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Shell Growth of the Sand Snail, *Umbonium costatum* (Kiener) in Hakodate Bay

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Abstract

Shell growth of the sand snail, *Umbonium costatum* in Hakodate Bay, Hokkaido was studied during the period October 1982 to November 1988. The age of each sand snail was determined by counting the number of shell rings. Recruitment season was also studied from July to September 1987 and from June to September 1988 to determine the initial month of the 0 age group. In 1987 newly recruited juveniles appeared in August and in 1988 they appeared from July to September but were most abundant in August. This indicates that the 0 age group begins in August. The equation representing seasonal growth was obtained following Pauly and Gaschutz's modified Bertalanffy equation; $Lt=22.024[1-\exp\{-0.793(t/12-0.050)+0.150(\sin(2\pi(t/12-0.421))\}]$, where Lt=shell diameter (mm) and t=age in months. Seasonality of shell growth in this species is strongly affected by temperature. However, various other factors could also have considerably affected shell growth because shell growth from April to July was much greater compared to the period October to January in the same temperature condition.

The gastropod, sand snail *Umbonium costatum* belongs to family Trochidae, subfamily Umboniinae (Takenouchi, 1986). This species commonly inhabits exposed sandy shores in Japan and is distributed locally at high density (Akiyama and Matsuda, 1979). According to Ozawa (1983), Umboniinae are distributed from the Indian Ocean to the eastern Pacific Ocean and live gregarioully in soft bottom in contrast to most archaeogastropods which inhabit rocky shores and graze on algae. Fretter (1975) reported that *Umbonium vestiarium* are deposit and suspension feeders which is rare in gastropods.

In general, age determination is necessary when studying population dynamics of marine animals with overlapping generations. Most studies on population dynamics of molluscs have been performed on the basis of age determination (Hancock, 1973; Goshima, 1982; McGrorty et al., 1990). Growth and body size of individuals are related to population dynamics through fecundity and mortality (Levitan, 1989). Linear relationships between body size and fecundity (Shokita, 1979; Hughes, 1986; Hines, 1991) and size-related mortality and size refuse have been shown in many species (Nojima et al., 1980; Goshima, 1982). They are among the important concepts of life history strategy (Southwood, 1988). Ecological studies on *U. costatum* are very few (Kikuchi and Doi, 1987). Investigations on growth and population dynamics have not yet been done. This paper reports age determination and shell growth, factors important in population dynamics, in *U. costatum*.

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Materials and Methods

Samples were collected almost every month in the inner part of Hakodate Bay (41°48′N, 140°43′E) from October 1982 to November 1988. The sampling area was about 800 m wide from shore line to offshore and about 4.8 km long from Nanaehama Beach to the estuary of Ohno River. A more detailed description of the sampling area has previously been presented by Noda (1991). Samples were collected by a small Smith-McIntyre grab sampler with 0.05 m^2 in sampling area. The temperature of the sediment was measured immediately after grab sampling. Sand snails were separated from sediment by using a 1 mm mesh and then fixed in 10% sea water formalin. All specimens were brought to the laboratory for analysis. Snails with broken ridges on aperture were not included in the analysis.

A number of narrow grooves were observed on the body whorl of *U. costatum* (Fig. 1). Among these grooves, the growth bands (composed of dense lines) were distinguished clearly from other indistinct growth line which were not observed in all individuals. In this study, the growth band which appears as a dense line is referred to as ring (Fig. 1). The availability of ring for age determination was estimated as follows: (1) if new rings on all animals were formed sharply and annually, cumulative frequency of individuals with new ring on ridge of aperture was examined in all individuals collected from October 1982 to November 1988; (2) if individuals with the same number of rings came from the same cohort, the number of rings and shell diameter were measured in each animal, and temporal change of size distribution was determined from October 1982 to September 1984.

Samples collected from July to September 1987 and from June to September 1988 were used in recruitment season study. Surface sediment covering an area of 50 cm^2 was subsampled from sediment collected by a small Smith-McIntyre grab sampler at 20–35 sites. Samples were fixed in 5% buffered sea water formalin and brought to the laboratory. Sand snail juveniles that were retained on the 0.125 mm mesh were sorted, counted, and measured using a stereo microscope with an optical micrometer (to the nearest 0.05 mm).

