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ORIGINAL PAPERS

Life Cycle, Population Dynamics and Production of the Mudsnail *Ecrobia maritima* (Milaschewitsch, 1916) (Gastropoda: Prosobranchia) at the Romanian Coast of the Black Sea[1]

M. Carare[a] and V. Surugiu[a, *]

[a] *"Alexandru Ioan Cuza" University of Iasi, Faculty of Biology, Iaşi, RO-700505 Romania*

**e-mail: vsurugiu@uaic.ro*

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Abstract—Life cycle, population dynamics, growth, and annual production of *Ecrobia maritima* (Milaschewitsch, 1916) associated with the eelgrass *Zostera noltei* bed in the southern part of the Romanian Black Sea coast were investigated. Monthly quantitative random samples were taken from June to October 2015 and the collected snails of *E. maritima* were counted, measured, and weighted. The mudsnail *E. maritima* appears to be an annual species in the study area. The analysis of the size-frequency histograms indicated that recruitment took place over a brief period in June–July, after which the breeding population died. Growth of the overwintered cohort was slow during the cold season. A period of rapid growth of the new generation took place in June–July. The average life span was estimated at approximately 12–14 months. Under unfavourable conditions, individuals of *E. maritima* were observed to burrow into the sediment. Therefore, during the study period, the population of snails showed considerable variations of the above-ground density. The mean density of snails during the 5 months of study was 3204 ± 1419 ind. m^{-2} and the mean biomass was 7.54 ± 3.06 g fresh weight (FW) m^{-2}. The cohort production over 5 months of study was estimated at 14.11 g FW m^{-2}. The obtained value for turnover ($P/\overline{B}$ = 1.87) is comparable to the estimates for other species of Hydrobiinae in similar habitats.

Keywords: Black Sea, Gastropoda, *Ecrobia maritima*, population dynamics, life cycle, secondary production

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INTRODUCTION

The prosobranch mudsnail *Ecrobia maritima* has been originally described from the Black Sea by Milaschewitsch [14] and subsequently reported from several brackish-water environments in the Aegean Sea [10, 15, 16, 21]. Field data indicate that this species tolerates salinities from 5 to 58 PSU in the Black and Azov seas [4] and from 0.3 to 35.1 PSU in the Aegean Sea [10, 11]. In the Mediterranean lagoons *E. maritima* may reach population densities of up to 375000 ind. m^{-2} [11]. Such high densities make this mudsnail an important link in the food web between primary producers (diatoms) and top predators (fishes and waterfowl). Population dynamics of *E. maritima* was studied by Kevrekidis and Wilke [10] in the Evros Delta (northern Aegean Sea) and by Chukhchin [5] in the Bay of Sevastopol (northern Black Sea). However, very little is known about the biology and ecology of this species at the Romanian Black Sea coast.

E. maritima is one of the most common benthic species in the Black Sea coastal eelgrass habitats [4, 20]. In the last 50 years, a drastic decline of areas occupied by eelgrass beds has been reported in the Black Sea. One of the major factors accelerating the loss of eelgrass beds is the anthropogenic eutrophication. Because planktonic and epiphytic algae absorb nutrients more rapidly than eelgrasses, their outbreaks reduce the penetration of light, thus, preventing the growth of light-sensitive seagrasses. Another cause for the decline of eelgrasses in the Black Sea is the collapse of fishing which reduced grazing on epiphytes that live on the grass blades [19]. Because *E. maritima* is a surface deposit-feeder, grazing on benthic and periphytic diatoms, bacteria, and detritus [6], it plays an important role in controlling the development of epiphytic algae and, thus, contribute to the long-term persistence of the eelgrass habitats. Therefore, the main goal of this study is to assess the population dynamics, life cycle, growth, and secondary production of *E. maritima* in eelgrass meadows at the Romanian coast of the Black Sea.

MATERIALS AND METHODS

Study Site

Investigations were carried out from June to October 2015 at a single sampling site located at Mangalia (43.8042° N, 28.5917° E; the southern part of the

[1] The text was submitted by the authors in English.

