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The shell organic content in the energy budget of *Mytilus trossulus* from the South Baltic

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ABSTRACT

The amount of organic matter and its energy values in shells of *Cerastoderma glaucum, Macoma balthica* and *Mytilus trossulus* from the Gulf of Gdańsk were estimated by chemical extraction and by microcalorimetry.

The mean organic matter content varied from 0.54% in *C.glaucum*, to 5.21% in *M. balthica* and 5.92% in *M. trossulus*. Energy values of shell organic matter ranged from 15.15 (± 1.41) $J.mg^{-1}$ in *M. balthica* to 20.17 (± 1.60) $J.mg^{-1}$ in *M. trossulus* and 23.88 (± 1.56) $J.mg^{-1}$ in *C. glaucum*.

Organic content and energy value of shells were specific and related to microgeographic distribution (environmental factors) of the population/or sediment type. Seasonal changes of these parameters were also observed. *M. trossulus* shells of 25-50 mm in length showed higher organic matter content (5.5 to 6.19%), but lower energy value (18.92 to 19.99 $J.mg^{-1}$) than those of 5-25 mm length (5.27 to 5.61% and 20.59 to 21.09 $J.mg^{-1}$ respectively).

The energy content accumulated in the shell represented from 5.4% of total energy content in *C. glaucum* to 17.6% in *M. balthica* and 22.3% in *M. trossulus*, and therefore plays an important role in the bivalves' energy budget.

RÉSUMÉ

Le contenu en matière organique de la coquille dans le budget énergétique de *Mytilus trossulus* du Sud de la Mer Baltique.

La quantité de matière organique et sa valeur énergétique ont été évaluées pour les coquilles de *Cerastoderma glaucum, Macoma balthica* et *Mytilus trossulus* de la baie de Gdańsk, par extraction chimique et microcalorimétrie.

Le contenu moyen en matière organique varie de 0,54% chez *C.glaucum*, à 5,21% chez *M. balthica* et 5,92% chez *M. trossulus*. La valeur énergétique de la matière organique de la coquille varie entre 15,15 (± 1,41) $J.mg^{-1}$ chez *M. balthica*, 20,17 (± 1,60) $J.mg^{-1}$ chez *M. trossulus* et 23,88 (± 1,56) $J.mg^{-1}$ chez *C. glaucum*.

Le contenu en matière organique de la coquille et sa valeur énergétique sont spécifiques, et corrélés avec la microdistribution géographique (facteurs de l'environnement) de la population, ou avec le type de sédiment. Des changements saisonniers ont aussi été observés. Des coquilles de *M. trossulus* de 25-50 mm de longueur ont un contenu en matière organique plus élevé (5,5 à 6,19%), mais celui-ci a une valeur

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énergétique plus faible (18,92 à 19,99 J.mg^{-1}) que celles de 5-25 mm (5,27 à 5,61% et 20,59 à 21,09 J.mg^{-1} respectivement).

Le contenu énergétique accumulé dans la coquille represente entre 5,4% du contenu énergétique total chez *C. glaucum*, 17,6% chez *M. balthica* et 22,3% chez *M. trossulus*, et joue donc un rôle important dans le budget énergétique de ces bivalves.

INTRODUCTION

In spite of their low species biodiversity, bivalves are one of the most important components of the Baltic Sea benthic fauna resources. They are often dominant organisms in respect with size and biomass. In the biocenosis of coastal zone, *Mytilus trossulus* Gould, 1850, *Macoma balthica* (Linné, 1758) and *Cerastoderma glaucum* (Bruguière, 1789) play the most significant role. Although without any present commercial value *M.trossulus* forms extensive beds reaching up to 70% of biomass of animals living on a hard sediment (Jansson and Kautsky, 1977; Zmudziñski and Osowiecki, 1991) and plays a key role in the matter and energy flow in the Baltic (Kautsky and Evans, 1987; Wiktor, 1990). *C. glaucum* can be characterised as a prevailing species on a shallow and sandy bottom, while *M. balthica* on deeper muddy bottom. For reminder, multivariate analysis of morphological shape and molecular analysis of genetic variation have led to the recognition of three *Mytilus* sibling species: *M. edulis* Linné, 1758, *M. galloprovincialis* Lamarck 1819, and *M. trossulus* Gould 1850 (for a review see: McDonald *et al.*, 1991; Suchanek *et al.*, 1997).

