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ECOLOGICAL AND MORPHOLOGICAL FEATURES OF THE BIVALVE *ASTARTE BOREALIS* (SCHUMACHER, 1817) IN THE BALTIC SEA NEAR ITS GEOGRAPHICAL RANGE

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ABSTRACT During 1999 and 2000 macrozoobenthos surveys were made in the Mecklenburg Bight (western Baltic Sea). In total 116 stations were investigated between March and September. *Astarte borealis* showed a wide distribution at depths between 12 and 26.5 m. Mean abundance at these depths was 47 ind./m^2 with a biomass (AFDW) of 0.5 g/m^2. Maximum densities observed at these depths were 541 ind./m^2 and 16 g/m^2, respectively. In comparison to a data set of the 1960s, a decreased *A. borealis* population was found. *A. borealis* ranged from 1.2 to 28.7 mm in shell length. Most (78%) individuals in the population measured <10-mm shell length, indicating strong recruitment in the Bight during recent years. Larger size classes (>20 mm) were observed only sporadically and in low numbers. Shell length to wet weight and ash free dry weight correlations are given. Mean wet meat yield was 14.5%. The individual ash free dry weight decreased with increasing shell length from 9.1% (<5 mm) to 5.6% (>25 mm) with a mean value of 7.4%. All results were compared with data from populations in Russian Arctic and adjacent waters.

KEY WORDS: *Astarte borealis*, distribution, abundance, size, meat yield, Baltic Sea, Mecklenburg Bight

INTRODUCTION

The bivalve, *Astarte borealis*, is an arctic-boreal species that occurs in Arctic, North Atlantic and adjacent waters (Zettler 2001). Some data are known from the North Pacific waters such as Japan, Sea of Ochotsk, Behring Street, British Columbia and at the Aleutian Islands (e.g., Coan et al. 2000; Higo et al. 1999; Skarlato 1981). *A. borealis* find its most extensive distribution in Arctic waters of Russia (e.g., Antipova 1978; Filatova 1957; Gagaev 1989; Matveeva 1977). It extends from the Barents Sea, via Kara and Laptev Sea to Chukchi Sea and to areas of northern Alaska, Greenland (Ockelmann 1958) and Spitzbergen (Hägg 1904). At the Grand Banks off Newfoundland, it reaches high abundance in sandy bottoms around 130 m depth (Prena et al. 1999). In Europe this bivalve extends from Iceland (Thorarinsdottir 1997) and off Faeroes and Norway (Brattegart & Holthe 1997) to the northern North Sea (Johansen 1916) via Kattegat (Rasmussen 1973) into the western Baltic Sea and reaches there, its eastern limit of distribution in the Bornholm basin (see Fig. 1) (Demel & Mulicki 1954; von Oertzen & Schulz 1973). Thus, the Baltic population represents the most southern occurrence, an outpost of the mainly arctic area of distribution. The largest populations in the Balic are found in the Kiel and Mecklenburg Bights in depths below 15 m (Kühlmorgen-Hille 1963; Schulz 1969; Zettler et al. 2000). *A. borealis* is among the longest living species in the Baltic and is an important indicator of environmental conditions. Beside salinity and sediment structure, oxygen concentration has a strong influence on the composition of Baltic Sea fauna and flora. Although *A. borealis* is highly resistant to oxygen depletion (von Oertzen 1973; Oeschger 1990) frequent and long lasting periods of anoxic conditions finally diminish or kill the species. This has resulted in a severe decrease of the Baltic Sea population of *A. borealis* during recent decades in the deeper parts of the Mecklenburg Bight (Gosselck et al. 1987; Schulz 1968).

Information on the population biology and morphological features (growth, age, size) of this species is limited. Some investigations on production, growth, population size, and morphological features were carried out in Russian Arctic Waters (Antipova 1978; Gagaev 1989; Matveeva 1977). Within the framework of an autecological analysis of glacial relict species in the Baltic Sea, investigations on the reproduction of *A. borealis* were carried out in addition to experiments concerning its resistance and metabolic adaptations (von Oertzen 1972, 1973; von Oertzen & Schulz 1973). Schaefer et al. (1985) studied biometric features of *A. borealis* in Kiel Bight, the westernmost part of the Baltic Sea. They investigated several relationships between shell length and weight and their applicability for taxonomical distinguishing of species of the genus *Astarte*.