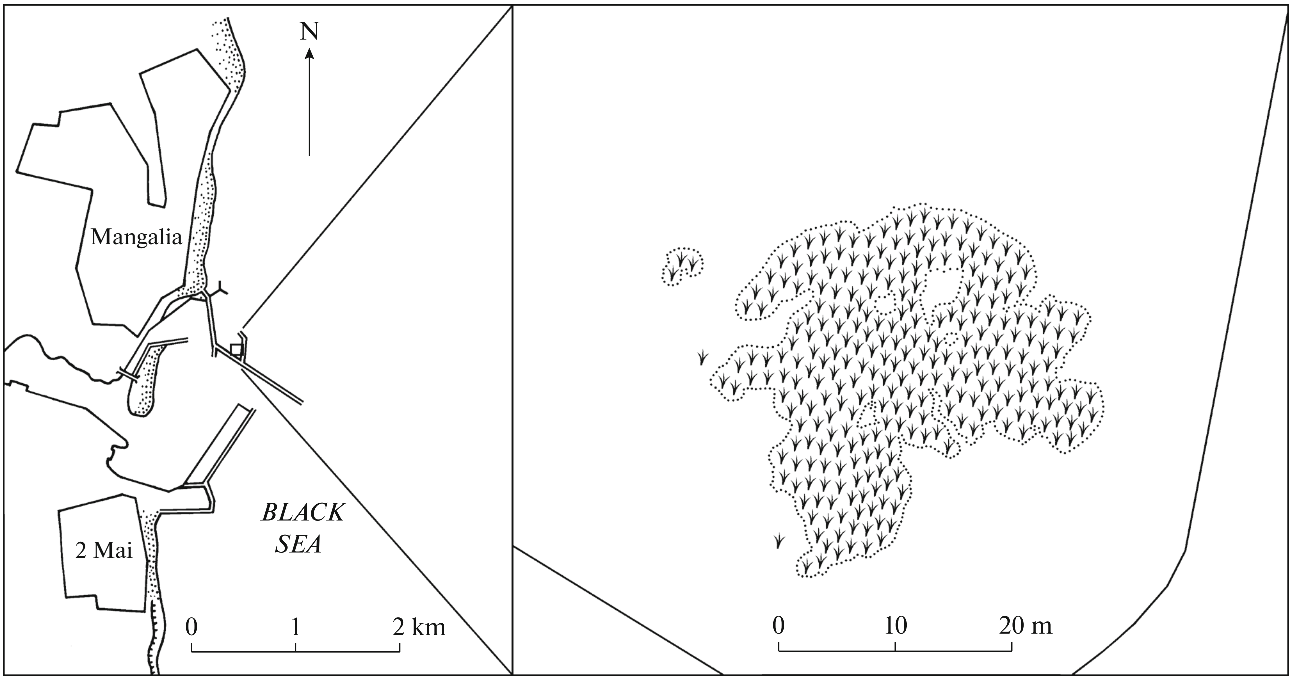

Fig. 1. Location of the sampling site of *Ecrobia maritima* at Mangalia, southern Romanian Black Sea coast.

Romanian Black Sea coast). The study site is represented by a dwarf eelgrass *Zostera* (*Zosterella*) *noltei* meadow situated at a depth of 1.5 m and about 30 m distance from the shoreline (Fig. 1). In the sampling area, water salinity varied between 15.63 and 18.65 PSU. Changes in water temperature ranged from 8.2 to 28.2°C. Dissolved oxygen concentration fluctuated between 9.94 and 14.06 mg L^{-1}. The sediment consisted of very fine siliceous sand (the mean grain size ranging from 111 to 122 μm; Trask's sorting coefficient $So = 1.414$) with 2–9% silt fraction. Sediment organic matter content was 0.7%. Salinity, temperature, dissolved oxygen, and pH of bottom seawater were recorded in situ in each sampling period by means of a portable multi-parameter analyser CONSORT C535. Sediment characteristics were established by dry sieving through 6 sieve fractions (2, 1, 0.5, 0.25, 0.125, and 0.063 mm) and each fraction was dried for 24 h at 80°C before weighting. Total organic matter content (TOM, %) was estimated as the weight loss of samples ashed in a furnace for 4 h at 450°C after drying for 24 h at 60°C (loss-on-ignition method).

Sampling Techniques

Quantitative random samples were taken at regular intervals over a period of 5 months with a hand-operated Plexiglas coring tube covering an area of 75.8 cm^2 (inner diameter 10 cm) to a depth of 10 cm. The samples were sieved in situ with seawater through a 0.5-mm mesh sieve and the remaining residue was preserved in 80% ethanol.