Since shell weight makes from about 86% of dry weight (DW) of *M trossulus* and *M. balthica*, to more than 91% of *C. glaucum*, its contribution to energy balance of an organism has a very important meaning. The shell organic content of molluscs can represent a significant fraction of the total organic content but it is often neglected in calculations of energy budget in these animals (Hylleberg *et al.*, 1978; Szaniawska, 1992).

Furthermore, periostracum of the bivalves made mostly from proteins and glycoproteins with soluble and insoluble parts is responsible for sediment deposits abounding in organic matter (e.g., mussel mud) which form a suitable habitat for other organisms like the meiofauna (Weiner and Lowestam, 1977).

This paper aims to assess the role of shell organic matter in energy balance of *M. trossulus* and *M. balthica* and how changes in shell biodeposits can effect environmental biotic and abiotic factors (e.g., sediment composition).

MATERIALS AND METHODS

Bivalves were sampled in 1991 on a monthly basis by dredging five locations of the Gulf of Gdansk characterized by various depth and sediment type (figure 1, table 1).

Thirty specimens of *M. trossulus* and *M. balthica* were analyzed on a monthly basis. Moreover, a *C. glaucum* population was punctually sampled for further comparison on three locations in April. The shell exterior was individually brushed and cleaned to remove fouling organisms then examined under a binocular for occurrence of endolitic organisms. The reduced salinity level (#6 ppt) actually limited endolitic organisms' colonization. After discarding the meat, the shells were rinsed with distilled water and dried to constant weight (12 h) at 60°C.

Although individually measured, the *M. balthica* and *C. glaucum* populations were homogeneous in size ranging from 10 to 15 mm length, while *M. trossulus* shells were divided into two size classes 5 to 25 and 25 to 50 mm. Amount of shell organic matter was estimated by extraction in 0.1M trichloroacetic acid (TCA) (Goulletquer and Wolowicz, 1989). Thirty shells of each species from site and/or class length were taken randomly and individually decalcified in TCA solution at 20°C. The organic content was estimated by filtering the solution on 0.7µm Whatman GF/F (ashed) filter paper. Retained material was rinsed with distilled water and dried to constant weight at 60°C for 48 h (Dame, 1972). TCA extraction was chosen because ignition overestimates the loss of organic matter as shown by Goulletquer and Wolowicz (1989), and TCA - extracted organic matter can be used for other analysis (e.g., biochemical, microcalorimetry).