The purpose of this study was to investigate the distribution, frequency and biomass of *A. borealis* in Mecklenburg Bight as the first extensive study on the population characteristics of this important indicator species near its geographical range. A further aim was to compare these results with existing data of the 1960s compiled by Schulz (1969). From one monitoring station (stn. 018), we have a long time data set to show the development of *A. borealis* within the last decades.

Area of Investigation

The Mecklenburg Bight is part of the Belt Sea and belongs to the transition area between North Sea and Baltic Sea (Fig. 1 and Fig. 2). It is connected with Kiel Bight via Fehmarnbelt and with Kattegat via the Belts. To the East, the Kadet Trench crossing the Darsser Rise connects it with the Baltic proper.

During 1999 and 2000 macrozoobenthos surveys were made in the Mecklenburg Bight. In total 116 stations were sampled between March and September (Fig. 2). Station depth ranged from 5 to 29.6 m. The sediment varied from fine sand at the shallowest stations to sand mixed with silt and clay at the deepest stations. Sediment characteristics and current data for the area have been published by Lange et al. (1991).

MATERIALS AND METHODS

Profiles of salinity were recorded throughout the water column using a CTD (conductivity/temperature/depth probe) system. Samples for bottom water oxygen were taken with a 5-l water sampler (mounted on the CTD) at 0.5 m above the bottom and oxygen levels determined by Winkler titration. Benthic samples were taken with a 0.1 m^2 Van Veen grab. Due to sediment conditions, grabs of different weights were used. Three replicates of

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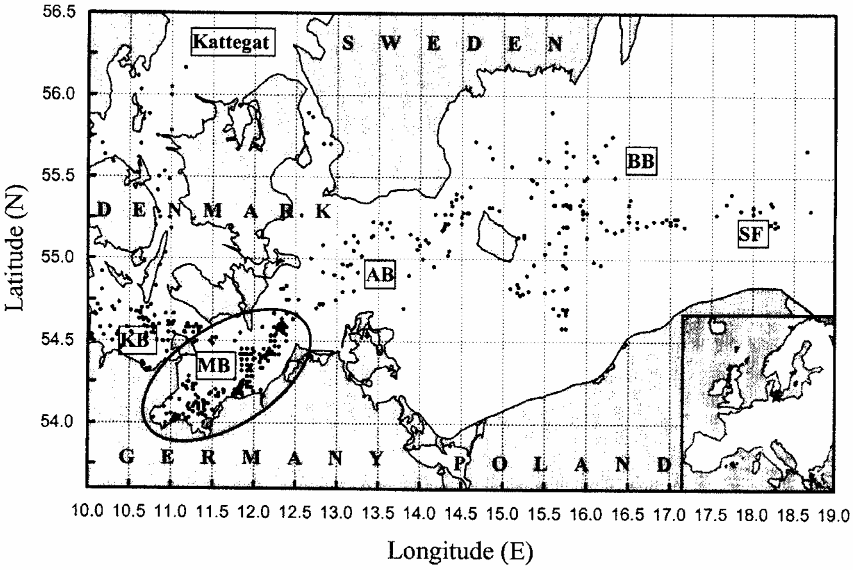

Figure 1. Distribution of *Astarte borealis* within the Baltic Sea. The sources of the data are Demel and Mulicki (1954), Kühlmorgen-Hille (1963), Löwe (1963), von Oertzen and Schulz (1973), Petersen (1918) and own observations. Due to a strong decrease and wide disappearance of this species mainly in the Bornholm and Arkona Basins not all dots represent recent locations. (KB-Kiel Bight, MB-Mecklenburg Bight, AB-Arkona Basin, BB-Bornholm Basin, SF-Slupsk Furrow, circled area refer to the present study and Fig. 2).

grab samples were carried out at each station. The samples were sieved through a 1-mm screen and animals preserved with 4% formaldehyde in the field. For sorting in the laboratory a stereo-microscope with 10–40× magnification was used.

