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ABSTRACT

Ocean Quahogs, *Arctica Islandica,* were collected over one year on a monthly basis from Kiel Bay, Western Baltic. The largest Quahog found during this study measured 75.1 mm. Statistically significant month to month variations in dry soft tissue weight and condition index were observed. The main period of increase in dry soft tissue weight was from May through September. Maximum weights were observed in September and minimum ones in March. The ratio between the two parameters was about 2:1, respectively. Soft tissue weight and condition index variations were most probably due to phytoplankton blooming and preparation for spawning. The regression equation of shell length (mm)-dry soft tissue weight (g) for *Arctica Islandica* in Kiel Bay was found to be as follows:

$\ln(\text{weight}) = -5.133 + 2.903 \ln(\text{length}) \quad (r = 0.971, P < 0.0001)$

ملخص

لقد تم في هذه الدراسة جمع عينات شهرية للمحـــار المعــروف باســم ***Arctica Islandica*** و ذلك على مدار عام من خليج كيل، غرب بحر البلطيق. وقد بلغ طــول الصدفة لأكبر عينة جمعت خلال هذه الدراسة ٧٥.١ ملم. وأظـــهرت التحليــلات الإحصائية للعينات وجود تباين في وزن الأنسجة و في الحالة الغذائية للمحار علـــى

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مدار العام؛ إذ إن وزن أنسجة المحار بدأ في الزياده في بداية شهر أيار حتى بلـــغ الحد الأعلى في شهر أيلول . أما أقل وزن فقد كان في شـــهر آذار، و قـــد بلغـــت النسبة بين الوزنين الأكبر والأصغر اثنين إلى واحد. و عليه فان التباين الحـــاصل في وزن أنسجة المحار و في حالته الغذائية مرتبط، على ما يبـــدو، بنمـــو الـــهوائم النباتية و التغيرات الفسيولوجية المصاحبة لعملية إنتاج الجاميتات. وأخيرا فقد تم فـــي هذه الدراسة حساب معادلة الانحدار بين طول الصدفة (ملم) ووزن الأنسجة (غـــم) للمحار من النوع المذكور من خليج كيل حيث وجدت على النحو التالي:

ln (وزن) = - 5.133 + 2. 903 ln (الطول) (r = 0.971, P < 0. 0001)

INTRODUCTION

The Ocean Quahog, *Arctica (Cyprina) Islandica* (Linneaus 1767), is a large bivalve mollusc with a thick, heavy shell which reaches a maximum length of 13 cm (Witbaard & Duineveld 1990). This mollusc is widely distributed through the boreal Atlantic and adjacent areas, the North Sea and in the Western Baltic (Jagnow & Gosselck 1987). In Kiel Bay, *A. Islandica* is a very important species of the benthic community with regard to biomass as well as production (Brey et al. 1990) dominating the biomass of the benthic community below water depths of 15 m (Arntz 1980). Moreover, this species constitutes an important part of the diet of commercially important fish. In terms of wet weight, it is estimated that *A. Islandica* contributes to 27% of total food intake of juvenile cod, 52% of adult cod, 14.1% of dab, 3.5% of whiting and 3.6% of plaice (Arntz 1973, 1974, 1977, 1980, Arntz & Weber 1970).

Arctica Islandica belongs to the slowest-growing and longest-lived of the pelecypods (family Arcticidae) (Forster 1981, Murawski et al. 1982). The largest Quahog ever-recorded from the Western Baltic measured 74 mm with an estimated age of 23 years (Brey et al. 1990) while individuals from the Atlantic may reach an age of > 100 years and a length of > 100 mm (Thompson et al. 1980a, Murawski et al. 1982).