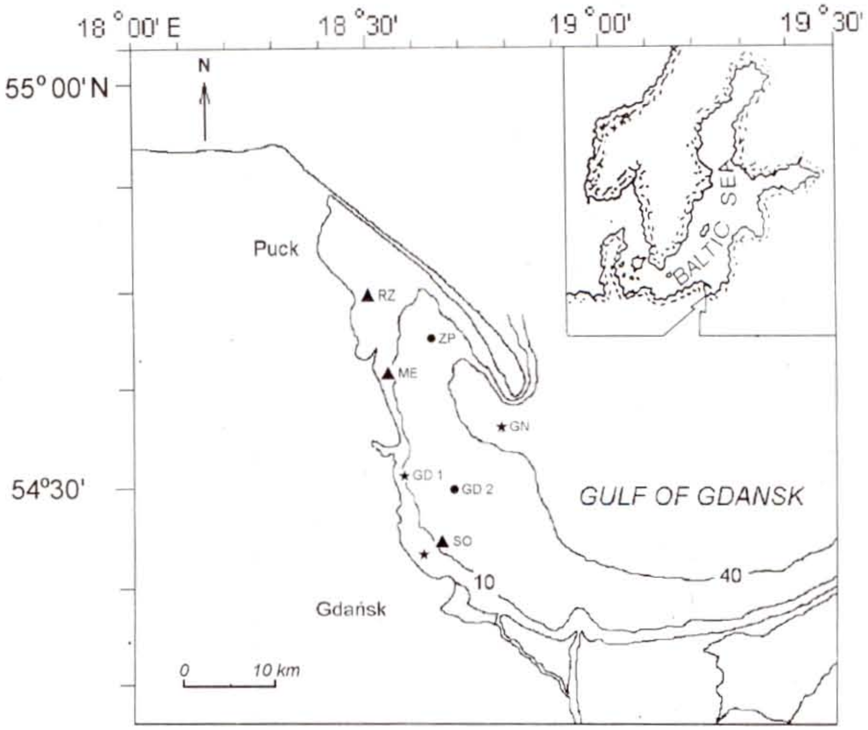

Figure 1. Experimental sites within the Gulf of Gdansk.

Table 1. Characteristics of the sampling sites.

Species	Site	Type of sediment	Depth (m)
C. glaucum	Rzucewo (RZ)	Sand + vegetation	2
	Sopot (SO)	Sand	5
	Mechelinki (ME)	Sand + vegetation	5
M.balthica	Puck Bay (ZP)	sand	15
	Gdynia (GD2)	Muddy-sand	20
M.trossulus	Sopot (SO)	sand	5
	Gdynia (GD1)	sand + vegetation	5
	Gdansk Bay (GN)	mud	40

Energy value of the organic matter was estimated using a microbomb calorimeter type KMB-2 (Phillipson, 1964; Klekowski and Baczkowski, 1973) calibrated with benzoic acid (caloric value 26.473 $J.mg^{-1}$). For each species sample, shell organic matter from 30 individuals were pooled, then pulverized and homogenized. Measurements of aliquots were carried out in triplicate.

Comparisons among species, sites and sampling period were performed using ANOVA's and linear multiple regressions (Statgraphics V.7).

Table 2. Shell organic content and energy values of shell organic matter (mean ± SD).

Species	Site	Samples (n)	% Shell organic matter (± SD)	Energy value (J.mg^{-1}) (± SD)
C. glaucum	RZ	120	0.66 ± 0.02	-
	SO	145	0.45 ± 0.01	24.03 ± 2.87
	ME	150	0.5 ± 0.01	23.73 ± 1.27
M. balthica	ZP	360	5.21 ± 0.54	14.80 ± 1.49
	GD2	360	5.44 ± 0.52	15.50 ± 1.36
M.trossulus	SO	360	5.39 ± 0.44	20.32 ± 1.84
	GD1	360	5.53 ± 0.20	20.29 ± 1.48
	GN	360	5.92 ± 0.44	19.91 ± 1.59

Table 3. Seasonal changes of *M. trossulus* shell organic content (%) (± standard deviation).

Site	SO		GD1		GN	
Size range (mm) Month	5 – 25	25 - 50	5 - 25	25- 50	5 -25	25 - 50
Jan	4.70 (0.16)	4.93 (0.21)	5.40 (0.1)	5.46 (0.1)	5.47 (0.1)	6.27 (0.21)
Mar	5.44 (0.11)	5.65 (0.15)	5.45 (0.1)	5.65 (0.14)	5.53 (0.09)	5.79 (0.11)
Apr	5.74 (0.16)	5.89 (0.18)	5.57 (0.1)	5.75 (0.09)	5.83 (0.12)	6.53 (0.13)
Aug	5.17 (0.16)	5.27 (0.17)	5.31 (0.12)	5.32 (0.11)	5.35 (0.08)	5.57 (0.08)
Nov	5.82 (0.16)	5.96 (0.18)	5.75 (0.09)	5.84 (0.11)	5.74 (0.12)	6.75 (0.11)
Dec	4.77 (0.16)	5.30 (0.24)	5.21 (0.14)	5.65 (0.11)	5.74 (0.09)	6.24 (0.14)
Average	5.27 ± 0.48	5.50 ± 0.40	5.45 ± 0.19	5.61 ± 0.19	5.61 ± 0.19	6.19 ± 0.44