The shell length of all collected individuals was measured with a vernier calipers to the nearest 0.1 mm for the length-frequency distribution and the length-meat weight relationship. In total about 414 specimen were measured. The valves and the wet meat of the

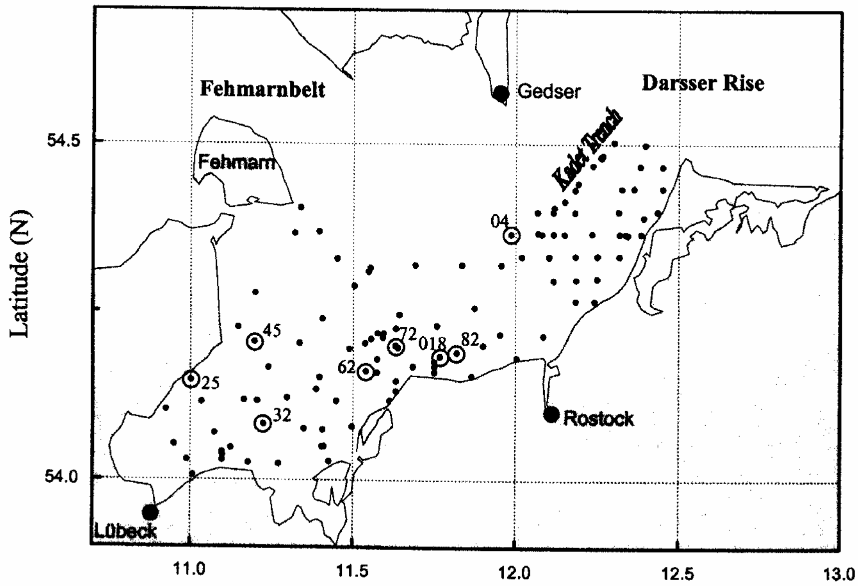

Figure 2. A map showing the investigation area with 116 stations in the Mecklenburg Bight (circled stations refer to text and Figs. 5 and 8).