The Biology and ecology of *A. Islandica* along the North American east Coast have been intensively studied (Loosanoff 1953, Murawski & Serchuk, 1979, Wenzloff et al. 1979, Thompson et al. 1980a, b, Jones 1981, Mann 1982, Murawski et al. 1982, Steimle et al. 1986, Kraus et al. 1989, Rowell et al. 1990, Fritz 1991). Studies on the

Baltic population of *A. Islandica* are, on the other hand, limited. Ecological significance, growth and production of *A. Islandica* from Kiel Bay were studied by Brey et al. (1990). Other studies examined resistance to oxygen deficiency and hydrogen sulfide tolerance (Theede et al. 1969), the reproductive cycle (Von Oertzen 1972) and metal contamination (Swaileh and Adelung 1994). The main objective of this paper is to provide information about body parameters, seasonal variation in dry soft tissue weight, condition index and the shell length-soft tissue weight relationship of *A. Islandica* in Kiel Bay.

MATERIALS AND METHODS

Sampling Protocol and Preparation of Samples:

Samples of *A. Islandica* (n=978) were caught by dredging on a monthly basis from central Kiel Bay at depths ranging between 21 and 23m. Sampling was carried out over a one-year period that started in July 1992 and ended in June 1993. Quahogs were cleaned of mud, frozen and transported to the laboratory. In the laboratory, specimens were thawed before shell morphometrics, tissue weights and condition indices were determined (Table 1).

Statistical Treatment of the Data:

All tissue weight measurements refer to the dry weight of soft tissues. Statistics were performed using SYSTAT statistical software package on a PC (Wilkinson 1992). In order to investigate month-to-month variations in dry soft tissue weight and condition index, only specimens having shell lengths between 30 and 60 mm were selected. Normal distribution of the data was tested with Kolmogorov-Smirnov test. Analysis of variance (ANOVA) was applied to investigate statistical differences in shell length, dry soft tissue weight and condition index. Where significant differences were observed, the Tukey test was used for pairwise comparisons. For shell length-soft tissue weight relationship analyses, animals of all sizes were considered. The shell length-soft tissue weight equation for bivalve molluscs is assumed as:

$$W = aL^b$$ where,

W = soft tissue dry weight (g)

L = shell length (mm)

a and b are constants.

Upon logarithmic transformation, the following linear equation is obtained.

$$\ln (W) = \ln(a) + b \ln (L)$$

RESULTS

During this study, a total of 978 Ocean Quahogs of all available sizes was collected. SumMary statistics of these specimens are given in Table 2. Shell length frequencies are shown in Fig. 1. The largest shell length recorded during the study was 75.1 mm. This largest specimen was collected from muddy sand at a depth of 22m.

Correlation coefficients (r) between each pair of body parameters of all specimens collected were calculated (Table 3). Each correlation was significant at $P < 0.0001$. However, shell measurements were more correlated with each other than to soft tissue weight.

Seasonality in Soft Tissue Weight:

Quahogs analyzed for month to month variations in their soft tissue weight (shell length 30-60mm) did not show any significant difference in their mean shell length, which ranged between 42.9mm in July and 47.1mm in September (Fig. 2a). Their mean soft tissue weight, however, indicated a significant month to month variation ($F_{3,600} = 4.312$, $P < 0.0001$). Specimens collected in September had significantly higher mean soft tissue weight than those captured in November, February, March, April & May (Fig. 2b), whereas all other pairwise comparisons between months were not significantly different (Tukey test). Soft tissue weight first increased in late spring and continued until the maximum (0.707g) was reached in September. Thereafter, a drastic decrease in the mean soft tissue weight began, which extended until November.

Seasonality in Condition Index:

Month to month variations in condition index of Quahogs of 30-60mm shell length were significant ($F_{3,392} = 8.684$, $P < 0.001$). Specimens collected in June and December had significantly higher mean condition index than those collected in other months (Fig. 3). In addition, specimens collected in October had significantly higher condition indices than those collected in February and March. However, condition indices for samples collected in July, August and September were missing because shells were mistakenly discarded before weights were determined.

Shell Length-Soft Tissue Weight Relationship:

Regression equation of shell length (mm) against soft tissue weight (g) was fitted for all specimens collected (n = 978). It was found to be as follows:

$\ln(\text{weight}) = -5.133 + 2.903 \ln(\text{length})$ $r = 0.971$, $P < 0.0001$.

