Secondary Production of *Monocorophium acherusicum* (Amphipoda, Corophiidae) in a Seagrass Bed (*Zostera marina*)

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We measured the secondary production of the amphipod *Monocorophium acherusicum* Costa in a seagrass bed (*Zostera marina* L.) in Gwangyang Bay, southern Korea. *M. acherusicum* biomass was positively correlated ($P<0.05$) with seagrass standing crop, suggesting that there were biological interactions between the two species. *M. acherusicum* displays two main breeding periods per year: spring (March to April) and fall (October to November). *M. acherusicum* biomass in the spring breeding periods was higher than in the fall. Annual secondary production of *M. acherusicum* was 3.54 g $DW/m^2/yr$ with an annual P/B ratio of 3.48. Secondary production and the P/B ratio of *M. acherusicum* were lower than those observed for other amphipods inhabiting seagrass beds. These results suggest that biological interactions between *M. acherusicum* and seagrass, as well as dietary competition with other amphipods can potentially cause declines in secondary production and the P/B ratio.

Key words: *Monocorophium acherusicum*, secondary production, seagrass beds, *Zostera marina*

Introduction

Gammarid amphipods are considered one of the most important secondary producers in seagrass beds (Fredette and Diaz, 1990). Amphipods utilize primary food sources, such as detritus and phytoplankton, and also serve as prey for higher level consumers, such as fish and large crustaceans (Nelson, 1979; Vetter, 1995; Derrick and Kennedy, 1997). Gammarid amphipods display rapid turnover rates (Drake and Arias, 1995), and can become dominant within seagrass beds (Jeong et al., 2004).

The corophiid *Monocorophium acherusicum* occurs along the west and south coasts of Korea, in Japanese coastal waters, and from Alaska to California along the Pacific coast of North America (Carlton, 1979; Ishimaru, 1994). *M. acherusicum* is the most widely distributed species of corophiid amphipod in the world's temperate-tropical waters (Bousfield and Hoover, 1997). A few studies have briefly addressed the distribution and systematics of *M. acherusicum* (Stebbing, 1899; Barnard and Karaman, 1991), whereas many studies have inves-

tigated amphipod secondary production (Jeong et al., 2006). However, most of these latter studies focused on amphipod species in unvegetated habitats (Jeong et al., 2006), and consequently, amphipod secondary production in seagrass beds remains largely unstudied Moreover, no attempts have been made to measure the secondary production of *M. acherusicum*.

The objectives of the present study were to measure annual variation in *M. acherusicum* biomass and to estimate this species' secondary production in seagrass beds in southern Korea.

Materials and Methods

Sampling

The sampling site was a sublittoral seagrass bed (*Zostera marina*) surrounded by rock in the northwest part of Namhae-do (34°48'N, 127°49'E), Gwangyang Bay, Korea (Jeong et al., 2006). Tidal levels were measured as the distance (cm) above and below mean sea level (MSL) at Gwangyang (NORI, 2002). The annual tidal range varied from 415 cm above to 22 cm below MSL. Seagrass beds were distributed along the shoreline and were 10-30 m wide and 90-100 m

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long. Water temperature and salinity ranged from 9.2-26.4°C and from 10.9-31.6 psu, respectively. During the rainy season, the lowest salinities occurred in August and were caused by runoff from the Seomjin River near the sampling site.

Sampling was carried out monthly from January to December 2002 at the spring tide low water mark. Three replicate samples were collected using a diver-operated hand-held net (15×15 cm mouth, 0.15 mm mesh). The net was carefully placed over the seagrass, covering the tips of leaves to the rhizome, and the mouth of the net was closed before cutting the rhizomes. To avoid disturbance of the sediments, we sampled the upper -15 cm of the bottom. The seagrass samples were transported to the laboratory, where animals were separated from the seagrass by rinsing with filtered sea water.

Seagrass dry weight was measured after drying for 24 hr at 60°C and weighed to the nearest 0.01 g using an electronic microbalance (Model UMT2, Mettler Instrument, Columbus, Ohio, USA). Animals separated from the seagrass were immediately preserved in 5% borate-buffered formaldehyde with filtered sea water. Individuals of *Monocorophium acherusicum* were sorted and counted under a dissecting microscope. The size of individuals was determined by measuring the length of the animal from the tip of the rostrum to the end of the telson under a dissecting microscope fitted with an image analysis system (Image Pro Plus 2.0, Media Cybernetics, Silver Springs, Maryland, USA).