The seasonal growth pattern of shell was determined by classifying the collected specimens into year groups. The shell diameter was measured and the mean of each year group was calculated. Monthly increment of shell diameter for each year group was estimated from the difference of monthly mean diameter. The growth equation representing seasonal growth was obtained following Pauly and Gaschutz's

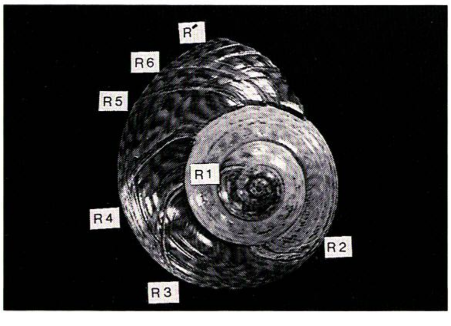

Fig. 1. Growth bands in *U. costatum*. Rl to R6 show clear growth bands observed in all individuals. R′ shows an indefinite band which is not always detectable.

modified Bertalanffy equation. This equation demonstrates body length Lt at t-month age (recited from Moreau, 1987).

$$Lt = L_\infty[1-\exp\{-k(t/12-t_0)+A\sin(2\pi(t/12-t_s))\}]$$

where: $A = ck/2\pi$,
L_∞ = theoretical maximum body length
k = growth coefficient
t_0 = theoretical age in month when $Lt=0$
c = altitude of amplitude
t_s = age in month when oscillation begins

The growth equation of sand snail was obtained by taking the mean growth values for monthly specimens of each year group and these values were fitted in the above equation using a computer program of simplex method (Okumura, 1986).

Results

Cumulative frequency of individuals with new ring collected by 1 mm mesh from October 1982 to November 1988 is shown in Table 1. Results showed that there was no individual with a new ring in March, whereas in the next two months, snails with a new ring appeared, and in June, most of the animals have formed a new ring, all individuals have a new ring in August. Figure 2 shows the temporal changes of size distribution of individuals belonging to different groups divided by their different ring number from October 1982 to September 1984. In October 1982, the group of snails below 8 mm diameter without rings changed to 1-ring group in June 1983 and to 2-ring group in June 1984. During this period, size distribution of this group had a continuous single mode but later overlapped with the size distribution of more than 3-ring groups. A small number of individuals without

Table 1. Cumulative frequency (%) of individuals with a new ring.

Month	1982–1983	1983–1984	1984–1985	1985–1986	1986–1987	1987–1988
Oct	0.0	0.0	0.0	0.0	0.0	0.0
Nov	—	—	0.0	0.0	—	0.0
Dec	—	0.0	0.0	0.0	0.0	0.0
Jan	—	—	—	—	—	—
Feb	—	—	0.0	0.0	—	0.0
Mar	—	0.0	0.0	0.0	0.0	0.0
Apr	—	0.0	7.6	6.2	—	—
May	0.4	6.2	74.3	100.0	94.3	95.5
Jun	100.0	87.7	97.0	—	97.8	100.0
Jul	100.0	98.4	99.7	100.0	100.0	100.0
Aug	—	100.0	100.0	100.0	100.0	100.0
Sep	100.0	100.0	100.0	—	100.0	100.0
Oct	100.0	100.0	100.0	100.0	100.0	—

