the first sighting of oviposition in the female brood pouch to assess sexual maturity due to the inability to observe any copulatory behavior. This is consistent with the behavior of some species such as *E. levis* which also do not exhibit precopulatory activity (Borowsky, 1986). Perhaps *G. halophila* does not exhibit precopulatory activity or its possible precopula is very brief and might have occurred unnoticed despite close observation. This is consistent with the assumption of Iribarne et al. (1995) on *Eogammarus oclairi* reproductive behavior.

Incubation period is another important parameter that impacts productivity. Previously, *G. bonnieroides* had been reported to have an incubation time of 5.4 ± 0.9 days (derived from the raw data listed in Nayar, 1956 experiment), which is consistent with our finding for *G. halophila*. Other findings in previously cultured amphipods such as *C. filosa,* (7–15 days at 28–30 °C); *P. hawaiensis,* (≈ 10 days at 26 °C); *Eriopisa chilkensis*, (12.0 days at 26 °C); *E. possjeticus*, (8.9 days at 21 °C), *C. grandimana*, (10.5 at 17 °C) are noticeably higher than those reported in the current study (Aravind et al., 2007; Baeza-Rojano et al., 2011; Browne et al., 2005; El Sayed et al., 2016; Xue et al., 2018). Therefore, the interplay factors such as fecundity, incubation time, and generation time may be the reason for the higher productivity of 0.90 juveniles per couple per lifespan recorded in this study.

In the same vein, Grabowski et al. (2007) described invasive amphipod species as having large broods, high fecundity, rapid maturation, more generations per year, and higher tolerances towards environmental changes, especially salinity. The study by Wongkamhaeng et al. (2012) reported that *G. halophila* was found inhabiting saltpans of the inner gulf of Thailand in 80 ppt hypersaline water. However, our study sampled the amphipod from the estuarine lagoons in Kelantan with a water salinity of 7 ppt. *G. halophila,* therefore, demonstrates an extreme tolerance to variation in salinity and perhaps other environmental conditions hence, qualifies as a potential invasive amphipod species. Several members of the genus *Grandidierella* such as *G. japonicas*, *G. bonnieroides,* and *G. gilesi* have been described as invasive species (Lo Brutto et al., 2016; Pilgrim et al., 2013; Wongkamhaeng et al., 2020). Presumably, the life history traits that facilitate successful amphipod invasions could also be highly beneficial for mass culture practices. However, there should be serious concerns over the invasive potential of this species. Therefore, its potential use, as an alternative feed for aquaculture must be considered in light of its potential threat to the environment.

5. Conclusion

G. halophila exhibited high fecundity, early maturation, and rapid incubation/development time. These all cumulate to the high productivity of the species as reported herein. *G. halophila* demonstrated favorable life history traits under laboratory conditions that are conducive to large-scale culture needed for aquaculture purposes. Further research on the nutritional analysis of cultured amphipods and the development of mass culture protocols for the amphipod species can be carried out. Also, while we opined that *G. halophila* could be an invasive species, more laboratory research is needed to establish this fact by knowing the tolerance levels of the species to a wide range of environmental factors.

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CRediT authorship contribution statement

Sharif Shahin: Conceptualization, Investigation, Writing – original draft. **Victor Tosin Okomoda:** Data curation, Writing – original draft, Writing – review & editing. **Sairatul Dahlianis Ishak:** Writing – review & editing. **Khor Waiho:** Writing – review & editing. **Hanafiah Fazhan:** Writing – review & editing. **Mohamad Nor Azra:** Conceptualization, Data curation. **Abdul Rahim Azman:** Formal analysis. **Koraon Wongkamhaeng:** Formal analysis. **Muyassar H. Abualreesh:** Resources. **Nadiah W. Rasdi:** Supervision. **Hongyu Ma:** Supervision, Resources. **Mhd Ikhwanuddin:** Supervision, Methodology, Project administration, Resources, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Mhd Ikhwanuddin reports financial support was provided by Golden Goose Research Grant. Not applicable reports a relationship with Not applicable that includes:. Not applicable has patent pending to Not applicable. Not applicable.

Data availability

Data will be made available on request.

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