Article

Seasonal changes of development and reproduction cycle of *Microdeutopus gryllotalpa* Costa, 1853 (Crustacea, Amphipoda) in the fouling community of the Odessa Bay, Black Sea

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Received 23 February 2023; *Accepted 30 March 2023*; *Published online 10 April 2023*; *Published 1 September 2023*

Abstract
Investigations of development of *Microdeutopus gryllotalpa* under conditions of the fouling community in Odessa Bay, Black Sea were carried out for two years from January 2013 to December 2014. Monthly samples were taken from the underwater surface of solid substrates located in the coastal zone of the Odessa Bay. In addition to quantitative parameters of these invertebrates, the characteristics of their reproduction, absolute fecundity, the total number of egg-laying during the life cycle, as well as the relationship between their body size, weight, and fecundity parameters were studied. The reproductive process of these crustaceans proceeded throughout the year, but its intensity increased synchronously with the increase the quantitative parameters of invertebrates in spring and autumn during periods of sharp changes in sea water temperature. The maximum absolute fecundity of female 8 mm in size was 64 eggs. The relationship between the wetweight and body length of oviparous females is isometric. The parameter of absolute fecundity is directly proportional to the body weight of the female. Under the conditions of the fouling community in the Odessa Bay, the female *M. gryllotalpa* can produce about 7 egg-laying during her life cycle.

Keywords *Microdeutopus gryllotalpa*; seasonal dynamics; fecundity; Odessa Bay; Black Sea.

Arthropods
ISSN 2224-4255
URL: http://www.iaees.org/publications/journals/arthropods/online-version.asp
RSS: http://www.iaees.org/publications/journals/arthropods/rss.xml
E-mail: arthropods@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

The representative of amphipod crustaceans *Microdeutopus gryllotalpa* in its zoogeographic origin is a North Atlantic species, which is widely distributed along the coasts of the Atlantic Ocean, as well as in the Mediterranean and Black Seas (Mosbahi et al., 2020; Teaca et al., 2006; Varigin, 2017). These crustaceans, which have a greenish-white color with small brown spots on the dorsal surface, are distinguished by their small size (body length up to 8 mm) and expressed sexual dimorphism. The basal segment of gnathopod II in males of this species is much wider than in females (Grese, 1985).

These crustaceans live mainly in the coastal zone of the seas, among the thickets of macrophytes (Varigin, 2021; Lenzi et al., 2022). In benthic settlements, they are sometimes found far from the coast at a depth of up to 50 m (Prato and Biandolino, 2005). *M. gryllotalpa* spend most of its life inside tubes built from plant particles and detritus (Borowsky, 1989). According to the mode of feeding, they belong to phyto-detritophages (Mancinelli et al., 2005). These crustaceans are well adapted to life in the fouling community, which is formed in the Odessa Bay by the bivalve mollusk *Mytilus galloprovincialis* Lamarck, 1819 (Aleksandrov, 2008). Within this coastal community among mollusks and macrophytes *M. gryllotalpa* find shelter and food (Preda et al., 2012; Varigin, 2018).

Like other inhabitants of the coastal zone of the sea, *M. gryllotalpa* has a wide range of adaptations to life under conditions of frequently changing abiotic environmental factors. This species is able to endure significant seasonal fluctuations in sea water temperature from 0 to 27°C and survive in a wide salinity range from 15 to 58‰ (Evagelopoulos et al., 2008). These ecologically flexible crustacean species play an important role in the life of marine communities. On the one hand, actively consuming microalgae and detritus, they are directly involved in the transformation of matter and energy in the aquatic environment (Aleksandrov, 2008). On the other hand, they themselves are a high-calorie food for marine fish (Kvach and Zamorov, 2001; Banaru and Harmelin-Vivien, 2009; Mendes et al., 2014). *M. gryllotalpa* is known to be among the invertebrates used in ecotoxicological studies (DelValls et al., 2002). This species is often used as a test subject for acute toxicity testing of seawater and sediment (Cesar et al., 2002; Casado-Martinez et al., 2006).