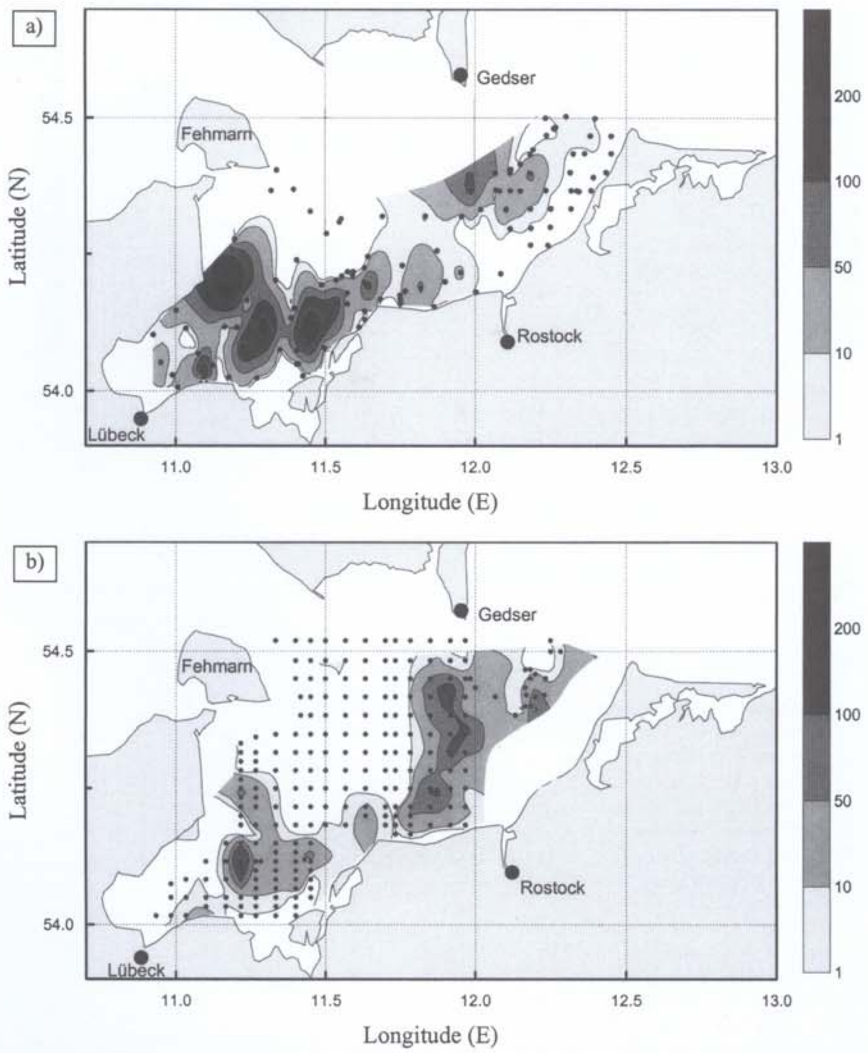

Figure 3. Distribution of *Astarte borealis* (ind./m²): (a) in 1999/2000 and (b) during the investigation period 1962–1965 (Schulz 1969).

specimen were weighted separately. Dry weight (DW) and ash free dry weight (AFDW) were determined to the nearest 0.01 mg. Length-frequency distribution for each station was calculated for 5 mm size classes. For the shell length to height relationship, 221 individuals from the 1999/2000 survey and 49 valves of *A. borealis* from the Zoological Collection of the University of Rostock (sampled in the 1980s from the Mecklenburg Bight) were measured.

The distribution map of *A. borealis* in the Mecklenburg Bight was made using Surfer 7.0 programme of Golden Software Inc. The recent distribution was compared with the results from Schulz (1969), whose data were transformed into the Surfer program to obtain a comparable map. For the long time series (1985 to 2000) of the monitoring station 018, the data of the Baltic Sea Research Institute Warnemünde and data from literature were used (Al-Hissni 1989; Voigt 1991).

RESULTS

Bottom Water Variables

Salinity throughout the water column ranged between 7.5 and 27.8 psu, while bottom water salinity of areas inhabited by *A. borealis* varied between 11.0 and 26.3 psu in 1999/2000. No oxygen depression was observed during the surveys. Up to a depth of 18 m, more than 5.0 mg/l oxygen was measured. In deeper parts of the Bight the oxygen content decreased to a minimum of 1.0 mg/l. *A. borealis* were found in an oxygen range of 1.5 to 8.1 mg/l. The

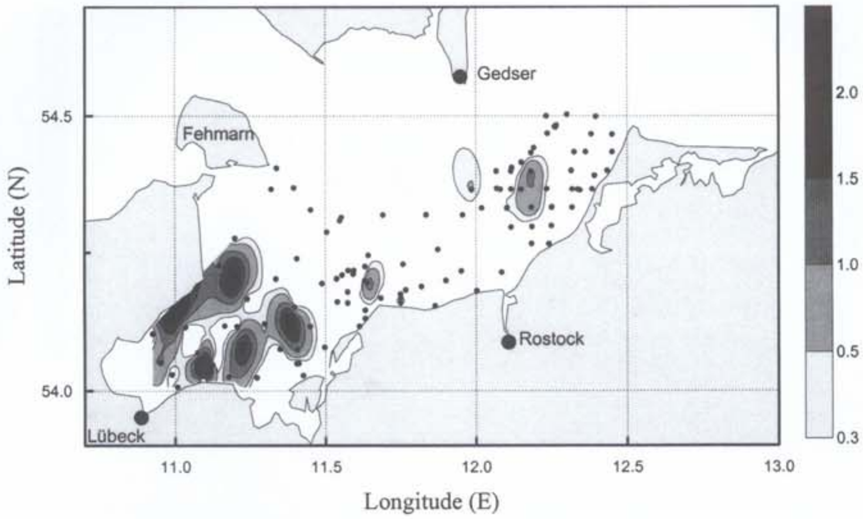

Figure 4. Biomass distribution of *Astarte borealis* (AFDW g/m²) in 1999/2000.

mean oxygen content in areas inhabited by the bivalve was 6.27 ± 1.98 mg/l.