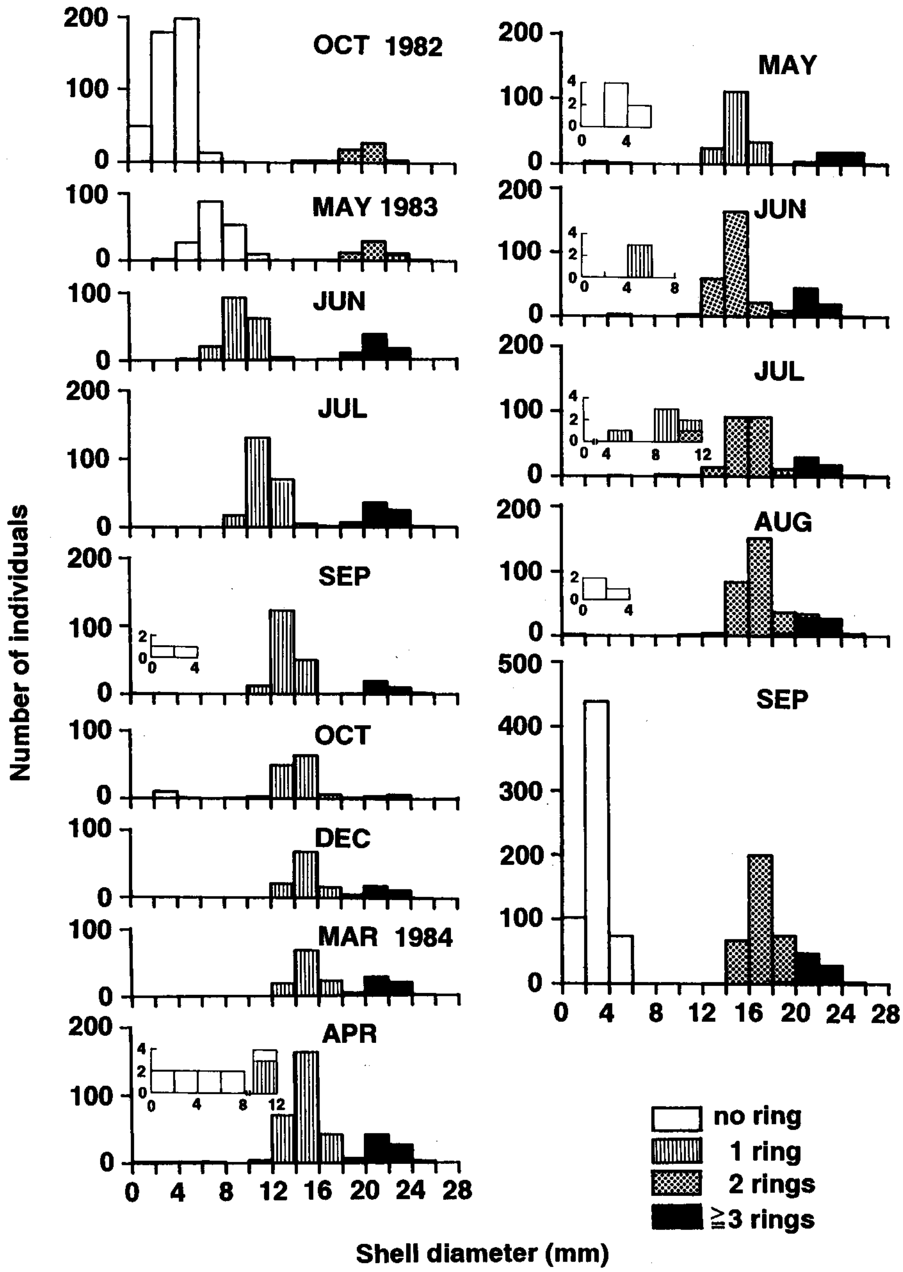

Fig. 2. Size frequency distribution of *U. costatum* collected from October 1982 to September 1984. Individuals collected in small number are represented by enlarged histogram.

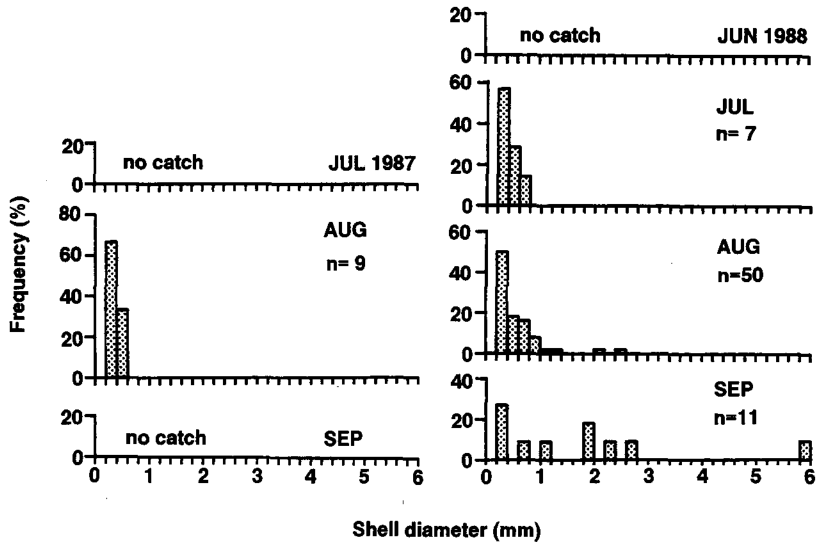

Fig. 3. Size frequency distribution of juvenile *U. costatum* collected in 1987 and 1988.

rings appeared in September 1983, and these deviated to 1-ring group in June 1984. In 1984, individuals without rings appeared in August and their number increased largely in September. The 2-ring group with one mode in October 1982 joined the more than 3-ring group in June 1983. As mentioned above, first ring appeared in 0 age and was formed once a year in limited season which was relatively short in all ages. Hence, the number of rings can be used for age determination of sand snails.

