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Biometric studies on the bivalves *Astarte elliptica*, *A. borealis* and *A. montagui* in Kiel Bay (Western Baltic Sea)

R. Schaefer, K. Trutschler & H. Rumohr

Institut für Meereskunde; Düsternbrooker Weg 20, D-2300 Kiel 1, Federal Republic of Germany

ABSTRACT: The three *Astarte* species were studied in June 1983 at two sites in Kiel Bay, "Süderfahrt" and "Schleimünde", at 20 m depth. Shell length to live wet weight correlations are given for all three species; for *A. elliptica* also shell-free dry weight, shell dry weight, ash-free dry weight of the soft body and ash-free dry weight of the shell are recorded as functions of the shell length. In the logarithmic length/weight regression analysis the coefficients of slope for *A. elliptica* and *A. borealis* are 3. For *A. montagui*, that coefficient is significantly greater than 3. Weight conversion factors, calculated for *A. elliptica*, revealed a mean weight composition of 31.5 % water in the mantle cavity and tissue water, 64.5 % shell ash, 2.1 % organic content of shell, 1.7 % organic content of the soft body and 0.4 % ash of the soft body. An isometric growth of shell length and shell breadth is confirmed for *A. borealis*, while *A. montagui* exhibits positive allometric shell growth and changes its shape during life.

INTRODUCTION

In Kiel Bay (Western Baltic), three species of the bivalve genus *Astarte* are found in sandy sediments below 15 m water depth (Kühlmorgen-Hille, 1963). The three species *Astarte elliptica* (Brown), *A. borealis* (Schuhmacher) and *A. montagui* (Dillwyn) are mostly co-occurring, sometimes even in similar densities (Arntz et al., 1976). Their spatial distribution has been shown to be aggregated (Dold, 1980). Information on the growth rates and longevity of the *Astarte* species has not been reported in the literature, but Jaeckel (1952) assumed a maximum age of more than two years.

Astarte species represent an important part (about 15 %) of the total biomass in Kiel Bay (Arntz, 1980; Weigelt, 1985) and since population parameters are not known, this paper attempts to answer the following questions: (a) What are the relationships between shell length and weight? (b) Are the different weights optionally convertible? (c) Is shell shape applicable as a taxonomic feature to distinguish *A. borealis* from *A. montagui*?

This paper, in accordance with the recommendations of the Baltic Marine Biologists (WG 11), sets up a list of conversion factors to facilitate benthic production studies, and attempts to model parts of the ecosystem (Rumohr et al., in prep.).