Features of the life cycle of *M. gryllotalpa* are described mainly for representatives of the Atlantic-Mediterranean population of these crustaceans (Drake and Arias, 1995; Borowsky, 1989; Myers, 1971). In the northwestern part of the Black Sea, where there are specific conditions due to its shallow water and low salinity, such investigations have not been carried out. The aim of this study was to identify the annual dynamics of the quantitative parameters of the amphipod *M. gryllotalpa* in connection with its reproduction cycle in the conditions of the coastal fouling community of the Odessa Bay of the Black Sea, where this crustacean is a mass species.

2 Materials and Methods

The material was collected on the underwater surface of solid substrates located in the coastal zone of the Odessa Bay of the Black Sea. Samples were taken monthly for two years from January 2013 to December 2014. The collection of crustaceans was carried out using a metal frame, 20×20 cm in size, covered with mill gas. The contents of each frame were washed through a system of sieves with a minimum mesh size of 0.5 mm. Selected individuals of *M. gryllotalpa* were counted, their sex was determined, body length was measured with an accuracy of 0.1 mm and wet weight (after drying the animals on filter paper) with an accuracy of 0.001 g. When describing the dynamics of quantitative parameters of crustaceans, generally accepted parameters of abundance (N) ind.$\cdot$m^{-2} and biomass (B) g$\cdot$m^{-2} were used.

The absolute fecundity of crustaceans, considered as the total number of eggs produced by a female in one brood, was determined using their direct count in each oviparous female. The possible number of egg-laying produced by the female *M. gryllotalpa* during the life cycle was determined by the formula (Khmeleva, 1988):

$$N = 1.35(L_{max}/L_{min})^{2.5} \qquad (1)$$

where: N – the number of egg-laying produced by the female *M. gryllotalpa* during the life cycle; L_{max} and L_{min} – the maximum and minimum lengths of oviparous females, mm.

Correlation-regression analysis was used to establish the relationship between the size and weight characteristics of crustaceans, as well as between the parameters of absolute fecundity and the length (weight) of *M. gryllotalpa* females.

3 Results and Discussion

The analysis of the obtained material showed that live specimens of *M. gryllotalpa* were found in almost all samples taken monthly during 2013-3014. At the same time, the quantitative parameters of the development of these crustaceans were very variable. Seasonal fluctuations in the abundance of *M. gryllotalpa* during the research period occurred with different intensity (Fig. 1).