Table 4. ANOVA table for the shell organic content (%) function of the 3 variables 'site', 'length', and 'month'.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Main effects					
Site	36,7153	2	18,3577	382,32	0,000
Length	40,5579	43	0,943206	19,64	0,000
Date	55,4287	5	11,0857	230,87	0,000
Residual	49,4088	1029	0,0480163		
Total	215,747	1079			

RESULTS

Shell organic content

Shell organic matter contents were quite similar between both species *Macoma balthica* and *Mytilus trossulus* ranging from 5.21% to 5.92% respectively (table 2). In contrast, organic content of *C. glaucum* shell was limited varying from 0.45 to 0.66%.

Monthly data, sites and size comparisons were carried out on *M. trossulus* shell organic content (table 3). The ANOVA table demonstrates that all factors, 'site', 'length' and 'date' have a statistically significant effect on the shell organic percentage at 95% confidence level (table 4). Each component effect is reported on figure 2. All the information were combined and a highly significant multiple linear regression model was established explaining 45% of the variance ($P<0.01$). The output shows the results of fitting this model to describe the relationship between the organic content percentage and the three independent variables (figure 3). The equation of the fitted model is:

$$\text{Organic content} = 4.5501+0.240658*\text{site} + 0.01202*\text{date} + 0.01851*\text{length}$$

Therefore, percentage of organic matter on small shell size (5-25mm) was significantly lower compared to large shell (25-50mm), and a significant trend of increasing organic percentage was reported from sandy to muddy areas concomitant to increased depth (table 1, figures 1,2). With regard to the monthly data, shell organic percentage showed a consistent increasing trend along the year but august and december data (figure 2). In contrast to *M.trossulus*, shell organic percentage of *M.balthica* did not show any significant difference between sites (table 5). Organic shell content tended to vary among species, reaching the higher (5.73%) and lower (4.78%) values in spring and summer for *M.balthica* (table 5).

Energy value of shell organic matter

Significant differences among species were noted with regard to the energy value of the organic matrix. The energy varied from a 14.8 $J.mg^{-1}$ minimum value for *M. balthica* from the Puck Bay (ZP) to a 20.32 and 24.03 $J.mg^{-1}$ maximum values for *M. trossulus* and *C. glaucum* from Sopot (SO) respectively (table 2).

Energetic values of the organic matrix were quite similar among sites for *M. trossulus* and were not related to sediment type (table 6). Although not significant, energy values for this species tended to be lower for larger shell (25-50 mm) (table 6). Moreover, a seasonal increasing trend over month was noted for the energy value of *M. trossulus* shell organic matter (table 7).

Table 5. Seasonal changes of shell organic content (%) (± standard deviation).

Species	*Macoma balthica*	
Site	ZP	GD2
Month		
Apr	5.63	5.73
May	5.97	5.73
Jun	5.09	4.89
Jul	4.78	5.02
Sep	5.02	5.16
Oct	5.21	5.17
Average	5.28 ± 0.44	5.28 ± 0.36