Size frequency distribution of individuals collected in 0.125 mm mesh from July to September 1987 and from June to September 1988 is shown in Fig. 3. The minimum shell diameter of collected individuals was 0.200 mm. During the sampling period, no juveniles were found in June, and a few of them appeared only in July 1988. In August, there were juveniles of less than 1 mm collected in 1987 and 1988. Furthermore, in August 1988, the recruitment reached a peak. The size distribution of the juveniles in August 1988 showed a mode at 0.2-0.4 mm class and extended to more than 1 mm class. In September, individuals of less than 1 mm could still be found but were less in number compared to those in the more than 1 mm classes. These results indicate that August was the peak of settlement. Thus, this month was used to indicate initial age of *U. costatum*.

Mean shell diameter of each year class from October 1982 to November 1988 is shown in Fig. 4. From these, the monthly mean diameter was obtained and the values fitted in the growth equation (Fig. 5) as follows:

$$Lt=22.024[1-\exp\{-0.793(t/12-0.050)+0.150\sin(2\pi(t/12-0.421))\}] \quad (1)$$

Where Lt = shell diameter (mm) at t-month age.
The obtained growth curve fitted well with the observed values (Fig. 5).

Monthly increment of shell diameter of each year class from 0-month age to 36-month age is represented by the difference in monthly mean shell diameter (Fig.

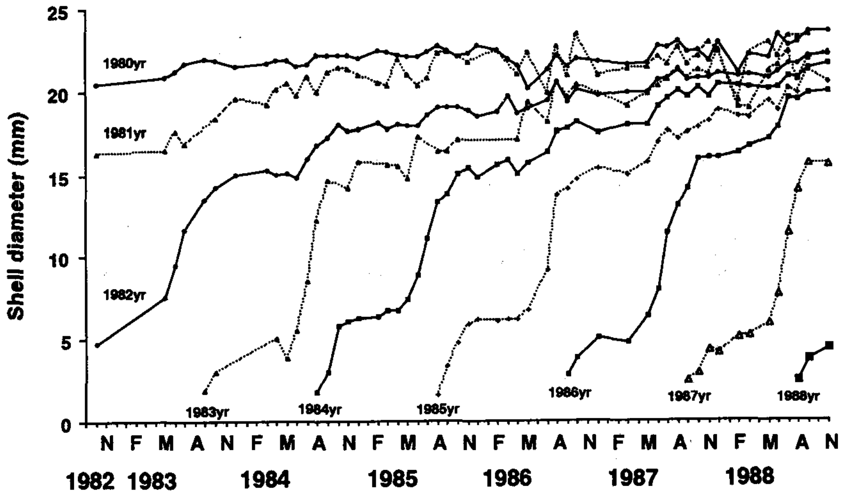

Fig. 4. Mean shell diameter of *U. costatum* for each year class from October 1982 to November 1988.

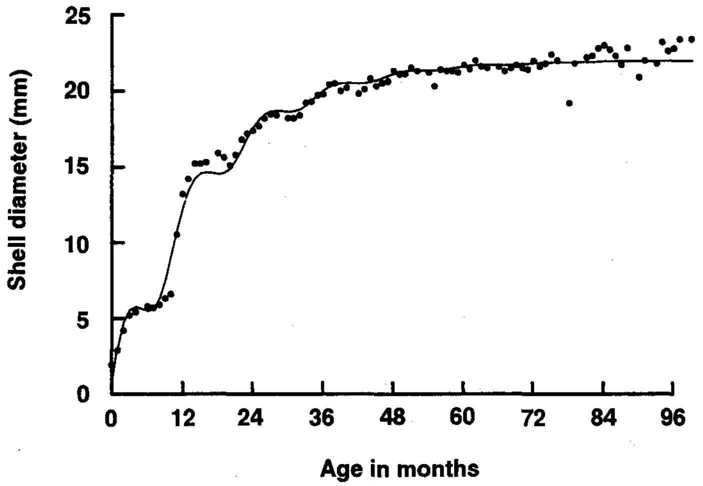

Fig. 5. Growth curve of *U. costatum* plotted by age in months. Dots represent year class means as shown in Fig. 4.