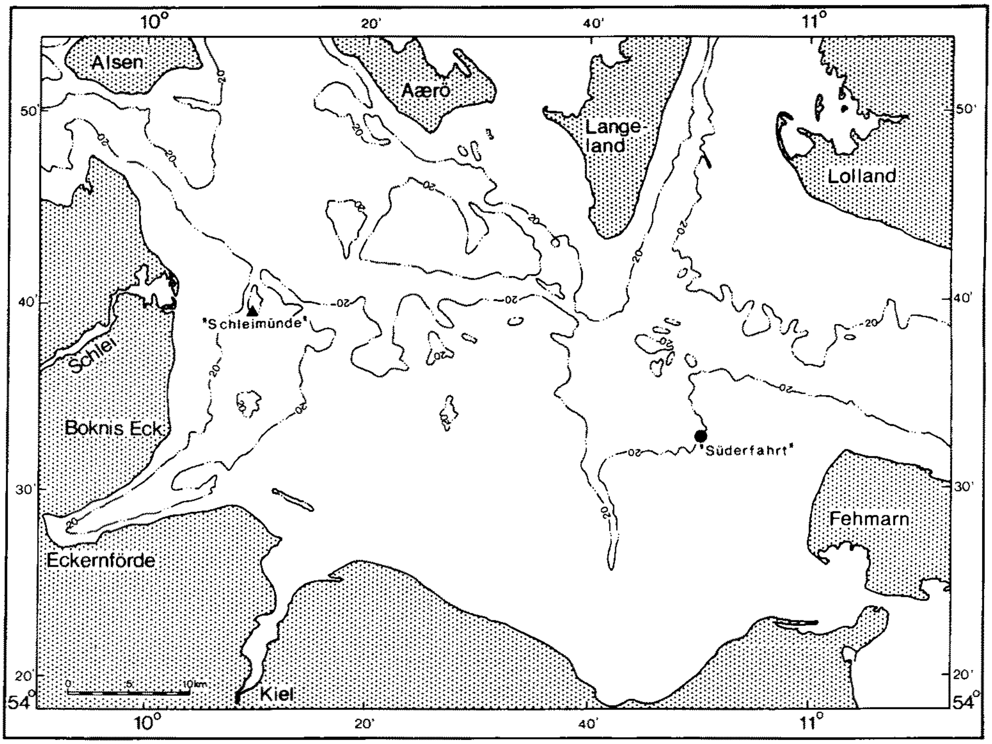

Fig. 1. Sampling sites in Kiel Bay (Western Baltic)

MATERIALS AND METHODS

Two sites in Kiel Bay – "Süderfahrt" in the central part and "Schleimünde" in the western area – were sampled at water depths of 20 m on 9 and 16 June, respectively (Fig. 1). Sediment surfaces at both stations were oxic, composed of coarse sand with gravel and pebbles, and, at "Schleimünde," a high proportion of mud. At "Süderfahrt", the sediment was muddy sand.

We used a triangular dredge with an edge length of 40 cm, holding a net of 5 mm mesh, and a 0.1 m^2 Van-Veen grab weighing 60 kg. The dredge and grab catches were passed through 1-mm sieves. The retained material was transferred to 50-l plastic trays, and washed several times to remove polychaetes and algae. The live *Astarte* specimens were stored in sea water at 5 °C for a maximum of 48 h prior to analysis.

Using a sliding gauge, we measured the shell length of 4121 specimens altogether, and the shell breadth of 305 *A. borealis* and 504 *A. montagui,* always rounding off to the lower 0.1 mm. The shell length is defined as the maximum distance between the posterior and the anterior margin of the shell. The shell breadth (Petersen, 1958; Richter & Rumohr, 1976) is the greatest distance between the two closed valves.

All specimens of one 0.5 mm length class were weighed together to the nearest 0.001 g. Average class values were used in the regression analysis. For the determination of live wet weight including the shell (LWW = live wet weight), the external water was removed by dabbing with blotting paper until no more visible moisture was left on the paper. The dry weights of *A. elliptica* from "Süderfahrt" were determined using about ten specimen of each length class above 5 mm. The soft parts (SFDW = shell-free dry weight) and shells (SDW = shell dry weight) were dried separately to constant weight at 80 °C for 24 h. Ash-free dry weights of the soft parts (SFAFDW = shell-free ash-free dry weight) and the shells (SAFDW = shell ash-free dry weight) were then recorded after the tissues had been burned in a muffle oven at 500 °C for 24 h.

Linear regression equations were fitted to the logarithmic shell length to weight, and shell length to shell breadth data. The assumed length to weight equations $W = aL^b$ (Ricker, 1975) became $\log_{10}W = \log_{10}a + b \log_{10}L$ with W = wet, dry or ash-free dry weights in mg; L = shell length in mm.

The coefficients a and b were estimated from the regression lines. Conversion factors between the different weights were computed as means over the whole length spectra.

Since for both species the dispersion in shell breadth increased with shell length, the data were converted to natural logarithms, regression analysis was then carried out. The assumed length to breadth regressions were derived from $B = cL^d$ and became $\log_e B = \log_e c + d \log_e L$ with B = shell breadth in mm, L = shell length in mm, c, d = coefficients estimated from the regression lines. For all a, b, c and d values, as well as for the weight conversion factors, 95 %-confidence intervals were calculated employing Student's t with n-2 degrees of freedom (Sachs, 1984).