Distribution, Abundance and Biomass

In 1999/2000, *A. borealis* was distributed between 12 and 26.5 m depth in the Mecklenburg Bight. The species showed a very patchy density distribution (Fig. 3a). In the shallow areas 10 m depth with fine sand sediments, no *A. borealis* were found. Furthermore, the muddy zones of the outer Mecklenburg Bight and the outer Kadet Trench with strong currents and stony substrates were not inhabited. The highest abundance was found in the southeastern part of the Bight with a maximum of 400 to 500 ind./m² and an AFDW of 4 g/m² (water depth around 16.5 m). Thirty-five years ago (in the mid 1960s), *A. borealis* reached medium densities between 10 and 50 ind./m² with a maximum of 100 ind./m² in the eastern central part of the Bight (Schulz, 1969) (Fig. 3b). At depths below 20 m of the innermost area (Lübeck Bay) and western outer Bight no *A. borealis* were found. The comparison of the main distribution areas of the 1960s with the results of the present study showed a clear change.

The highest biomass was observed at the coast off Holstein and Mecklenburg (water depth about 16.0 m) with an ash free dry weight (AFDW) of 5–16 g/m² (Fig. 4). Within water depths of 12 and 27 m, *A. borealis* reached a mean abundance of 47 ind./m² and a biomass (AFDW) of 0.5 g/m².

The development of the abundance of *A. borealis* at stn. 018 (see Fig. 2 for location) during the last 15 years is shown in Figure 5. From 1985 to 1989 abundance increased from around 50 ind./m² to about 400 ind./m². By the mid 1990s and through to 2000 abundance at the same station declined dramatically to 10–20 ind./m².

In the present study the highest abundance was observed in depths between 12 and 22 m (Fig. 6). In this depth range, *A. borealis* settled in an abundance of between 20 and 100 Ind./m².

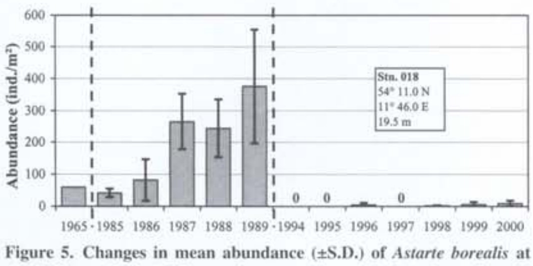

Figure 5. Changes in mean abundance (±S.D.) of *Astarte borealis* at stn. 018 over the last 15 years in comparison with data from the mid 1960s (Schulz 1969).

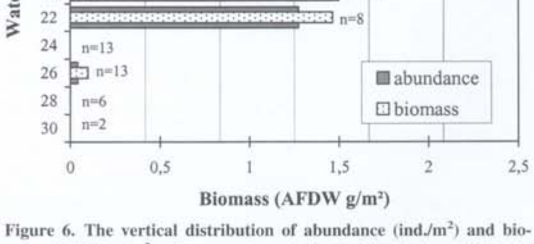

Figure 6. The vertical distribution of abundance (ind./m²) and biomass (AFDW g/m²) of *Astarte borealis* in the Mecklenburg Bight in 1999/2000 (n = number of included stations of each depth intervall).

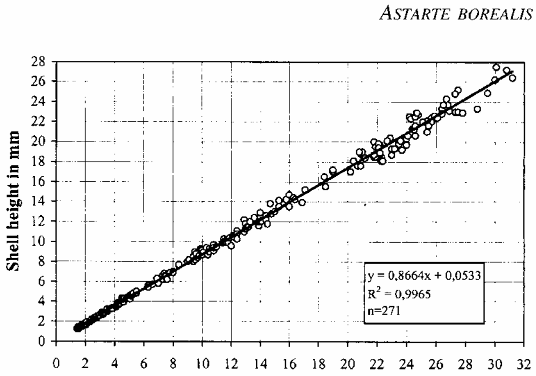

Figure 7. Shell height-length relationship of *Astarte boeralis* from the Mecklenburg Bight.

The biomass (AFDW) reached average amounts of 1.8 g/m^2 at 15–22 m with a maximum of 2.4 g in 15–16 m interval. In shallower and deeper areas no or only single specimens were found.

Population Structure, Meat Yield and Growth

Measured shell lengths of *A. borealis* ranged from 1.2 to 31.2 mm (Note, this range included both the survey and the collection material, see earlier). The shell length to shell height relationship is linear as indicated in Figure 7. The mean ratio length to height was 1.15 ± 0.04 and varied from 1.05 in minimum up to 1.25 in maximum, independent of shell length.