6a). Figure 6b shows the monthly mean bottom temperature. Although a slight difference was observed among year classes, there was an apparent seasonality of shell growth in *U. costatum*. The first peak of monthly increment in shell diameter was from August at 0-month age to October at 2-month age. The decrease in growth rate was accompanied with the decline in bottom temperature and shell increment remained at a low level from November to March of the following year. Before the rise in bottom temperature, shell increment increased from March at 7-month age and

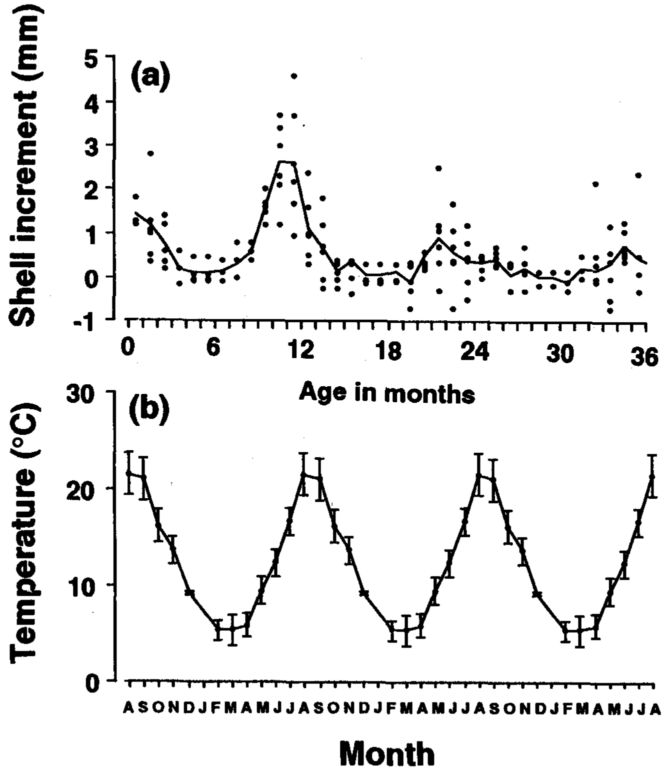

Fig. 6. Monthly increment in shell diameter for each year class from 0 to 36-month age (a), and the corresponding monthly mean bottom temperature (b). Line in (a) represents mean of monthly values and vertical bers in (b) indicate standard deviations.

achieved a peak from June to August. From August at 12-month age, shell increment rapidly decreased and remained at a low level from August to March of the following year. From April at 20-month age, shell increment increased and achieved a peak from May to June, faster than the previous year. Shell increment gradually decreased and stayed at a low level from October to March the following year. From April at 32-month age, seasonality of shell increment was similar to the previous year. To further investigate the relationship between seasonal growth and bottom temperature, correspondence between monthly increment of shell diameter and mean bottom temperature was calculated every two months (Fig. 7). In any year age, the minimum monthly shell increment appeared from January to March when the mean bottom temperature was lower than 6°C. On the other hand, monthly shell increment was high from July to October when mean bottom temperature was more than 15°C. However, shell increment from April to July was much higher than from October to January in the same bottom temperature condition.