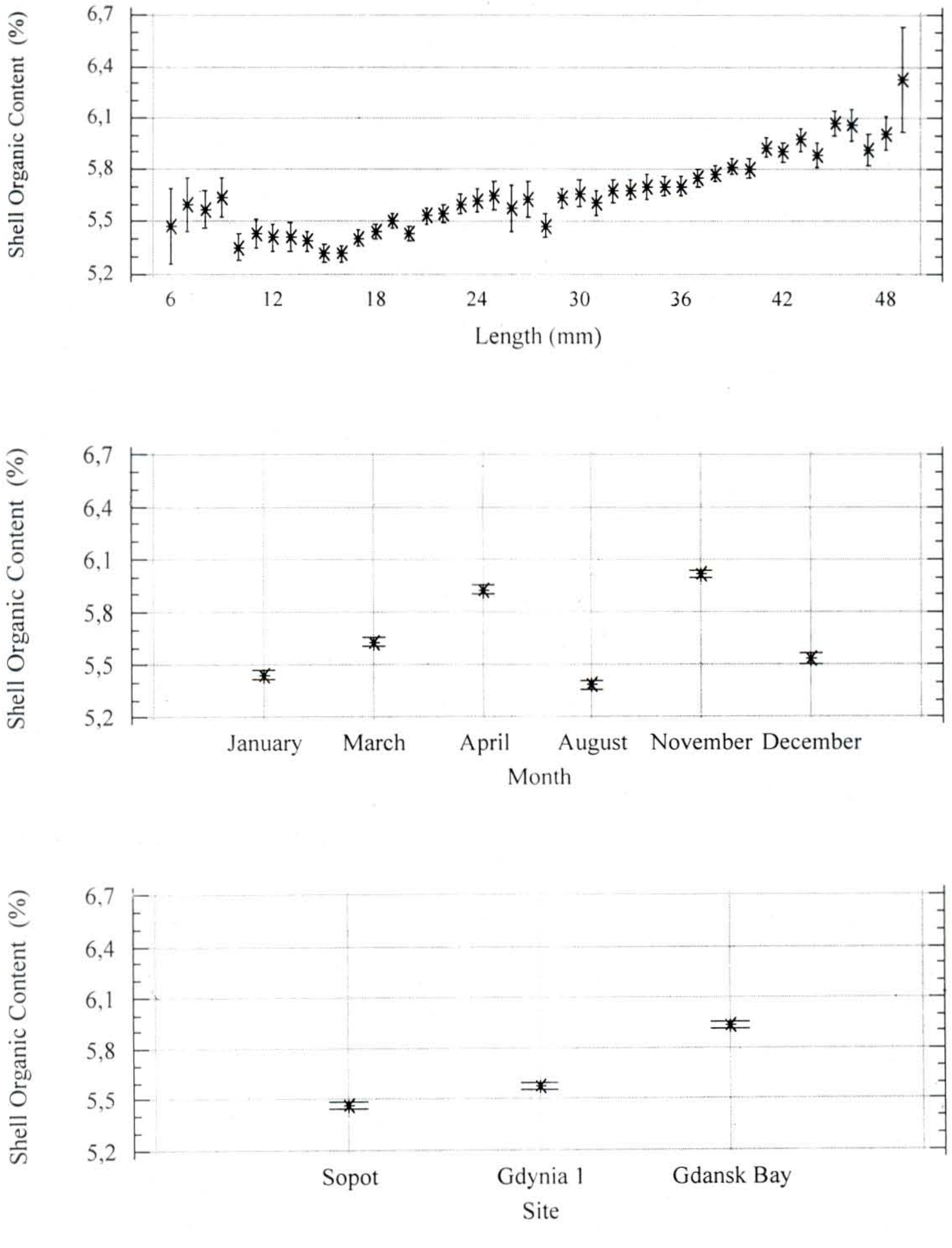

Figure 2. ANOVA results: 'length', 'month', and 'site'component effect on shell organic content (%)

Table 6. Energy value of *M. trossulus* shell organic matter from different type of sediment and animal size.

Nature of sediment	Size of animals (mm)	Energy value (J.mg^{-1})
Sand	5 - 25	21.09 ± 1.33
	25 - 50	19.55 ± 2.03
Vegetation	5 - 25	20.59 ± 1.08
	25 - 50	19.99 ± 1.86
Mud	5 - 25	20.90 ± 1.44
	25 - 50	18.92 ± 1.06

Table 7. Seasonal changes of energy value (J.mg^{-1}) in shell organic matter (mean).