Laboratory Procedures

In the laboratory, living mudsnails were removed from other macrobenthos under a Nikon SMZ800 stereomicroscope and then counted. A number of specimens collected in August 2015 were sent to the University of Giessen (Germany) for molecular analysis. Mitochondrial DNA sequencing indicated that mudsnails belong to *Ecrobia maritima* (Thomas Wilke and Justine Vandendorpe, pers. commun.). Live snails were counted and measured. Height of shell (*HS*, from apex to anterior margin of the aperture) was measured with a calibrated ocular micrometer under a stereomicroscope to the nearest 0.01 mm at 20× magnification. Also, the maximum width of the shell (*WS*) was measured for biometric relationships. Fresh weight (*FW*) with shell was determined by weighting each individual snail on a Mettler AK160 analytical balance to the nearest 0.1 mg. Prior to weighting, excess water was removed by blotting specimens on a filter paper.

On the basis of shell lengths, *Ecrobia maritima* individuals were separated into 0.25-mm size-classes, assuming that size-frequency distributions of the age classes were normally distributed (Shapiro–Wilk test for normality).

Data Analysis

The number of individuals in each size-class, the average shell height, and standard deviation were estimated by FiSAT II software package [8, 9]. The different age classes were regarded as separate cohorts and their production was calculated separately. The aver-

Table 1. Production calculation for the two cohorts of *Ecrobia maritima* population from Mangalia studied from June to October 2015

Cohort	Sampling date	N, ind. m^{-2}	Mean HS, mm	Standard deviation HS, mm	Mean FW, mg	B, g FW m^{-2}	P, g FW m^{-2}
C1	27.06.2015	797	3.34	0.17	4.08	3.252	
C1	22.07.2015	796	3.51	0.31	4.52	3.598	0.35
Total C1							0.35
C2	27.06.2015	89	1.59	0.13	0.89	0.079	
C2	22.07.2015	3452	2.26	0.60	1.83	6.317	6.24
C2	24.08.2015	4248	2.36	0.41	2.00	8.496	2.18
C2	26.09.2015	3806	2.76	0.32	2.76	10.505	3.06
C2	23.10.2015	2832	2.31	0.31	1.92	5.437	2.28
Total C2							13.76
Total C1+C2							14.11

age fresh weight of individuals from a given age class was estimated from the average height of shell of the age class as $FW = aHS^b$, where FW is fresh weight, HS is height of shell, a is specific body mass (intercept), and b is regression slope. The parameters a and b were estimated from linear regression of logFW versus logHS (base 10).

Growth was inferred through the Modal Progression Analysis (MPA) from the apparent shift of the means in a time series of length-frequency histograms. Decomposition of polymodal distributions into their components to identify the means was done by the Bhattacharya's method [9]. The results obtained from the Bhattacharya's method were subsequently refined with the Hassleblad's NORMSEP routine.

The total secondary production of a cohort was calculated by the growth-survivorship method [22].

RESULTS

Temporal Fluctuations of Abundance and Biomass

In total, 181 individuals of *Ecrobia maritima* were sampled during 5 months of study. Population density of *E. maritima* fluctuated significantly during the period of study (Table 1). These fluctuations were caused by the seasonal recruitment of juveniles (with $HS < 1.5$ mm) and by the fact that under unfavourable conditions (e.g. strong storms, low temperature, high pressure from predators) individuals of *E. maritima* were observed to burrow into the sediment. The density strongly increased from 885 ind. m^{-2} in June to 4248 ind. m^{-2} in July due to appearance of newly hatched recruits, then gradually decreased to 2832 ind. m^{-2} in October due to mortality. The mean density of mudsnails was 3204 ± 1419 ind. m^{-2}.

A peak of snails' biomass was recorded in July (9.92 g FW m^{-2}) due to recruitment. A decrease in August to 8.50 g FW m^{-2} is attributable to higher rates of mortality, while a slight increase to 10.51 g FW m^{-2} in September could be explained by prevalence of growth over predation. Afterwards, the biomass gradually decreased from 5.44 g FW m^{-2} in October to 3.33 g FW m^{-2} in June (Table 1). The mean biomass over the sampling period was 7.54 ± 3.06 g FW m^{-2}.