Biomass

Additional biomass samples were collected from March to May 2004. After collection, live individuals of *M. acherusicum* were sorted under a dissecting microscope and placed separately into vials filled with filtered sea water. Animals were then transported to the laboratory and were allowed to clear their guts. Subsequently, all live *M. acherusicum* were incubated for 48 hr without food. After incubation, live animals were rinsed with distilled water and the body length (BL, in mm) was measured. For dry weight measurements, specimens were dried for 24 hr at 65°C and then individually weighed to the nearest 0.1 μg using an electronic microbalance. Relationships between dry weight (DW, in mg) and BL were estimated using the exponential equation: $DW = aBL^b$.

Secondary production

Amphipods cohorts within seagrass beds were difficult to separate; thus, *Monocorophium acherusicum* secondary production was estimated using the size-frequency method (Hynes, 1961). This method is based on the use of the average size-frequency distribution to sum the total losses between size classes, based on monthly samples taken throughout the year (Hamilton, 1969). We used Benke's (1979) modification of the basic production equation of the Hynes method (Hynes, 1961; Hamilton, 1969):

$$P=(I\sum_{j=1}^{i}(\overline{N_j}-\overline{N_{j+1}}) \times \sqrt{\overline{W_j}\ \overline{W_{j+1}}}) \times (365/\text{CPI})$$

where P is annual production, I is the number of times loss factor, i is the number of size classes, N_j is the mean number of individuals in size class j (averaged over the entire year), W_j is the mean DW of individuals in size class j, and CPI is the cohort production interval (in days) from hatching to attaining the largest size class. When there were differences in the maximum length of males and females, we selected the lower times loss factor to avoid overestimating production (Waters and Hokenstrom, 1980). Annual production was the sum of production in each size class multiplied by 365/CPI to account for multiple broods (Benke, 1979). The life cycle of corophiid amphipods ranges from 8-11.5 months (Moore, 1981). The life cycle of *M. acherusicum* was nearly 1 year (Jeong, unpublished data), therefore the value of 365/CPI was not modified. The accuracy of the size-frequency method increases with the use of smaller size intervals (Cushman et al., 1978). The mean size of newly hatched juveniles of *M. acherusicum* was 0.8 mm (Fig. 2); therefore, we used 1 mm size class intervals to estimate secondary production.

Results and Discussion

Biomass

Seagrass standing crop exhibited two peaks throughout the year (Fig. 1). The first peak occurred when the standing crop increased from 60 g DW/m² in February to 838.51 g DW/m² in May, which was followed by a decrease to 240.43 g DW/m² in August (Fig. 1). After September, the standing crop increased again to reach a second peak at 338.60 g DW/m² in November (Fig.1). The biomass distribution of *Monocorophium acherusicum* was similar to patterns in seagrass standing crop (Fig. 2). *M. acherusicum* biomass and seagrass standing crop were signify-cantly positively correlated (Pearson's correlation test n=181, r²=0.67, P<0.05). *M. acherusicum* is an herbivorous feeder. The main food of *M. acherusicum* consists of seagrass tissues and benthic diatoms (Jeong, unpublished data). Seagrass standing crop
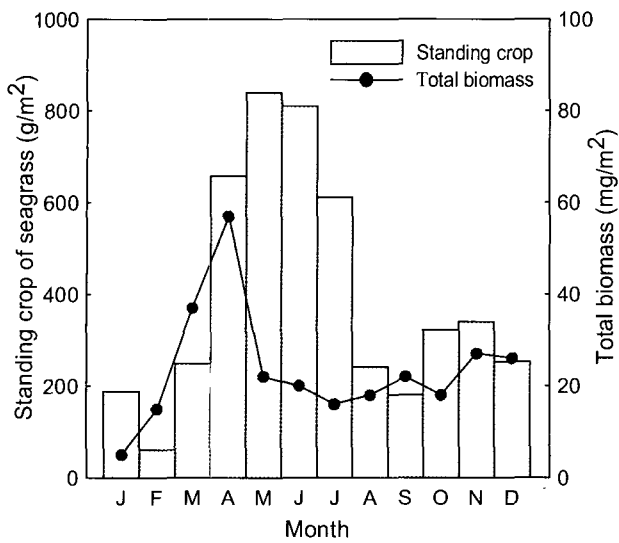
Fig. 1. Seasonal variation in total biomass (DW) of *Monocorophium acherusicum* and standing crop (DW) of seagrass.
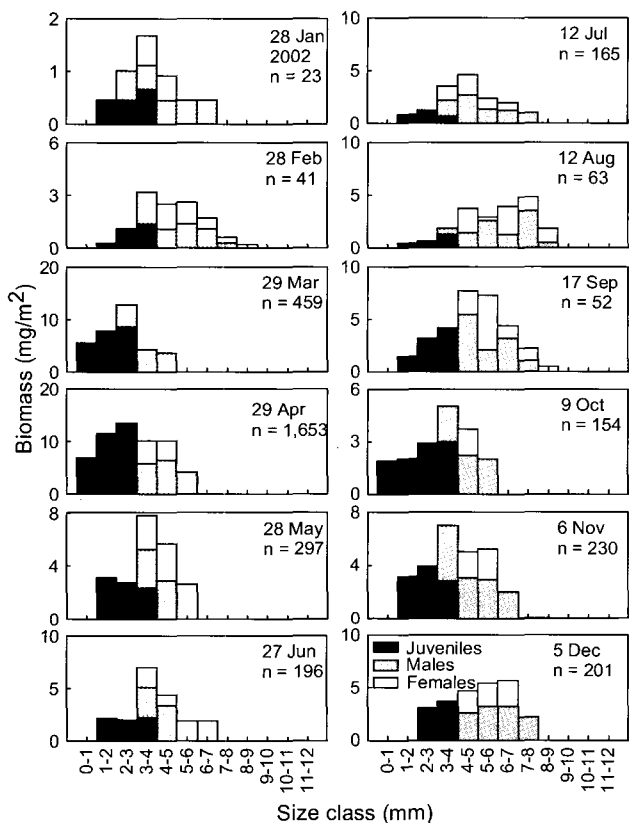