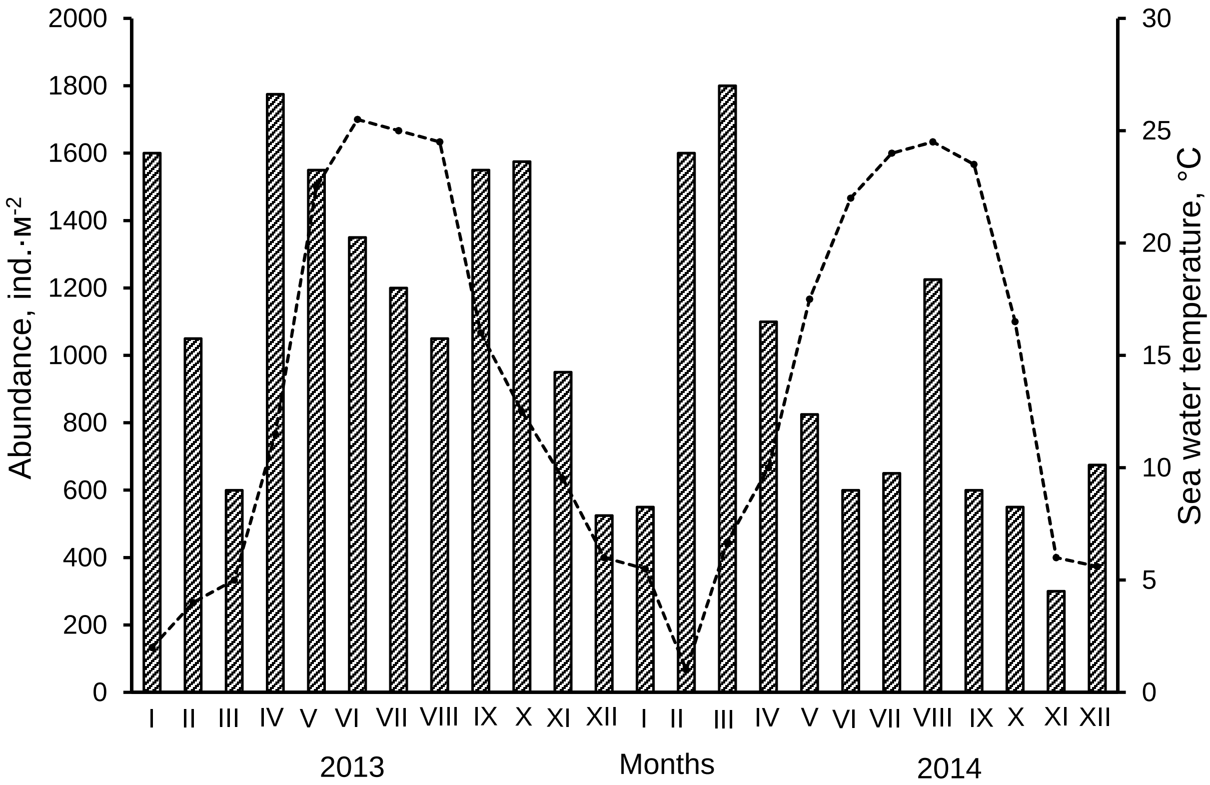

Fig. 1 Dynamics of abundance of *Microdeutopus gryllotalpa* (shaded columns) in the fouling community of Odessa Bay against the background of seasonal seawater temperature variability (dashed line).

As can be seen from the diagram (Fig. 1), in 2013 the peak of crustaceans abundance (1775 ind.$\cdot$m^{-2}) was observed in April, and in 2014 – in March (1800 ind.$\cdot$m^{-2}). Thus, the largest outbreaks of *M. gryllotalpa* abundance in both cases were observed in the spring. At the same time, in 2014, these parameters reached a maximum a month earlier than in 2013. This phenomenon is due to the fact that in crustaceans, as poikilothermic animals, all life processes, including reproduction, are associated with sea water temperature. Moreover, in this case, the decisive factor for starting the reproductive process was both the water temperature indicators and, to a determining extent, the rate of their change.

In 2013, the water temperature increased gradually from January to March (2°–4°–5°). From March to April there was a sharp increase in temperature up to 11.5°C and then in May – up to 22.5°C. During this period, there was a sharp increase in the number of crustaceans, due to the beginning of the reproduction process. In 2014, the spring warming of the water mass had a slightly different character. In January of this year, the temperature was 5.5°C, and in February it dropped to 1.0°C. From February to March, there was a sharp increase in temperature to 6.7°C. This served as a signal for the start of breeding process and a corresponding increase in the number of crustaceans.

The next, less expressed peak in the abundance of *M. gryllotalpa* was observed in autumn. In 2013, it happened in September (1550 ind.·m^{-2}) and October (1575 ind.·m^{-2}), and in 2014 – in August (1225 ind.·m^{-2}). In this case, the decisive factor was a sharp decrease in water temperature from August to October from 24.5°C to 12.6°C in 2013 and from 24.5°C to 16.5°C in 2014 (Fig. 1).