RESULTS

All shell length to weight regression statistics are presented in Table 1. The relationship of length to LWW (live wet weight) of *Astarte borealis* has a coefficient of slope (i.e. b) of 3, whereas the regression line for *Astarte montagui* with a coefficient of slope of 3.475 reveals a reduced length growth compared to the other two shell

Table 1. Statistics describing regression equations between shell length (mm) and weights (mg) for the three *Astarte* species. ± 95 % – c.i.: 95 % – confidence interval; $\log_{10}a$: point of interception; b: coefficient of slope; m: mean number of specimens per length class; n: number of investigated length classes; r: correlation coefficient of the regression analysis; LWW: live wet weight; SDW: shell dry weight; SFDW: shell-free dry weight; SAFDW: shell ash-free dry weight; SFAFDW: shell-free ash-free dry weight

Site / Date	Species	Weight	$\log_{10}a$ ± 95 %– c.i.	b ± 95 %– c.i.	r	n	m
Schleimünde 16. 06. 1983	*A. elliptica*	LWW	−0.835 ± 0.051	3.087 ± 0.042	0.999	57	28
	A. borealis	LWW	−0.617 ± 0.044	3.035 ± 0.038	0.999	47	6
	A. montagui	LWW	−1.011 ± 0.124	3.475 ± 0.144	0.997	18	28
Süderfahrt 09. 06. 1983	*A. elliptica*	LWW	−0.498 ± 0.068	2.878 ± 0.058	0.998	53	27
		SDW	−0.799 ± 0.064	2.974 ± 0.053	0.998	49	9
		SFDW	−2.084 ± 0.096	2.791 ± 0.079	0.995	49	9
		SAFDW	−2.291 ± 0.311	2.951 ± 0.259	0.982	23	3
		SFAFDW	−2.563 ± 0.118	3.126 ± 0.128	0.995	36	10