Fig. 2. Seasonal variation in biomass (DW) of *Monocorophium acherusicum*.

was tightly correlated with the food items of *M. acherusicum*, as was previously observed by Fredette and Diaz (1990) for *Gammarus mucronatus*.

The significant relationship between BL and DW of *M. acherusicum* is presented by the regression equation:

$$DW = 0.025 \, BL^{2.16} \, (n = 159, r^2 = 0.90, P<0.05).$$

M. acherusicum Breeding periods were also closely related to seagrass growth periods. The biomass of each size class was lower in the fall than in other seasons, but the proportion of small individuals was higher in the fall (Fig. 2). The biomass of small individuals (<3 mm) was greater than that of large individuals (>3 mm) in the spring and fall, whereas the biomass of large individuals increased during the summer and winter before the breeding period. The maximum lengths of males and females were 8.25 mm and 8.75 mm, respectively. The annual biomass of *M. acherusicum* was 1.02 g DW/m²/yr.

Mean dry weights of *M. acherusicum* were low during the spring, and then rapidly increased during the summer (Fig.3). The maximum mean dry weight was 0.92 mg in August (Fig. 3). During the spring and fall breeding periods, densities were high, even though mean dry weight was lower than in other periods (Fig. 3). Jeong et al. (2006) reported that the density of *Jassa slatteryi* rapidly increased from April to May, followed by high densities in June and July. In contrast, the density of *M. acherusicum* increased from February to April and then rapidly decreased in May (Fig. 3). *J. slatteryi* feed primarily on benthic diatoms, algal tissues, and detritus (Jeong et al.,
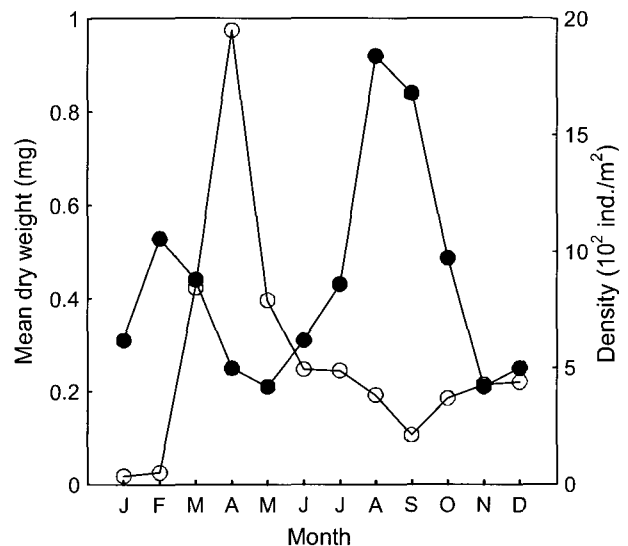

Fig. 3. Seasonal variation in mean dry weight (solid circles) and density (open circles) of *Monocorophium acherusicum*.