Seasonal variability of biomass parameters of *M. gryllotalpa* in general terms repeats the dynamics of its abundance (Fig. 2). However, there are some peculiarities associated with the seasonal variability of the age structure of the crustacean population. The variability of the age and, accordingly, the size structure of the population of *M. gryllotalpa*is associated with the appearance of new generations of crustaceans and the growth of individuals included in them. One of the indicators characterizing the age structure of a population is the average weight of an individual (Zaika, 1983). With the mass appearance of juveniles, this indicator decreases, and when the crustaceans reach the definitive size, it increases.

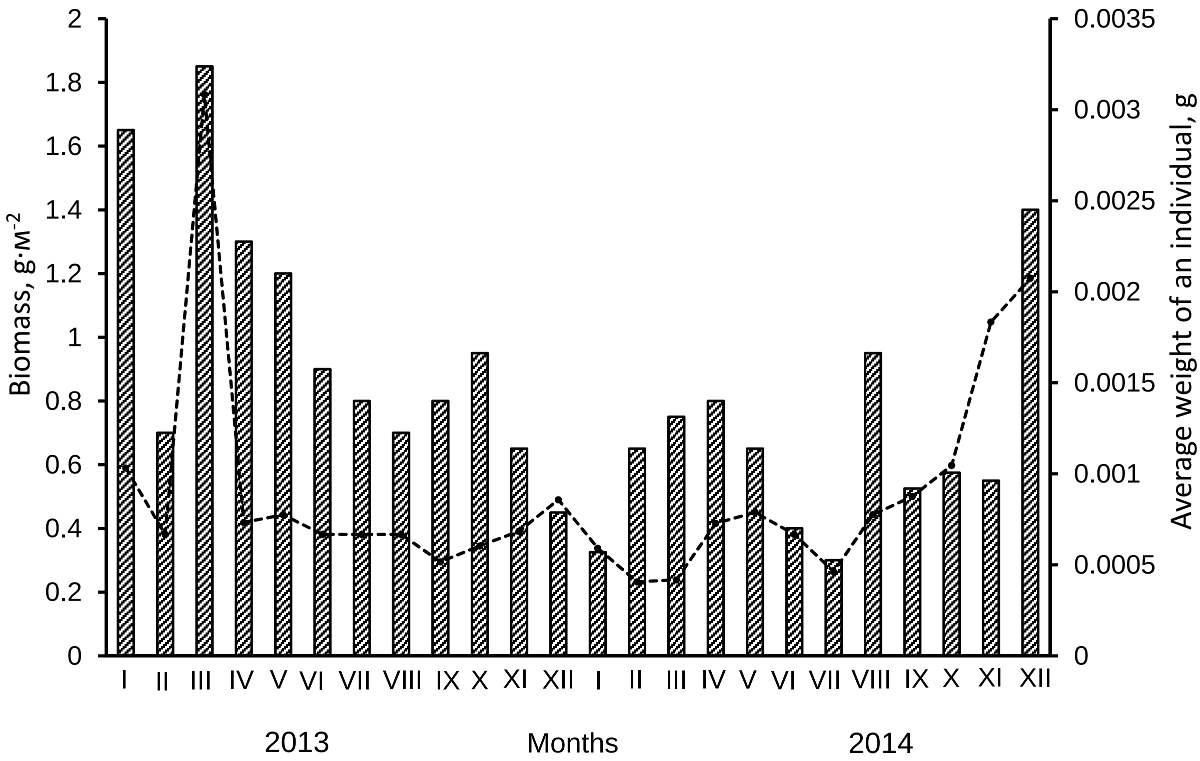

Fig. 2 Dynamics of biomass (shaded columns) and seasonal variability of average weight of an individual (dashed line) of *Microdeutopus gryllotalpa* in the fouling community of Odessa Bay.