DISCUSSION

According to a growth curve for *A. Islandica* presented by Brey et al. (1990) which was suggested to be representative for the greater part of Kiel Bay, the age of the specimens collected during this study lies between 2 and 23 years. During this study, three specimens were found to have a shell length greater than 74 mm. According to Brey et al. (1990) this was the largest length ever-recorded for this species in the Baltic. Compared to Quahogs from the Northwest Atlantic, which can reach lengths of 110 mm and an age of 221 years (Kraus et al. 1989), *A. Islandica* from Kiel Bay are much smaller and younger. The reasons behind this difference between the two populations are not known, but this could be due to physiological limitations on size caused by some characteristics of the Baltic Sea such as oxygen deficiency and the mesohaline water. (Brey et al., 1990).

The strong correlations between pairs of shell measurements indicate that the shell of *A. Islandica* grows regularly in the three shell dimensions (SL, SW and SH) and in SWT. Shell measurements correlated stronger to each other than to soft tissue weight. This could be attributed to the fact that the rate of growth in the shell and soft tissue do not occur simultaneously (Hilbish, 1986) and that soft tissue weights vary by month, shell size does not.

Seasonality in Soft Tissue Weight:

Seasonal variations in soft tissue weight of molluscs are well-known. They are reported to be due to food availability and gonadal development (Dare and Edwards 1975, Sundet & Vahl 1981, Hilbish 1986, Swartz 1991). In the present study, the main period of increase in soft tissue weight coincided with the period of gonadal development of A. *Islandica* (Jones 1981, Mann 1982, Rowell et al. 1990), and food availability (Graf et al. 1984, Smetacek 1984, Smetacek et al. 1987). The increase in soft tissue weight comes directly after the spring phytoplankton blooming in Kiel Bay. This blooming represents 1/3 of yearly input from the pelagic to the benthic system (Graf et al. 1984, Smetacek 1984, Smetacek et al. 1987). During this period, the sedimented phytoplankton form a green carpet on the seabed. Because this sedimented organic matter is in the form of living cells, its nutritional value is high, making the benthos respond quickly (Graf et al. 1984, Smetacek 1984). The filter feeder *Macoma Balthica* increased its lipid and carbohydrate content significantly during this period (Graf et al. 1982).

Arctica Islandica spawn, thus losing weight, when the bottom water temperature reaches approximately 13.5°C (Loosanoff 1953, Jones 1981). Muus (1973) found the larvae of *A. Islandica* in the Oresund plankton during all months of the year, while Jorgensen (1946) found the greatest number in October and November. In the present study, it is possible that A. *Islandica* started releasing gametes in early September, when bottom water temperature measured at 21m water depth in Kiel Bay reached nearly 13°C (U. Fiedler, IfM, Kiel, pers. comm.). The minimum weight of A. *Islandica* was reached in March after the winter (non-growth) phase of phytoplankton which extends from December to February in Kiel Bay (Smetacek et al. 1987).

Dare and Edwards (1975) studied seasonality in soft tissue weight of *Mytilus Edulis* from Conwy Estuary, North Wales. They found the maximum dry soft tissue weight in summer and autumn, when proteins and carbohydrates were maximum. The weight decreased through winter to a post-spawning minimum in spring. Sundet and Vahl (1981) studied seasonality in the weight of *Chlamys Islandica* from Balsfjord, northern Norway. They found the maximum total weight of soft tissues (except gonad) in August and maximum gonadal weight in June. Swartz (1991) studied seasonality in the tissue weight of *Macoma Balthica, Scrobicularia Plana, Mya Arenaria* and *Cerastoderma edule* from the Dutch Wadden Sea. He found the maximum body weight of all four bivalve species in May and June and the lowest weight in November to March. The highest weight was about twice as much as the lowest one. Results of the above-mentioned studies are in reasonable agreement with the results obtained in this study. However, Fritz (1991) studied seasonality in soft tissue weight of *A. Islandica* (Standard size = 95mm shell length) off New Jersey. He observed no clear seasonal variation in soft tissue weight. He mentioned the lack of synchrony of reproductive cycles of individual bivalves at a given site to be a possible explanation.