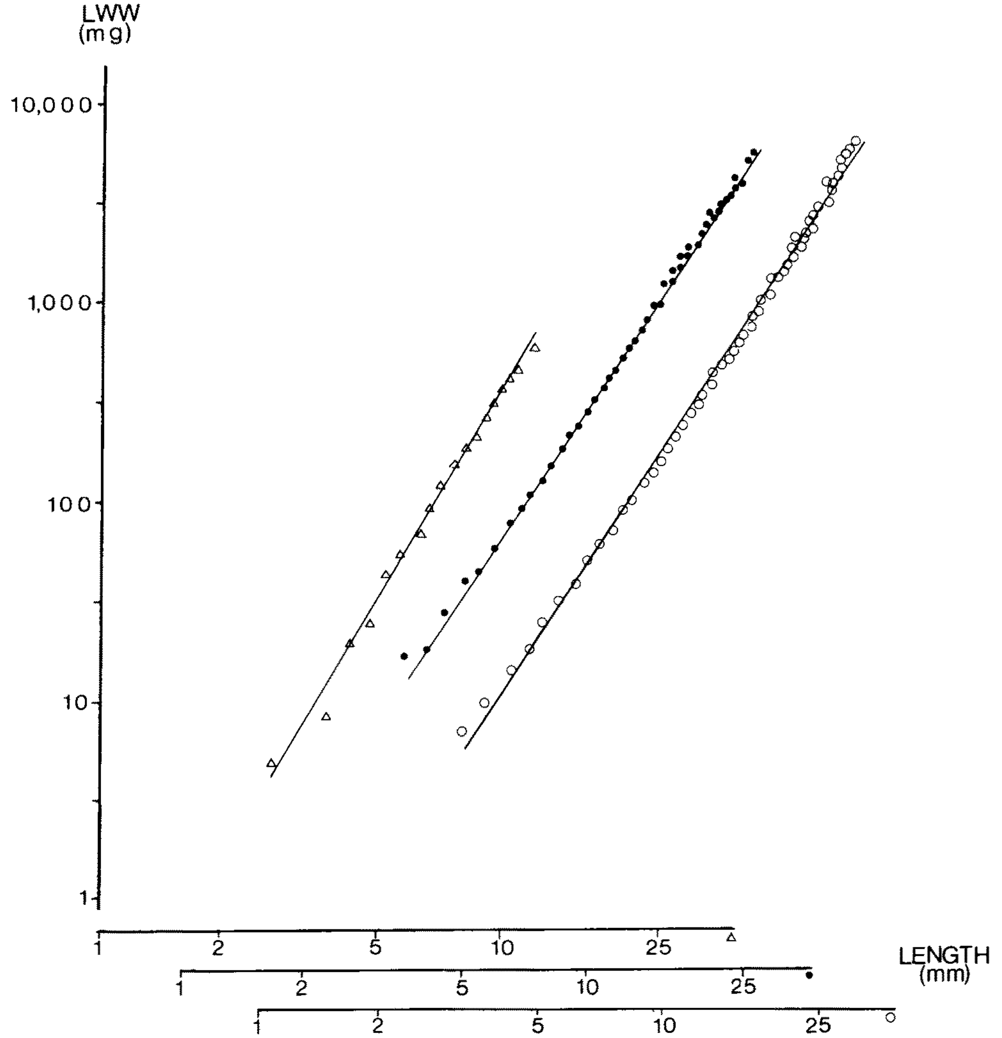

Fig. 2. Shell length–LWW (live wet weight) relations of the dredge samples at "Schleimünde"; △ *Astarte montagui*, ● *A. borealis*, ○ *A. elliptica*, plotted logarithmically ($\log_{10}$)

dimensions (Fig. 2). For *Astarte elliptica* these coefficients of the LWW lines from the two sites (Figs 2 and 3) differ significantly ($p \leq 0.05$). At "Schleimünde" b is significantly greater than 3, at "Süderfahrt" less than 3. Although length to SDW (shell dry weight) and length to SAFDW (shell ash-free dry weight) regressions from *A. elliptica* at "Süderfahrt" alone have coefficients of slope of 3, the dry weight of the soft parts shows a slower weight increase in relation to the shell length (Fig. 3; Table 1). The coefficient of slope from the length to SFAFDW (shell-free ash-free dry weight) line, however, is isometric (i.e. $b = 3$). Weight conversion factors for the "Süderfahrt" *A. elliptica* population and the 95 %-confidence intervals, expressed in percent, are given in Table 2. Thus