Table 1. Estimation of secondary production of *Monocorophium acherusicum* on the seagrass beds of Gwangyang Bay by the size-frequency method. Biomass expressed as dry weights

Size group (mm)	Density (ind./m²)	Mean wt. (mg)	Standing stock (g/m²)	Individuals lost (ind./m²)	Wt. at loss (mg)	Weight loss (g/m²)	Number of time loss	Production (g/m²)
0 - 1	0.25	0.00	0.00	-35.31	0.02	0.00	9.00	-0.01
1 - 2	35.56	0.09	0.00	-62.22	0.14	-0.01	9.00	-0.08
2 - 3	97.78	0.23	0.02	-284.45	0.30	-0.09	9.00	-0.77
3 - 4	382.23	0.40	0.15	-80.00	0.50	-0.04	9.00	-0.36
4 - 5	462.23	0.63	0.29	235.56	0.83	0.20	9.00	1.77
5 - 6	226.67	1.10	0.25	84.44	1.32	0.11	9.00	1.00
6 - 7	142.23	1.59	0.23	115.56	1.68	0.19	9.00	1.74
7 - 8	26.67	1.77	0.05	14.22	1.85	0.03	9.00	0.24
8 - 9	12.45	1.93	0.02	12.45	0.00	0.00	9.00	0.00
		Total biomass	1.02		P:B ratio	3.48	Total production	3.54

Table 2. Secondary production, P (g DW/m²/yr) and annual P/B ratio for amphipods inhabiting seagrass beds

Species	Location and depth (m)	Habitat	P	P/B	Source
Gammarus mucronatus Say, 1818	Chesapeake Bay (0.3-1.0), U.S.A.	Seagrass beds	14.3	23.6-76.8	Fredette and Diaz, 1990
Gammarus mucronatus Say, 1818	York River, U.S.A.	Seagrass beds	5-10	15.8-36.8	Fredette and Diaz, 1986
Jassa slatteryi Conlan, 1990	Gwangyang Bay (1-1.5), Korea	Seagrass beds	20.07	5.21	Jeong et al., 2006
Monocorophium acherusicum Costa, 1851	Gwangyang Bay (1-1.5), Korea	Seagrass beds	3.54	3.48	The present stuty

2004). Thus, the diets of *M. acherusicum* and *J. slatteryi* may overlap considerably. This large overlap in dietary composition increases interspecific competition for food (Yu et al., 2003), which can cause declines in amphipod population density and biomass (Sarvala, 1986; Hill, 1992). Therefore, we suggest that competition for food between *M. acherusicum* and *J. slatteryi* may have led to low densities of *M. acherusicum* from May to July.

Production

Marine amphipods have a wide range of secondary production according to species and habitat type (Jeong et al., 2006). Amphipod production in unvegetated habitats ranged from 0.1-47 g DW/m²/yr (Jeong et al., 2006). In contrast, the highest production in seagrass beds (20.07 g DW/m²/yr) was reported for *Jassa slatteryi* in Gwangyang Bay, Korea (Table 2). *Monocorophium acherusicum* secondary production was 3.54 g DW/m²/yr (Table 1), which was lowest among the observed production of seagrass-dwelling amphipods (Table 2). Secondary production of marine benthic amphipods in seagrass beds often increases with increasing amphipod density (Fredette and Diaz, 1986). Consequently, the low secondary production in *M. acherusicum* may be related to the observed low densities of this species (compared to other amphipods).

P/B ratios of benthic amphipods are generally higher in vegetated than unvegetated habitats (Orth et al., 1984). P/B ratios of amphipods living in seagrass beds ranged from 5.21 to 76.8 (Table 2). The annual P/B ratio of *Monocorophium acherusicum* was 3.48, which was low compared to other seagrass amphipods (Table 2). Dauvin (1989) reported that the P/B ratio appears to be closely related to the number of amphipod generations. A high number of generations and subsequent high P/B ratios are characteristic of short-lived, multivoltine species (Kemp et al., 1985; Donn and Croker, 1986). *M. acherusicum* has fewer generations than other amphipods, perhaps leading to the lower P/B ratios.

In comparison to other habitats, seagrass beds provide a superior substrate for diverse and abundant invertebrate communities (Orth et al., 1984). In seagrass beds, benthic amphipods are an important food resource for fishes and crustaceans. Recently, in a year-round survey in Gwangyang Bay, the secondary production of *Jassa slatteryi* was estimated as 20.07 g DW/m²/yr, which was the highest production observed for seagrass-dwelling amphipods (Jeong et al., 2006). In addition, *Gammaropsis japonicus* exhibited the highest abundance during the year (Jeong et al., 2004). High abundance and secondary production of amphipods may play important roles in the energy flow between primary production and higher consumers in the seagrass beds of southern Korea. Therefore, to better understand the role of amphipods in seagrass bed ecosystems, we need more detailed information on these species' life cycles and secondary production.

Acknowledgements

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