The population structures of selected stations are shown in Figure 8. The size structure varied between the stations. The 0–10 mm size class composed about 78% of the population. Larger size classes (>20 mm) were observed only sporadically and in low numbers. The dominant 0–5 mm size class at most of the investigated stations represents the survivors of the settlement during the last two years. Only at stn. 25 was the size structure dominated by older specimens.

Relationships between shell length and individual weights (whole wet weight, wet meat weight and ash free dry weight) are shown in Figure 9. These graphs include all measured specimen (1.2 mm to 28.7 mm) from the 1999/2000 survey. The smallest meat wet weight was 0.09 mg at a shell length of 1.2 mm and the largest one was 1.17 g at 28.3-mm shell length. The estimated mean regression line indicates the average meat yield per unit shell length of *A. borealis*. Differences between the station means were not statistically significant. The ash free dry weight varied between 0.08 mg (1.9 mm in length) and 0.29 mg (28.5 mm in length). The estimated regression lines of weights for different stations did not differ significantly. The results indicate that throughout the Mecklenburg Bight *A. borealis* contained approximately the same meat per unit shell length for the range of length considered. The mean wet meat yield (percentage of total wet weight) of different size

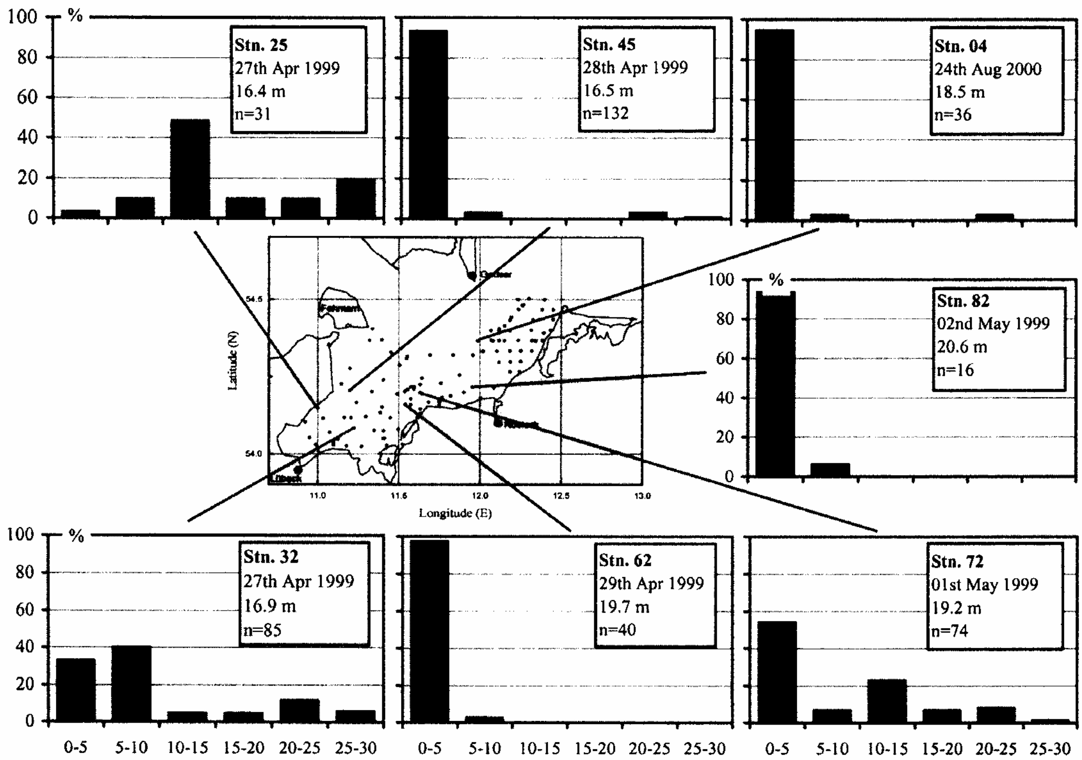

Figure 8. Shell length-frequency distribution for 5 mm size classes of *Astarte borealis* at several stations in depths between 16.4 m and 20.6 m in Mecklenburg Bight in 1999/2000.