Length–Weight Relationship

The correlation between the height of shell and the fresh weight was very strong and statistically highly significant ($N = 181$, $r = 0.9164$, $P < 0.01$). The allometric equation was $FW = 0.3449HS^{2.0494}$ for weight interval of 0.5–7.3 mg (Fig. 2). Because the exponent $b < 3$, the length increases faster than weight grows (negative allometric growth). A strong positive and highly significant correlation was found between the shell height and the shell width ($N = 181$, $r = 0.8979$, $P < 0.01$). The mean ratio between shell height and the shell width was estimated at 2.05 (Fig. 3). This ratio increased with the size of mudsnails (Fig. 4).

Population Structure, Life Cycle, and Growth

The mudsnails were separated into 12 size classes, with the smallest snail found having a shell length of 1.19 mm and the maximum shell length reaching 4.0 mm.

The analysis of the length–frequency histograms showed that recruitment mainly occurred between June and July and the breeding population died soon after recruitment. Size distributions were polymodal only in June and July and unimodal from August onwards (Fig. 5). Therefore, two cohorts could easily be distinguished: one was composed of overwintered snails (cohort C1) which disappeared in July, and the other was composed of the young-of-the-year (cohort C2) which first appeared in June (with $HS = 1.59$ mm).

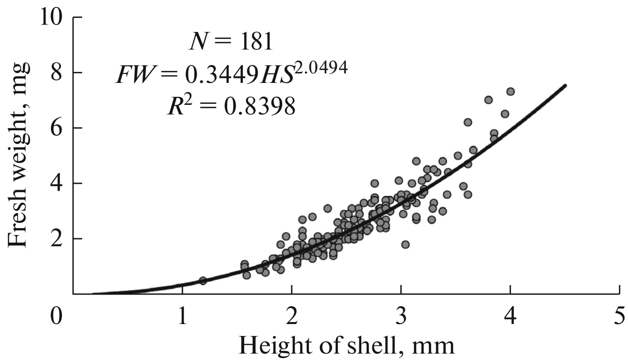

Fig. 2. Relationship between the shell length and the fresh weight of *Ecrobia maritima* from Mangalia, the Romanian coast.

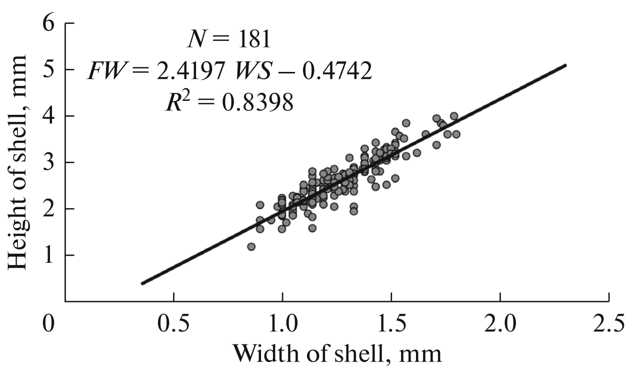

Fig. 3. Relationship between the shell length and the shell width of *Ecrobia maritima* from Mangalia, the Romanian coast.

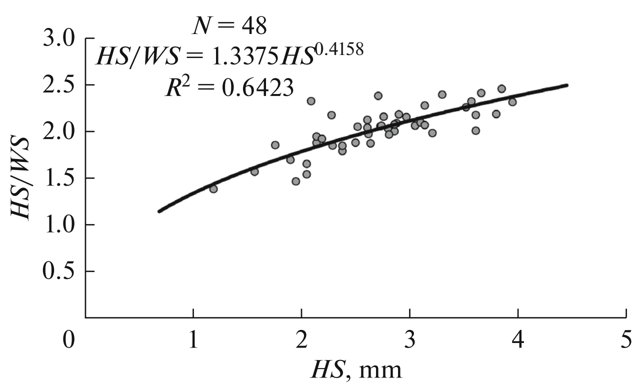

Fig. 4. Relationship between the size and the *HS*/*WS* ratio of *Ecrobia maritima* from Mangalia, the Romanian coast.

A period of rapid growth of the new generation C2 took place in June–July ($\Delta HS = 0.67$ mm month^{-1}). The recruited cohort C2 attained a mean shell length of 2.78 ± 0.32 mm in September (Table 1). The mean size of this cohort decreased from September to October indicating an increase of mortality. Higher growth rate during summer is a result of higher temperatures and increased food availability in the form of periphytic algae, bacteria, and associated detritus.