Seasonality in Condition Index:

Condition index (Fig. 3), indicating the nutritional state of an individual, shows similar results to those obtained from soft tissue weight (Fig. 2). The nutritional state of *A. Islandica* started improving in late spring. According to the available results and as can be expected, the nutritional state of *A. Islandica* was deteriorated in winter since molluscs undergo an obligatory period of winter starvation due to low plankton biomass during this period (Bayne & Newell 1983, Smetacek et al. 1987). However, it is difficult to conclude about the condition indices in July, August & September since the data were missing. The nutritional state of *A. Islandica* is expected to be high since soft tissue weight during this period was increasing.

Shell Length-Soft Tissue Weight Relationship:

Bearse (1976) calculated the shell length-soft tissue weight relationship for *A. Islandica* from Rhode Island as:

$\log(weight) = -3.0391 + 2.355 \log(length)$, $n = 129$

Murawski and Serchuk (1979) calculated the same relationship for *A. Islandica* from the Middle Atlantic Shelf as:

$\ln(weight) = -9.5896 + 2.888 \ln(length)$, $n = 2564$

In the present study, *A. Islandica* from Kiel Bay were found to have the following relationship:

$\ln(weight) = -5.133 + 2.903 \ln(length)$, $n = 978$

The regression slope calculated for Quahogs from Kiel Bay (2.903) and that calculated for Quahogs from the Middle Atlantic Shelf (2.888) are very close to each other. This could be an indication for similar growth pattern even though both populations differ largely in potential size and age as indicated in the literature and shown here by the different intercepts (-5.133 & -9.5896). Although, the regression equation calculated by Bears (1976) based on Log_{10} transformation, comparing his slope (2.355) with the above mentioned slopes is still possible since the slope is not affected by any type of data transformation, but the intercept will vary. The slope for Quahogs from Rhode Island seems to be lower than those calculated in this study and by Murawski and Serchuk (1979). This could be due to either different growth pattern or to the small sample size he used (n=129).

Finally, in spite of the harsh Baltic Sea environment i.e. the mesohaline water, frequent oxygen deficiency periods in bottom waters especially in summer and the great salinity variations during the year, *A. Islandica* in the Baltic Sea still share some common growth patterns with *A. Islandica* from other stable Marine habitats like the north west Atlantic. Moreover, results of the present study are in accordance with literature published for other bivalves. However, populations of *A. Islandica* from the Baltic and the Atlantic are clearly different in their mean age and size.

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Table 1: Description of methods used for assessment of shell morphometrics, shell weight, soft tissue weight and condition index of individual Ocean Quahog, *Arctica Islandica.*

Shell Length (SL):	greatest antero-posterior distance measured to the nearest 0.1 mm.
Shell Width (SW):	greatest distance through both valves measured to the nearest 0.1 mm.
Shell Height (SH):	greatest distance from umbo to ventral shell Margin (not perpendicular to SL) measured to the nearest 0.1 mm.
Shell Weight (SWT):	dry shell weight determined to the nearest 0.1 mg after being oven-dried for two days at 60°C.
Dry Body (meat) Weight (DBW):	weight of the whole soft dry tissues determined to the nearest 0.1 mg after 1 week of freeze-drying followed by oven-drying at 60°C for 2 days.
Condition Index (CI%):	DBW/(DBW + SWT)*100

Table 2: SumMary statistics of *Arctica Islandica* specimens collected during this study from Kiel Bay. For abbreviations see Table1.