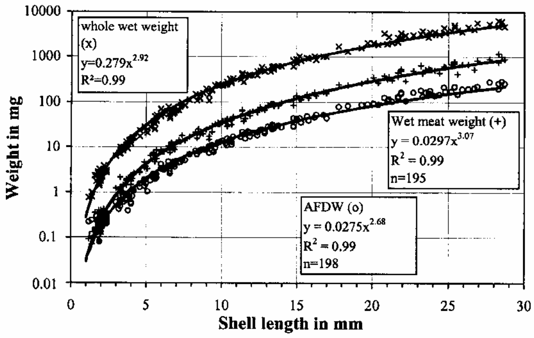

Figure 9. Estimated relationships between shell length and whole wet weight (+), wet meat weight (x) and ash free dry weight (o) for *Astarte borealis*. The corresponding equations for the calculated best fit regression lines are given in the figure.

classes varied in a range between 12.21% and around 16.4% with a minimum at 5% and a maximum at 23% (Fig. 10). The mean meat was 14.5%. With 9.1%, the highest amount of organic content (ash free dry weight) appeared in the 0–5 mm shell size class. The lowest organic content was 5.6% in the 25–30 mm size class. The difference was significant (t-test, $p < 0.001$). The mean organic content of dry weight ranged from 4.05% to 31.2% with a mean value of 7.4%.

DISCUSSION

Distribution, Abundance and Biomass

The occurrence of *A. borealis* in the Mecklenburg Bight has been known since the 19th century when the first investigations on the benthic fauna of the Baltic Sea took place (von Martens 1871; Wiechmann 1869/70). While the main Baltic populations live in the Kiel Bight and in parts of Sound and Belt, the distribution in the Mecklenburg Bight and the Arkona Basin represent the most eastern recent occurrence of this species in the Baltic Sea (see Fig. 1 and von Oertzen & Schulz 1973). Due to the decreasing salinity, *A. borealis* has its natural limit of distribution in areas east of Arkona Basin. Formerly, the distribution reached the deep parts of the Bornholm Basin as far as the Slupsk Furrow (Demel & Mulicki 1954; Jaeckel 1952; von Oertzen & Schulz 1973). Due to long

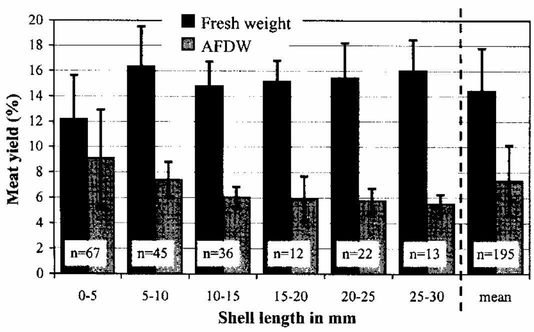

Figure 10. Mean individual percentage of wet meat yield and ash free dry weight in 5-mm size classes of *Astarte borealis* from the Mecklenburg Bight in 1999/2000 (±S.D.).

lasting oxygen depletion in the last decades the bivalve had nearly disappeared in this area (Andersin et al. 1978). Today, *A. borealis* occurs in this region only in the Slupsk Furrow and only in depths between 60 and 70 m (Warzocha 1995).