Growth of the cohort C1 was slow during the cold season ($\Delta HS = 0.13$ mm month^{-1}), probably due to the drop in the temperature and to the limited food resources. This cohort attained a mean shell length of 3.65 ± 0.19 mm in July when it vanished. Through cohort recognition and tracking, the average life span of *E. maritima* was estimated at 13 ± 2 months, depending on the time of recruitment and interannual variations.

Secondary Production

Over the sampling period, the major production took place in the 2015 year-class, which accounted a production of 13.76 g FW m^{-2} (Table 1). Taking into account both cohorts' growth and mortality, the total production (*P*) for 5 months of sampling was estimated at 14.11 g FW m^{-2}. The production to biomass ratio ($P/\bar{B}$) was estimated at 1.87 a^{-1}.

DISCUSSION

Monthly fluctuations in abundance of *Ecrobia maritima* showed seasonal variations having the lowest values in spring and the highest values in summer. The mean density of the population of *E. maritima* at Mangalia, with 3204 ind. m^{-2}, is lower than that observed by Kevrekidis and Wilke [10] in the Monolimni Lagoon (Evros Delta, the northern Aegean Sea) with 9740–14570 ind. m^{-2}. The abundance of hydrobiinid snails is positively correlated with the presence of benthic vegetation [2, 3, 7, 12, 13]. Indeed, we did not find any *E. maritima* in adjacent bare sandy sediments. This is because the plant cover better protects mudsnails from predation and has a high habitat complexity and stability [12]. Also, finer particle size caught within eel-grass beds results in a higher organic matter content, which can be used as food source by *E. maritima*. Temporal fluctuations in abundance could be related also to the ability of hydrobiinids to survive periods of harsh environmental conditions by burrowing into the substrate. They can survive up to 4 months in a state of inactivity and become rapidly active once the conditions improve [3].

The mean biomass of *E. maritima* found in the present study ($\bar{B}$ = 7.54 g FW m^{-2}) was comparable with the values observed by Kevrekidis and Wilke [10] (1.66–3.2 g ash-free dry weight m^{-2}).

The maximal shell lengths attained by *E. maritima* at Mangalia (4.0 mm) are in the range of those presented by various authors: 3.3–4.9 mm in the Monolimni Lagoon [10], up to 4.5 mm in length at Feodosia [14], and 5.6 mm in the Sevastopol Bay [4]. In the