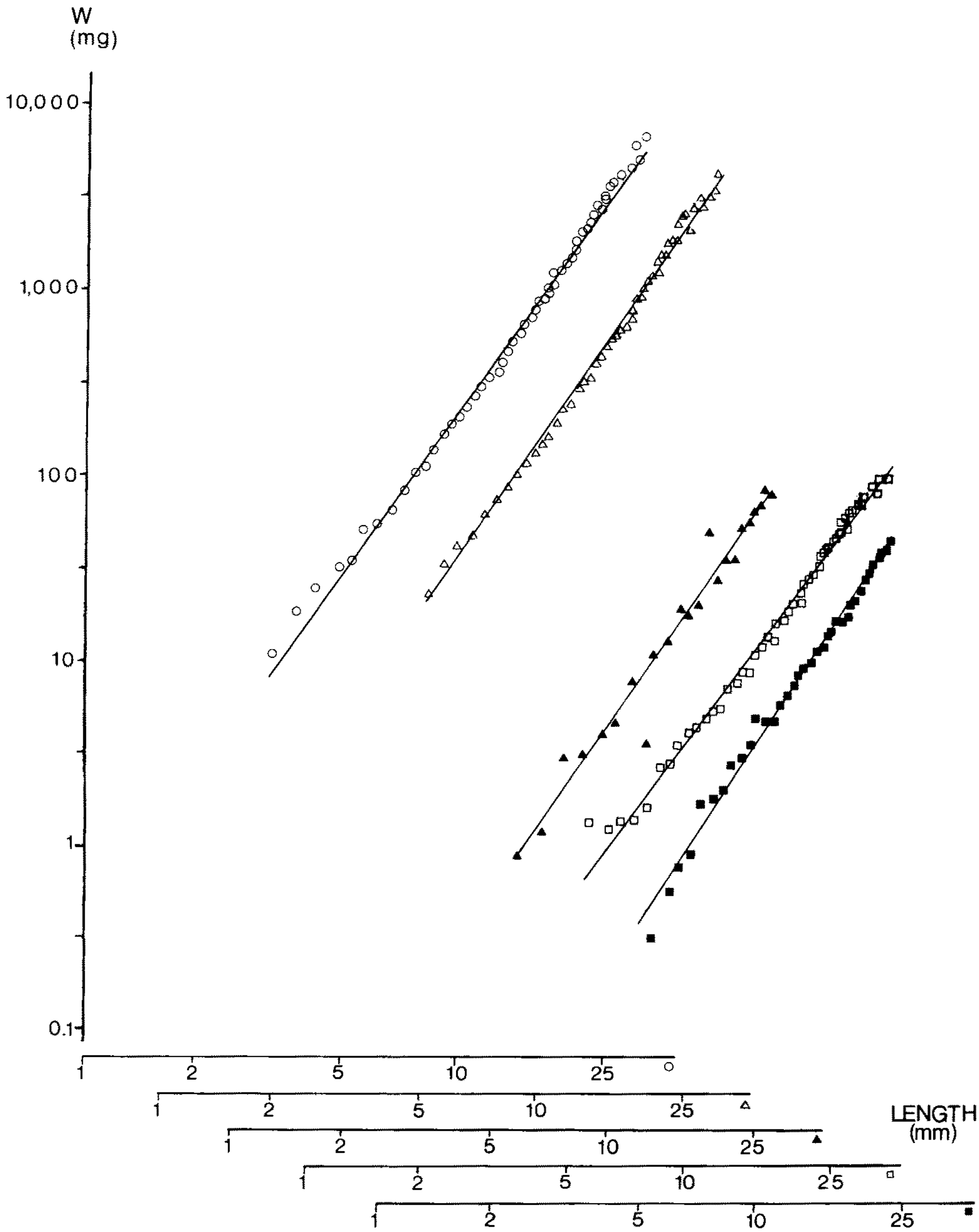

Fig. 3. Shell length–weight (W) relations of *Astarte elliptica* dredged at "Süderfahrt", plotted logarithmically. ○: LWW (live wet weight), △: SDW (shell dry weight), ▲: SAFDW (shell ash-free dry weight), □: SFDW (shell-free dry weight), ■: SFAFDW (shell-free ash-free dry weight)

Table 2. Conversion factors relating the investigated weights of *Astarte elliptica* at "Süderfahrt"; $\bar{x}$: mean percentage of weight quotient (see also Table 1)

Weight	$\bar{x} \pm 95\%$– c.i.	n
$\frac{SDW}{LWW}$	66.438 ± 0.963	49
$\frac{SFDW}{LWW}$	2.105 ± 0.096	49
$\frac{SAFDW}{LWW}$	2.064 ± 0.220	23
$\frac{SFAFDW}{LWW}$	1.770 ± 0.091	36
$\frac{SFDW}{SDW}$	3.171 ± 0.146	49
$\frac{SAFDW}{SDW}$	3.129 ± 0.328	23
$\frac{SFAFDW}{SDW}$	2.648 ± 0.138	36
$\frac{SAFDW}{SFDW}$	98.634 ± 12.045	23
$\frac{SFAFDW}{SFDW}$	81.558 ± 6.837	36
$\frac{SFAFDW}{SAFDW}$	90.549 ± 17.658	18

the weight composition of a mean specimen of *A. elliptica* at "Süderfahrt" amounts to 31.5 % water in the mantle cavity and tissue water, 64.3 % shell ash, 2.1 % organic content of the shell, 1.7 % organic content of the soft body and 0.4 % ash of the soft body.