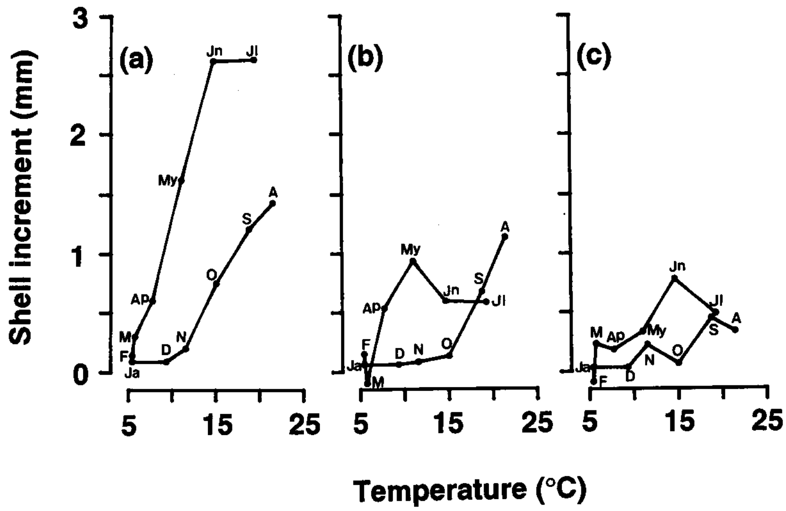

Fig. 7. Relationship between monthly increment in shell diameter of *U. constatum* and mean bottom temperature. Ages of samples: (a) 0-12 months; (b) 12-24 months; (c) 24-36 months. **A**: August-September; **S**: September-October; **O**: October-November; **N**: November-December; **D**: December-January; **Ja**: January-February; **F**: February-March; **M**: March-April; **Ap**: April-May; **My**: May-Jnne; **Jn**: June-July; **Jl**: July-August.

Discussion

In animal populations which have overlapping generations, age determination is the initial step in studies on growth, life history and population dynamics. The age determination for gastropods has generally been made by the comparison of length-frequency distribution (Goodwin, 1978; Nishino et al., 1983; Fujinaga, 1987), and by counting the number of shell rings (Williamson and Kendall, 1981). In this study, the age of sand snails was determined by counting the number of rings. Age determination by the method of comparison of length-frequency distribution may easily have errors and might not be applicable in old individuals which grow slowly.

In general, growth in gastropods has easily been measured as a linear increment of the shell, and the growth pattern has been represented by age in year and shell size relationship (Hughes, 1980; Staikou et al., 1988). Shell growth can also be converted to somatic growth by using the allometric relationship between body (tissue) weight and shell size. However, in species which show a remarkable shell growth in restricted seasons, as shown in this study, the growth equation obtained from shell size per year might represent the growth pattern incorrectly. Pauly and Gaschutz's modified Bertalanffy equation sometimes shows relatively large degrowth because the equation is not monotone increasing function. In this case, application of this equation causes a serious problem because degrowth of shell is unusual in molluscs. However, this equation makes possible to continuously demonstrate periodic growth pattern such as seasonal growth occuring almost synchronously among different year-age. In this study, the obtained growth curve coincides approximately with actual data. Only a small degrowth was shown from December to Feburary and fitting was not good from 9 to 20-month age.

In several species of molluscs, slow growth for several months after settlement was found (Thompson et al., 1980), thus, there is the possibility of underestimating age. In the present study, the settlement of *U. costatum* occurred from July to September and registered a peak in August. The period during which the sand snails are smaller than 1 mm after settlement is about a month. This is considered relatively short because the 0 age group was first collected a month after the appearance of animals smaller than 1 mm in 1987 and 1988. It seems reasonable to indicate August as the initial month for age determination in *U. costatum*.

In various species of gastropods, seasonal growth has been observed (Paul et al., 1977; Shepherd and Hearn, 1983; Tutschulte and Connel, 1988) and the major factors affecting this are thought to be seasonality of sea water temperature (Ekaratne and Crisp, 1984), season of gonadal development and release (Fretter and Graham, 1976; Ekaratne and Crisp, 1984; Tutschulte and Connel, 1988), and seasonal changes in availability of food (MacQuaid, 1981; Burgett et al., 1987). In the present study, bottom temperature was the only factor measured affecting seasonal growth. Growth of *U. costatum* almost stopped from February to March when bottom temperature was lowest and had a peak between May and August which coincided with a high bottom temperature. However, shell growth from April to July was much higher compared to the period October to January in the same bottom temperature condition. Apparent correlation between monthly bottom temperature and monthly shell increment was not always observed in this study.

It is evident, at least, that seasonality of shell growth in this species is strongly affected by temperature. However, various other factors could also have affected growth considerably. For elucidating the cause of seasonality in growth of this species, it is necessary to study the seasonality of food availability, ingested energy, and energy allocation. The results of the present study seem to offer good information on population dynamics and functional biology of *U. costatum*.

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