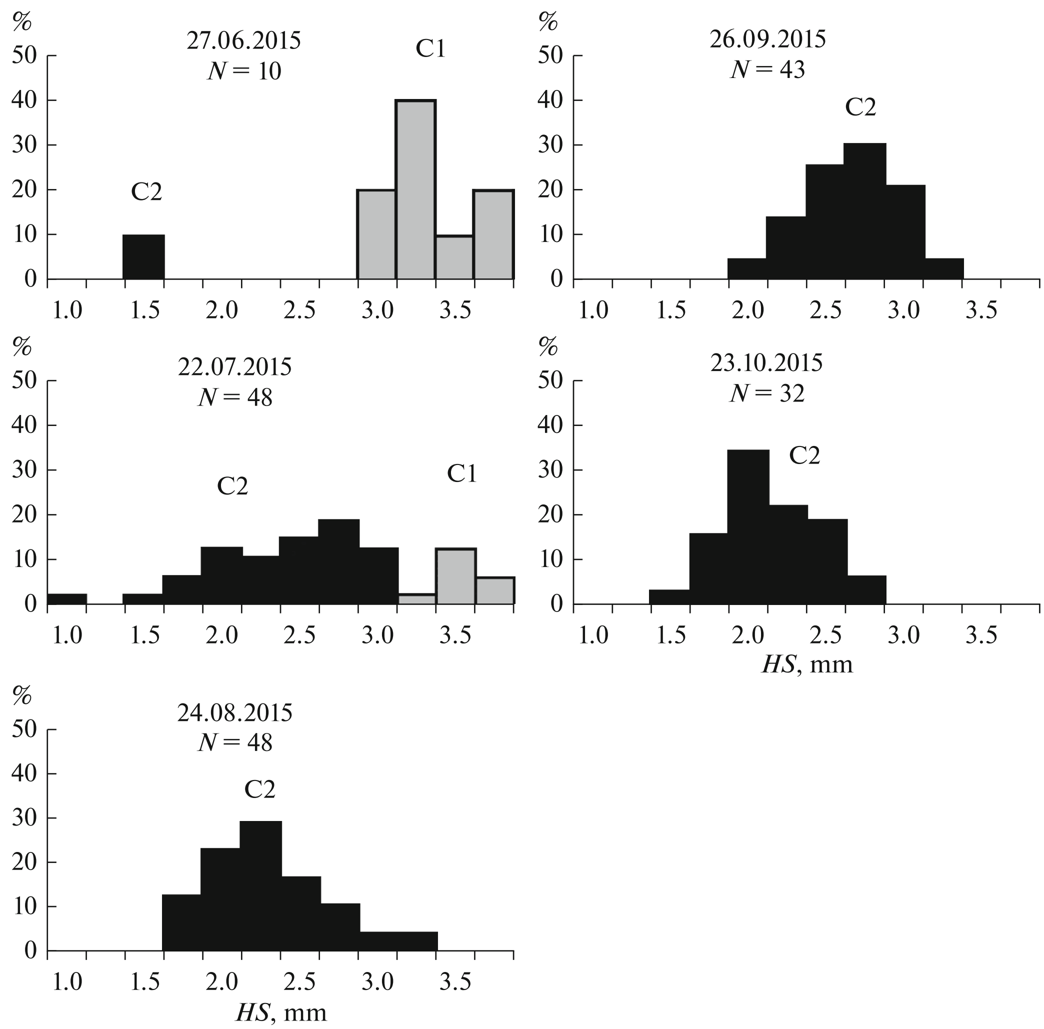

Fig. 5. Size-frequency histograms of *Ecrobia maritima* from Mangalia over the sampling period (the 2014 cohort is grey, the 2015 cohort is black). Sampling dates are indicated. *N*, number of individuals analyzed.

Monolimni Lagoon, length ranged from 0.55 to 4.78 mm [10].

The length–weight relationships have been described by exponential equations in different hydrobiinid populations. The regression slope *b* varied between 1.60 and 2.64, while the intercept *a* varied between 0.01 and 0.345 (Table 2). Sources of variability in length–weight relationship parameter values arise from differences in methods used for preservation (e.g. freezing, alcohol, formalin) and for individual weight determination (e.g. FW, DW, AFDW), from differences in environmental conditions (water temperature, salinity, resource availability, chemical pollution, etc.) and from physiological status of individuals [17].

Regarding the ratio between the height of shell and the width of shell, Chukhchin [6] indicated that in *Ecrobia maritima* [as *Hydrobia acuta*] this ratio ranges from 1.54 to 2.17. Also, Chukhchin [5, 6] showed that the value of this ratio increases with the depth, being less than 2.0–2.2 in nearshore areas and 2.5–2.7 at 2–5 m depth. In the present study we have found an average value of $HS/WS = 2.05$ that corresponds to a shallow-water habitat. Equation for correlation between the total length of the shell and the maximum width during our investigations closely resemble that obtained by Lillebø et al. [12] for *Peringia ulvae* (Pennant, 1777).

Growth rates observed in the present study showed a similar pattern to those previously reported by other authors [10, 12, 18]. These are usually the highest in the early summer, decrease from mid-summer to mid-autumn, practically cease in winter, and again slightly increase in spring. Lower growth rates during winter are most likely associated with lower water temperatures (and, hence, the lower metabolic rates) and more reduced food availability [10]. Chukhchin [6] reported that mudsnails living at greater depths usually have smaller shell size than those living near-shore due to reduced growth rates as the result of lower water temperatures.