Species	*Macoma balthica*		*Mytilus trossulus*		
Site	ZP	GD2	SO	GD1	GN
Month					
Jan	-	-	19.45	18.24	19.19
Feb	-	-	-	-	-
Mar	-	-	18.67	19.43	20,15
Apr	15.97	16.63	18.82	19.43	21.54
May	16.37	16.34	-	-	-
Jun	13.88	14.24	-	-	-
Jul	12.49	14.04	-	-	-
Aug	-	-	22.20	20.99	19.89
Sep	14.05	14.33	-	-	-
Oct	14.43	15.43	-	-	-
Nov	-	-	22.16	21.14	20.53
Dec	-	-	20.59	20.24	18.19
Average	14.53 ± 1.43	15.17 ± 1.13	20.32 ± 1.59	19.91 ± 1.10	19.92 ± 1.15

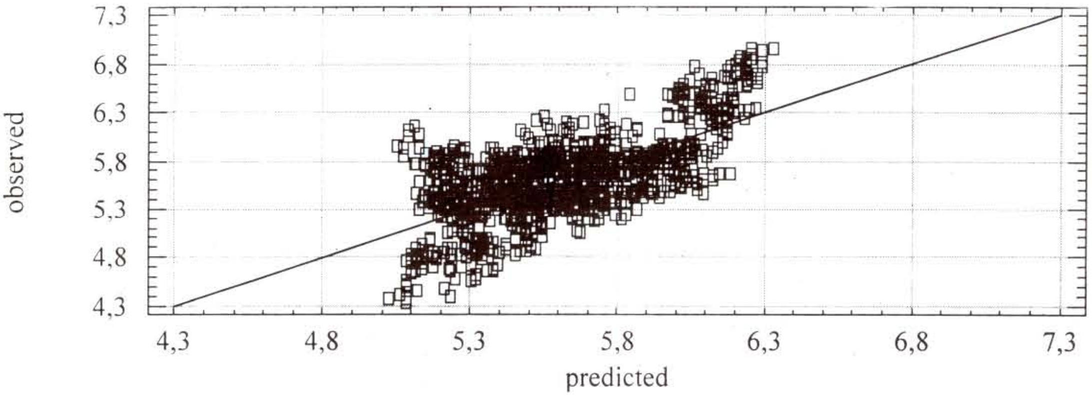

Figure 3. Multiple linear model of *M. trossulus* shell organic content function of shell length, site (1=Sopot; 2=Gdynia; 3=Gdansk Bay), and date.

Table 8. Percentage of shell organic matter in bivalve species.

Species	% of shell organic content	Method used	Author
Cardium edule	2.04	ignition	Hibbert, 1976
	0.53	chemical extraction	Goulletquer, Wolowicz,1989
Cerastoderma glaucum	1.43	"	Ivell, 1979
	0.43	"	Goulletquer,Wolowicz, 1989
	0.54	"	this study
Crassostrea virginica	0.896	"	Dame, 1972
Macoma balthica	5.32	"	this study
Mercenaria mercenaria	2.35	ignition	Hibbert, 1977
Mytilus edulis	3.0	?	Thompson, 1984
	5.0	?	Dare, 1975
	6.2	ignition	Kautsky, 1981
Mytilus trossulus	5.61	chemical extraction	this study
Ruditapes philippinarum	0.97	"	Goulletquer,Wolowicz, 1989
Scrobicularia plana	0.4	?	Hughes, 1970
Venerupis aurea	2.55	ignition	Hibbert, 1976

Table 9. Percentage of energy acumulated in shell organic matter and soft tissue of standard *Macoma balthica* (17 mm, 160.6 mg) (Szaniawska *et al.*,1986), *Cerastoderma glaucum* (15 mm, 461.9 mg) (Wolowicz, 1991) and *Mytilus trossulus* (15 mm, 42.9 mg) (Cuena Barron & Wolowicz, 1981).