N =	SL (978)	SW (978)	SH (978)	SWT (733)	DBW (978)	C1% (733)
Minimum	10.8	5.8	9.4	0.11	0.001	0.82
Maximum	75.1	63.7	71.0	39.82	2.753	18.01
Mean	42.5	22.2	37.2	7.77	0.520	5.85
Standard error	0.5	0.29	0.45	0.30	0.016	0.06

Table 3: Correlation coefficients (r) for $\log_e$ values of each pair of morphometric and weight measurements for *Arctica Islandica* specimens (n = 978, except for SWT where n = 733). Correlation coefficients were significant at $P < 0.0001$. For abbreviations see Table 1.

	SL	SW	SH	SWT
SW	0.991			
SH	0.996	0.991		
SWT	0.993	0.994	0.995	
DBW	0.971	0.972	0.973	0.977

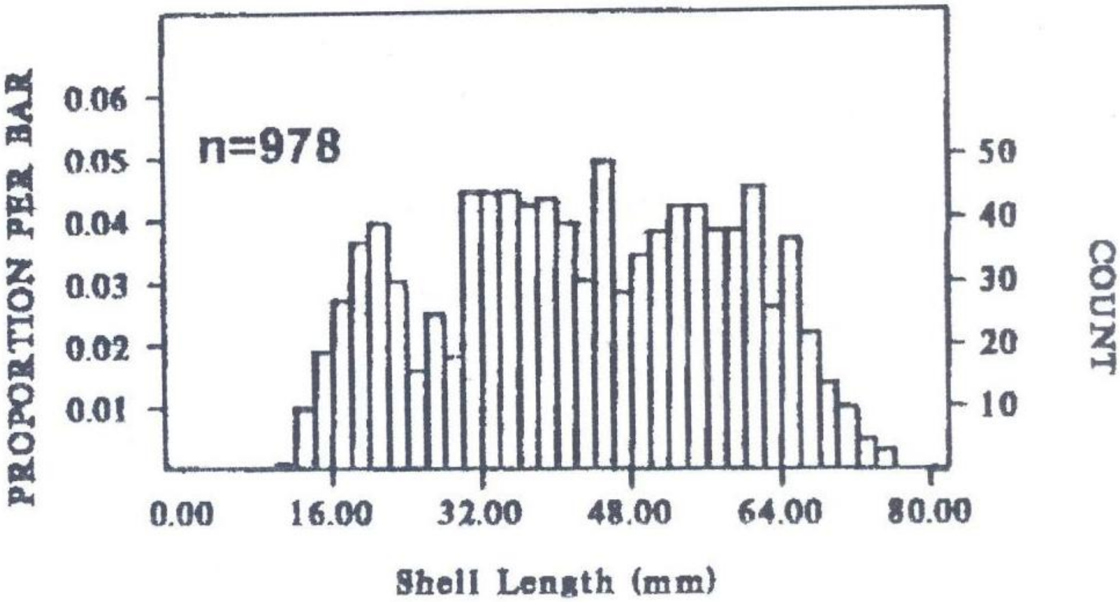

Fig. 1. Length frequency distribution of Arctica islandica from Kiel Bay, Western Baltic.