The growth exponents of the length to weight relationships of *A. borealis* and *A. montagui* calculated above, already suggest differences in the growth characteristics of the shells. The shell length to shell breadth regression statistics are given in Table 3. For *A. borealis* the coefficient of slope is not significantly ($p \leq 0.05$) different from 1, i.e. the quotient of breadth to length is constant (isometric length–breadth growth). Shell breadth is found to be 42.6 % of the shell length for *A. borealis*. *A. montagui* has positive allometric length–breadth growth ($d > 1$). In the investigated length range, the breadth to length quotient varies from 43.8 % for the lower length classes up to 59.1 % in the

Table 3. Regression statistics describing the relationship between shell length (mm) and shell breadth (mm) in *Astarte borealis* and *Astarte montagui*; $\log_e c$: point of interception; d: coefficient of slope (see also Table 1)

Species	$\log_e c \pm 95\%$– c.i.	$d \pm 95\%$– c.i.	r	n
A. borealis	−0.854 ± 0.045	0.986 ± 0.018	0.987	305
A. montagui	−1.048 ± 0.087	1.209 ± 0.043	0.927	504
separation line	−0.901	1.040		

upper length classes. The point of intersection of both regression lines lies out of the investigated length range at L = 2.4 mm and B = 1.0 mm. A straight separation line was graphically fitted ($\log_e B = -0.901 + 1.040 \log_e L$), dividing the two species in a logarithmic plot (Fig. 4).