Species		*M.balthica* (Szanawska *et al.*, 1986)	*C.glaucum* (Wolowicz, 1991)	*M.trossulus* (Cuena Barron & Wolowicz, 1981)
Shell	weight (mg)	138.0	420.7	36.8
	% organic matter	5.32	0.54	5.44
	energy value (J.mg^{-1})	15.20	23.73	20.84
	total energy (J.mg^{-1})	111.60	53.90	41.70
Tissue	weight (mg)	22.60	41.20	6.10
	energy value (J.mg^{-1})	23.58	22.15	23.78
	total energy (J.mg^{-1})	523.90	912.60	145.10
Energy %	shell	17.6	5.6	22.3
	tissue	82.4	94.4	77.7

DISCUSSION

The estimate of shell organic content are correlated with the species and the method used (for critical review, see Goulletquer and Wolowicz, 1989).

The results obtained in this study were within the range reported in the literature for other bivalves species (table 8). By way of example, *Macoma balthica* and *Mytilus trossulus* showed higher values than for *Cardium edule* (9.6%) and *Ruditapes philippinarum* (14.4%) (Goulletquer and Wolowicz, 1989). Moreover, cockles' data in this study were similar to those for *C. glaucum* (5.2%) originating from the Marennes-Oleron Bay (France)

The organic content in the shell of *M. trossulus* was correlated with the sediment type: the organic content increased correlatively with sediment softness. Therefore, muddy sediment led to increased shell organic content. This is likely due to the organic load at the sediment level in contact with the periostracum containing most of the organic matter (Wilbur and Simkiss, 1968).

A relationship between the seasonal shell organic content from *M. trossulus* and *M. balthica* and phytoplankton as well as chlorophyll content (spring and autumnal bacillariophycae bloom were reported by Pliñski *et al.*, 1982 and Latala, 1985 respectively). Seasonal changes of *M. trossulus* shell organic content showed the same pattern in our study. Food characteristics and availability were likely responsible for this pattern in addition to increased seawater temperature, responsible for the overall shell growth pattern. In contrast to Price *et al.* (1976) on bivalves, shell organic content tended to increase with age in the present study. However, energetic value of shell organic matter did not show any seasonal pattern in contrast to data on *Mercenaria mercenaria* from S. England (Hibbert, 1976).

The energetic value of shell organic matter is specific and shows a similar and concomitant seasonal change between shell organic content and soft parts (Wenne and Styczyñska-Jurewicz, 1985; Wolowicz, 1991; Szaniawska *et al.*, 1986). Although not significant, a global and similar trend was noted with regard to energetic value.

Kennedy *et al.* (1969) and Gregoire (1972) showed that the shell matrix is composed mainly of soluble and insoluble parts of proteins and glycoproteins and that their proportion varies according to species and environmental conditions. For this reason, the energy value of the shell matrix appears to be correlated with trophic conditions. Therefore, smaller/younger specimens showing higher energy turnover tend to have higher energy value for shell organic matter.

The shell organic content and their energy value play a critical role in bivalve's energy budget. Since the *C. glaucum* shell represents 91.5% of dry weight, the overall energy mobilized in shell matrix remains important in spite of its low organic concentration (Wolowicz, 1984). By way of example, energy computation per species using a "standard animal" specified by an average size, shows that the percentage of energy accumulated in the shell represents 5.4% to 22.3% of the total energy content in *C. glaucum* and *M. trossulus* respectively (table 9). Since individuals less than 25 mm length represent up to 90% of the mussel population in the Gulf of Gdansk, a significant energy accumulation results from dead animals deposits at the sediment level (Cuena Barron and Wolowicz, 1981). By way of example, a common average 700 g mussel biomass per m^2 would therefore lead to 0.8 $kJ.m^{-2}$ energy stored in shell deposits at the sediment level.

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