The maximum values of the average weight of an individual were recorded in the spring, when the population was represented mainly by large sexually mature specimens ready for reproduction. At the same time, the highest values of crustacean biomass were noted (Fig. 2). Thus, in March 2013, the biomass of *M. gryllotalpa* was 1.85g·m^{-2}, and already in April it decreased to 1.30g·m^{-2}. The average weight of an individual over this period also decreased significantly (Fig. 2). Moreover, this decrease in biomass was accompanied by an increase in abundance of crustaceans (Fig. 1). The fact is that at the end of the spring breeding process, most of the large overwintered individuals die, and the age structure of the population changes towards an increase in the proportion of juveniles with a lower biomass and greater abundance.

In the autumn of 2013, the biomass of crustaceans increased less significantly to $0.95 g\cdot m^{-2}$, since during this period young individuals born this year started breeding. A similar trend in crustacean biomass variability, but with lower quantitative parameters, was also noted in 2014. By the end of this year, there was an increase in both the biomass and the average weight of *M. gryllotalpa* individuals preparing to overwinter and start breeding next spring (Fig. 2).

The described phenomena can be explained by the connection between a significant increase in the quantitative parameters of *M. gryllotalpa* in the spring and autumn periods and the reproduction cycle of these crustaceans. The process of reproduction of *M. gryllotalpa* in the conditions of the fouling community of the Odessa Bay of the Black Sea took place during most of the year. This is evidenced by the presence of oviparous females and juveniles in samples collected in almost all seasons. The temperature of sea water during the studied period ranged from 1.0 to 24.5°C. The intensity of the reproductive process of crustaceans was very variable during the year. It proceeded most actively in spring and autumn, when outbreaks of abundance and biomass of these invertebrates were observed in the fouling community.

At the same time, spring reproduction always occurred most intensively. This is due to the size structure of the *M. gryllotalpa* population, represented in spring by large overwintered adults capable of leaving behind the maximum number of offspring. In autumn, the reproductive process was less intensive, since it involved young medium-sized females from the generations of the current year, which had lower fecundity. It is known that this parameter significantly depends on the size and mass of crustacean females (Grese, 1985).

Females *M. gryllotalpa* become sexually mature when they reach a body length of 3.5–4.0 mm (Longo and Mancinelli, 2014). A sexually mature female, being inside a self-constructed tube, selectively approaches the choice of a sexual partner. A female ready for breeding drives out other females from the dwelling and allows only sexually mature males into it. In this case, both partners occupy opposite ends of the tube. Copulation occurs immediately after the female molts (Hyne, 2011).

Embryogenesis of fertilized eggs occurs in the female's marsupium. Fully formed young individuals emerge from the eggs at the end of the incubation period. The duration of this period depends on the season of the year, and, accordingly, on the temperature of the sea water. In the warm period of the year, at a water temperature of 22–25°C, embryogenesis takes 4–8 days, and in the cold period, at temperatures below 9°C, its duration increases to 45 days. The newly born juveniles remain inside the female's marsupium for some time, then move inside the parental tube, and leave it only after the first molt (Grese, 1985).

Table 1 Dependence of the wet weight of males, non-oviparous and oviparous females of *Microdeutopus gryllotalpa* on their body length.

Group of individuals	ln*a*	S.e. ln*a*	*b*	S.e.*b*	r	St. er.
Males	-11.5519	0.4701	3.3436	0.5728	0.8894	0.1124
Non-oviparous females	-11.5455	0.6462	3.2247	0.3926	0.8732	0.2767
Oviparous females	-10.8461	0.3606	3.0452	0.1915	0.9574	0.1482

ln*a* and ***b*** – the coefficients of the equation $\ln Y = \ln a + b\cdot\ln X$, where ***X*** and ***Y***– the parameters of body length, wet weight or fecundity, **S.e.ln*a*** and **S.e.*b*** – the standard errors of the coefficients **ln*a*** and ***b***, **r** – the correlation coefficient, **St. er.** – the standard error of the equation

When describing the quantitative aspects of the reproduction process of the studied species, it is necessary to take into account the features of its size-weight ratios in specific habitat conditions. It is known that body size is a key factor determining the nature of the consumption of food resources by crustaceans (Mancinelli et al., 2007). In this regard, the nature of the dependence of the wet weight of males, oviparous and non-oviparous females of *M. gryllotalpa* on their body length was determined (Table 1).