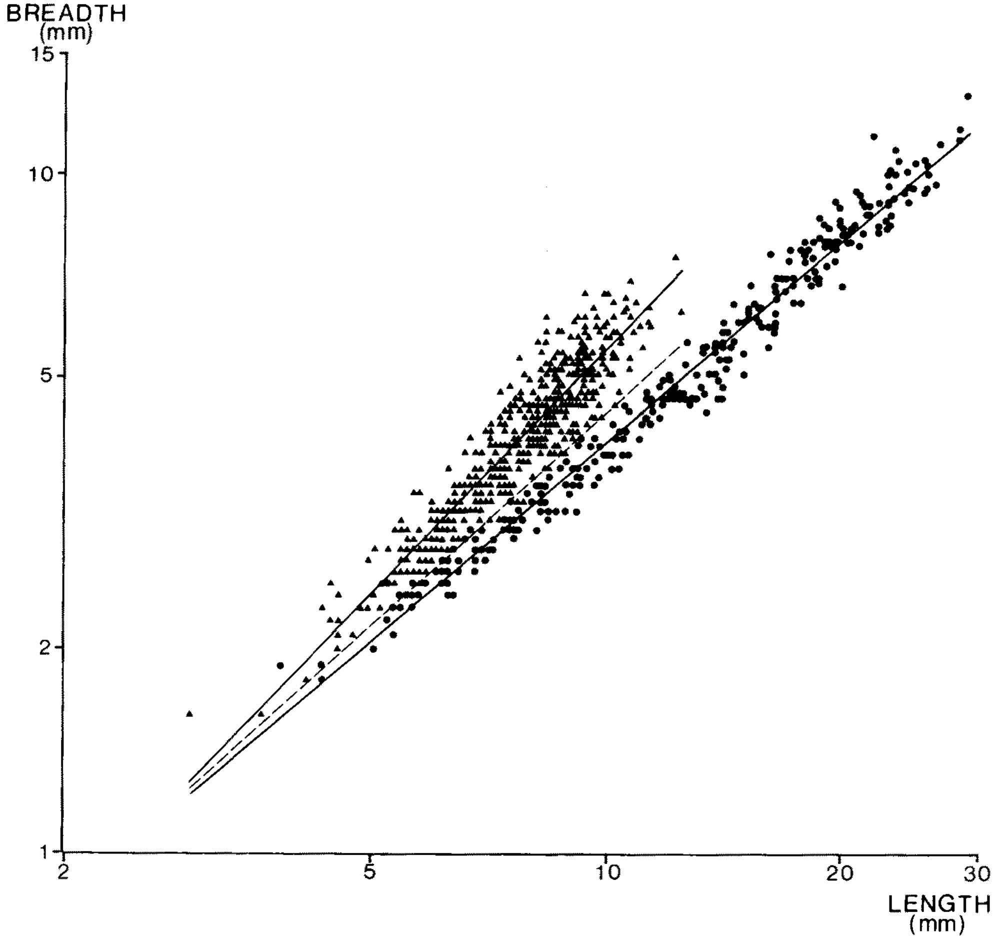

Fig. 4. Shell length to shell breadth relations of *Astarte borealis* (●; n = 305) and *A. montagui* (▲; n = 504) and graphically fitted separation line (--), plotted double logarithmically ($\log_e$)

DISCUSSION

All shell length to weight relations show very good correlation coefficients for the investigated length ranges. The differences in the two *Astarte elliptica* populations might be caused by hydrographical conditions. At "Süderfahrt", under direct influence of the Great Belt, *A. elliptica* was about 20 % heavier than at "Schleimünde". This might be interpretated as faster growth in length of *A. elliptica* at "Schleimünde" due to the location near the mouth of the Schlei, an eutrophicated brackish fjord with low salinity. Brey (1984) calculated the annual macrozoobenthos production for the shallow water area (5–15 m) at "Schleimünde" to be "more than twice as high (i.e. 78 gAFDW/m^2) as the average production of the remaining investigated area (30 gAFDW/m^2)" in Kiel Bay shallow water area. It follows that for a given length the "Schleimünde" specimens may have grown faster and are therefore probably younger.

The importance of larger bivalves like *Astarte* in an ecosystem can easily be overestimated, if calculated from total weights. The organic content of *A. elliptica* amounts to only 3.8 % of LWW (live wet weight), and only 45 % of this refers to the soft body. Ansell (1975) published weight conversion factors for the *Astarte* species in the Clyde Sea area over nineteen months. For *A. elliptica* he found variations in the ratio of shell wet weight (SWW) to live wet weight (LWW) in both sexes from 65.17 % to 73.88 %; in June–July the variation was 69.42 % to 69.67 %. The shell free dry weight (SFDW) to LWW-quotient varied for the same period from 2.65 % to 5.32 % and 4.17 % to 4.31 %, respectively. Since SWW is only about 1 % more than shell dry weight (SDW), the shells of Kiel Bay specimens with 66.44 % have the same percentage relationship to LWW. Ansell's SFDW to LWW-quotients from June–July are higher than our value (2.11 %). Our calculated weight conversion factors revealed relatively narrow 95 %-confidence intervals, i.e. the weights are all very well convertible over the whole investigated length ranges.

The identification of specimens of *A. borealis* and *A. montagui* by reference to the relationship between shell length and shell breadth is possible in the length range over 5 mm. Specimens with a breadth to length quotient greater than $B/L = 0.406\ L^{0.040}$ belong to *A. montagui*. The few very broad specimens identified as *A. borealis* (Fig. 4) might be individuals of *A. montagui*, in which the "microscopic fine pits" (Tebble, 1976) in the periostracum, the only reliable feature to distinguish *A. montagui* (Meyer & Möbius, 1872; Ockelmann, 1958; Tebble, 1976), were absent. Since variability in shape occurs with decreasing salinity (Remane, 1940), the question remains whether this feature can be applied for *A. borealis* and *A. montagui* in other areas.

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