Table 2. Production estimates for some related species of Hydrobiinae at different localities. *FW*, fresh weight, mg; *DW*, dry weight, mg; *AFDW*, ash-free dry weight, mg; *a*, specific body mass; *b*, regression slope; $\overline{B}$, mean annual biomass, g m^{-2}; *P*, annual production, g m^{-2} a^{-2}; $P/\overline{B}$, annual turnover; *, calculated for only 5 months

Species	Study area	Method	*a*	*b*	$\overline{B}$	*P*	$P/\overline{B}$	References
Ecrobia maritima (Milaschewitsch, 1916)	Mangalia, Black Sea, Romania	*FW* (with shell)	0.345	2.05	7.54*	14.11*	1.87*	[Present study]
Ecrobia maritima [as *Hydrobia acuta*]	Sevastopol Bay, Black Sea	*FW* (with shell)	0.263	2.27	–	–	–	[5]
Ecrobia maritima [as *Hydrobia acuta*]	Sevastopol Bay, Black Sea	*FW* (without shell)	0.066	2.18	–	–	–	[5]
Ecrobia maritima [as *Hydrobia acuta*]	Sevastopol Bay, Black Sea	*DW*	0.051	1.60	–	–	–	[5]
Ecrobia maritima	Monolimni Lagoon, Evros Delta, northern Aegean Sea, Greece	*AFDW*	0.0434	2.088	1.66–3.20	4.51–9.90	2.72–3.09	[10]
Ecrobia ventrosa (Montagu, 1803)	Leahova Lagoon, Black Sea, Romania	*AFDW*	0.026	2.09	–	–	–	[17]
Ecrobia ventrosa	Mecklenburger Bucht, Baltic Sea, Germany	*FW (with shell)*	0.081	2.142	43	–	–	[1]
Ecrobia ventrosa	Ichkeul Lagoon, Mediterranean Sea, Tunisia	*AFDW*	0.070	2.508	4.1	11.86	2.89	[3]
Ecrobia ventrosa	Kysing Fjord, Jutland, Baltic Sea, Denmark	*AFDW*	0.0417	2.279	4.58	8.40	1.83	[18]
Ecrobia ventrosa	San Francisco de Asís lagoon system, San Fernando, Bay of Cádiz, Spain	*DW*	0.1965	2.051	2.30	5.20	2.26	[7]
Ecrobia truncata (Vanatta, 1924)	Salt marsh pools near Rowley, Massachu-setts, USA	*AFDW*	0.1005	1.755	11.24	60.5	5.38	[13]
Hydrobia acuta (Draparnaud, 1805)	Hipersaline lagoon, Camargue, Mediterranean Sea, France	*AFDW*	0.01	2.64	0.17	0.786	4.54	[2]
Hydrobia acuta [as *Hydrobia neglecta*]	Kysing Fjord, Jutland, Baltic Sea, Denmark	*AFDW*	0.0290	2.521	6.72	5.86	0.87	[18]
Hydrobia glyca (Servain, 1880) [as *Hydrobia minoricensis*]	San Francisco de Asís lagoon system, San Fernando, Bay of Cádiz, Spain	*DW*	0.1546	2.106	14.0	29.0	2.07	[7]
Peringia ulvae (Pennant, 1777)	San Francisco de Asís lagoon system, San Fernando, Bay of Cádiz, Spain	*DW*	0.1344	2.622	2.51	5.5	2.19	[7]
Peringia ulvae	Mondego Estuary, Portugal	*AFDW*	0.0564	2.2381	70.2	93.7	1.33	[12]

E. maritima has a semelparous reproduction in the Black Sea [5]. *E. maritima* displays an annual life cycle both in the Black Sea [14, the present study] and the Aegean Sea [10]. In the Black Sea, the recruitment is prolonged and lasts throughout the summer from June onwards. In the Aegean Sea, the recruitment occurs in summer and autumn and occasionally in late winter [10]. Summer recruits are produced by overwintering snails. A small proportion of the mudsnail population lives up to 1.5 years, but most bred at one year. The average life span estimate for the Romanian Black Sea coast was similar to the estimate of about 12–18 months for the Sevastopol Bay [5] and for the Evros Delta [10]. According to Chukhchin [5], sexual maturity of *E. maritima* is reached at approximately 6 months (at a shell length of 2.5–3.0 mm).

The values for production and turnover obtained in the present study are comparable to previously reported estimates for other species of Hydrobiinae in similar habitats (Table 2). However, lower annual $P/\overline{B}$ ratio at the Romanian Black Sea coast as compared to population from the Evros Delta (Aegean Sea) may be a consequence of either lower sea-water temperatures in the Black Sea as compared to the Aegean Sea, or because of the prevalence of older individuals in the population of the Aegean Sea (lower predation pressure).

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflict of interest.

Statement on the welfare of animals. All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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