As can be seen from the data in Table 1, there is a high degree of correlation between the parameters of wet weight and length of crustaceans. The correlation coefficients of the regression equations in all cases range from 0.8732 to 0.9574. The relationship between the wet weight of oviparous females and their length is isometric in nature (the coefficient *b* in the regression equation is close to 3). In non-oviparous females and, to a greater extent, in males, this relationship is characterized by positive allometry (b > 3).

It is known that fecundity is the main reproductive indicator that determines the reproductive ability of animals. The prosperity of species in specific habitat conditions largely depends on the number of viable juveniles hatched from eggs. In crustaceans, absolute fecundity is directly related to the length, and hence the mass, of females. With their increase, the number of eggs produced in each egg-laying also increases (Khmeleva, 1988). The analysis performed confirmed the existence of such dependence for the oviparous females *M. gryllotalpa* living in the fouling community of the Odessa Bay (Table 2).

Table 2 Dependence of the absolute fecundity of *Microdeutopusgryllotalpa* females on the length and wet weight of their body.

Characteristic	**ln *a***	**S.e. ln*a***	***b***	**S.e. *b***	**r**	**St. er.**
Body length, mm	-1.7713	0.4997	2.6972	0.2674	0.9104	0.1952
Wet weight, g	8.2621	0.8671	0.9759	0.1695	0.8051	0.2768

Conditional designations are the same as in Table. 1

As evidenced by the data presented in Table 2, there is a close correlation between the parameters of absolute fecundity and the length (weight) of the studied crustaceans. The correlation coefficients in the regression equations are 0.9104 and 0.8051, respectively. The dependence of the absolute fecundity of *M. gryllotalpa* females on their body length exhibits some degree of negative allometry (b = 2.6972). The parameter of absolute fecundity is directly proportional to the body weight of the female, since the coefficient *b* in the regression equation in this case is close to 1.

The largest body length of an oviparous female *M. gryllotalpa* found during the research was 8.0 mm. In the marsupium of this female, 64 eggs were found. Of all the studied crustaceans, this individual had the maximum absolute fecundity. A female *M. gryllotalpa* of the same size from the coastal waters of Wales had a maximum fecundity of 58 eggs (Myers, 1971).

As is known, the ratio of body length parameters of *M. gryllotalpa* females present in the population determines the total number of egg-laying available to them during the life cycle (Khmeleva, 1988). The calculations performed showed that under the conditions of the fouling community of the Odessa Bay, the female *M. gryllotalpa* can produce about 7 egg-laying during the life cycle. This parameter, in accordance with formula (1), depends on the ratio of the maximum length of the female in the population to its minimum length. This ratio is the result of the response of the individuals that make up the population to the whole complex of environmental factors that affect them for a long time in a particular habitat (Khmeleva, 1988). Among the studied crustaceans, the minimum body length of oviparous females was 4.0 mm. Thus, the desired ratio was 2. It is known that under laboratory conditions, the female *M. gryllotalpa* can produce up to 11 egg-laying during the life cycle (Myers, 1971).

4 Conclusions

The nature of the seasonal variability of the quantitative parameters of *M. gryllotalpa* development under the conditions of the fouling community in the Odessa Bay of the Black Sea was determined by a number of factors, the main of which were the sea water temperature and the associated reproductive cycle of crustaceans. The reproduction process of *M. gryllotalpa* took place throughout the year, however, its intensity increased to a greater extent during the spring warming of sea water, and to a lesser extent – during its autumn cooling. In the same periods, a sharp increase in the abundance and biomass of crustaceans was noted. Under the studied conditions, the female *M. gryllotalpa* can produce about 7 egg-laying during her life cycle, and her maximum absolute fecundity is 64 eggs.

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