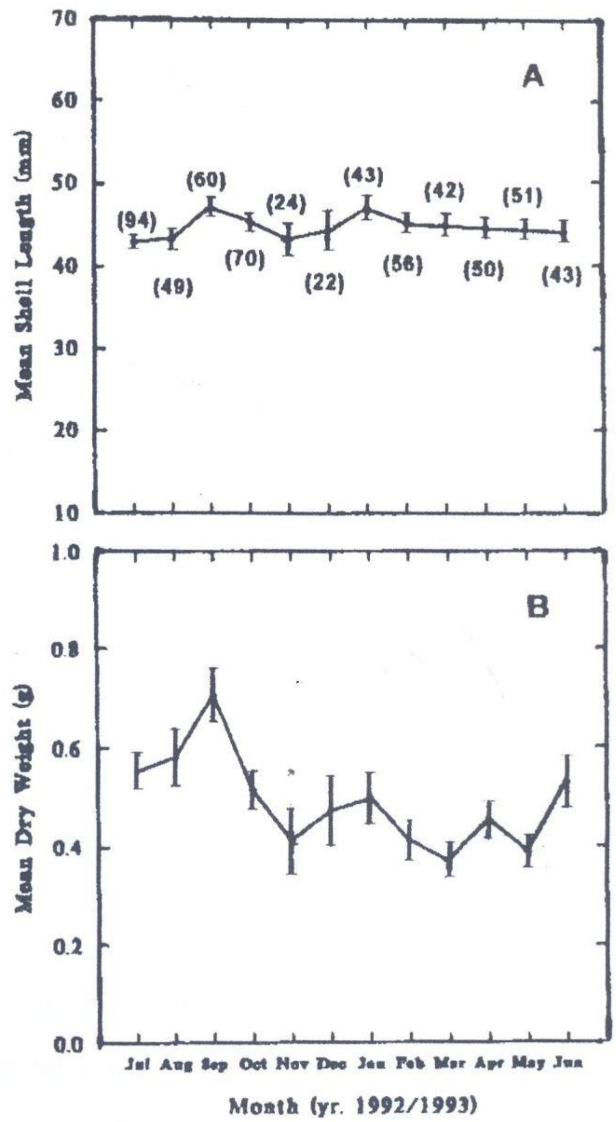

Fig. 2. Month to month variation in the dry meat weight of *Arctica islandica* (shell length 30-60 mm) collected from Kiel Bay from July 1992 through June 1993. Mean shell lengths of samples compared were not significantly different (a). Mean dry weights were significantly different at $P < 0.0001$ (b). Presented are means ± SE and number of specimens (in brackets).

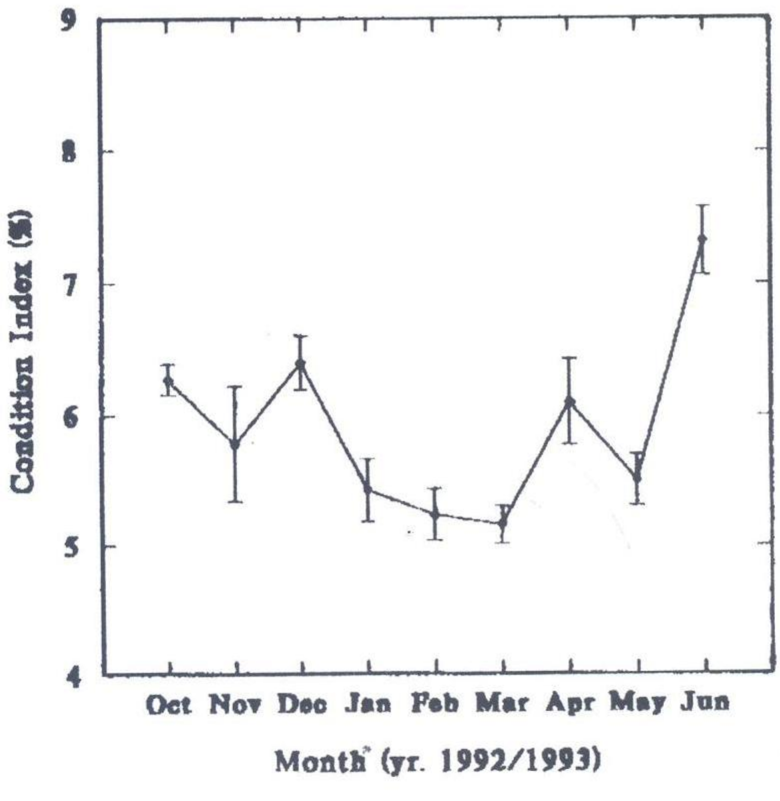

Fig. 3. Month to month variation in condition index of *Arctica islandica* (shell length 30-60 mm) collected from Kiel Bay from October 1992 through June 1993. Mean condition indices were statistically different ($P < 0.001$). Presented are mean condition indices (%) ± SE. For number of specimens analyzed each month see Fig. 2a.