The investigation of Schulz (1969) from 1962 to 1965, giving the distribution pattern of *A. borealis* in the Mecklenburg Bight, was used for comparison with the present study. In the 1960s, densities were between 10 and 50 ind./m^2 in mean (maximum 320 ind./m^2). During the 1980s, the abundance of the bivalve increased in waters near 20 m depth (e.g., at the monitoring station 018) (Köhn 1989; Voigt 1991). Due to a long period of oxygen depletion in the deeper part of the Lübeck Bay (the inner part of the Mecklenburg Bight), no *A. borealis* were found in the 1980s (Gosselck et al. 1987; Prena et al. 1997). In the 1990s, the density of *A. borealis* decreased in shallower regions of the Mecklenburg Bight, too. Recently, a mean abundance of approximate 50 ind./m^2 in depths between 11 and 26 m could be observed. The highest abundance and biomass was observed in the region between 16 and 22 m. The mean biomass reached 1 g/m^2 AFDW (17 g/m^2 wet weight). In comparison, at the beginning of the 1950s during the investigations of Kühlmorgen-Hille (1963) in the Kiel Bight *A. borealis* occurred in a mean abundance of between 4 and 52 ind./m^2. At the beginning of the 1970s Arntz et al. (1976) observed in the Kiel Bight the highest frequency and abundance in depths between 10 and 20 m with 74–83 ind./m^2 (max. 570 ind./m^2, 1240 g/m^2 wet weight). In adjacent waters of the Arkona Basin Löwe (1963) found *A. borealis* in quite high amounts of 13 g/m^2 wet weight. The largest biomass with about 70 g/m^2 he observed off the island of Falster and at the entrance of the Sound. Outside the Baltic in Russian Arctic waters, the main distribution area of the species, *A. borealis* colonises the littoral zone and reaches an abundance of about 200 ind./m^2 and a biomass of about 620 g/m^2 wet weight (Antipova 1978; Gagaev 1989; Matveeva 1977). *A. borealis* belongs to the most productive bivalves in this region (Gagaev 1989).

According to von Oertzen (1972), *A. borealis* has an extremely prolonged period of ripe eggs and sperms. The main spawning season is presumably in spring with the possibility of "portion spawning" the whole year (Köhn 1989; Matveeva 1977; von Oertzen 1972). *A. borealis* prefers sandy substrates and mixed sediments avoiding muddy sediments (e.g., Arntz et al. 1976; Schulz 1969). In the deeper parts (>22 m) of the Mecklenburg Bight, oxygen depletion in late summer prevents successful recruitment and growth of the juveniles. However, *A. borealis* is one of the most tolerant species to oxygen deficiency and to hydrogen sulphide (von Oertzen 1973; Oeschger 1990). Probably, the possibility of the high tolerance to oxygen deficiency is restricted to the adults, whereas the juveniles are more susceptible, causing settlement only in favourable years and depths. The lack of recruitment events is described for populations of Kiel and Mecklenburg Bight by Werner et al. (1974) and Köhn (1989). In shallower zones (between 15 and 20 m), no major hypoxic episodes have been observed in the recent past (Matthäus et al. 1999). Although recruitment can take place in the shallower areas, conditions for growth are suboptimal, probably due to the lower nutrition supply, lower salinity and higher temperature (Arntz et al., 1976; von Oertzen, 1973). In depths shallower than 11 m the mean salinity, 8–12 psu, is probably too low. The range of potency of *A. borealis* is 8–35 psu with an optimum between 14 and 30 psu (Jaeckel 1952; von Oertzen 1973).

Population Structure

The largest living *A. borealis* found in this survey was 28.3 mm long and 24.7 mm high. Valve material of the Zoological Collection of the University of Rostock (sampled in the 1980s) had a maximum length of 31.2 mm (26.4-mm height). Lenz (1882) found specimen of 36 mm in length (31-mm height) in the Lübeck Bay. The shell is quadrate to subtrigonal and compressed with a total shell length of 38 mm at boreal outposts (e.g., Baltic Sea, Jaeckel, 1952) and 55 mm in the Arctic Sea (Coan et al. 2000, Filatova 1957) with a mean of 25–45 mm (Dance 1977). In general, the shell length exceeds the height and the height/length indices vary from 0.8 to 0.9 (e.g., Ockelmann 1958). However, *A. borealis* is a variable species with several forms and varieties (see Zettler 2001). In the past, the great variability in morphological features resulted in a number of new species and subspecies descriptions (see Zettler 2001). Recent investigations of Høpner Petersen (2001) show a large variety of shell morphology within the genus *Astarte*. The material discussed in the present study had a high constancy in respect to the relation between length and height (Fig. 7).

Statements on population dynamics or size structure of *A. borealis* are very sparse in the literature. Some Russian studies (Gagaev 1989; Matveeva 1977) and few investigations on Baltic populations (Köhn 1989; Voigt 1991; Werner et al. 1974) have been carried out. During the studies of Köhn (1989) and Voigt (1991) in the Mecklenburg Bight the populations were dominated (89%) by individuals <6 mm in length. Larger sizes were observed only sporadically. In the present study, juvenile individuals were dominant at most of the stations investigated. Adult specimens (>20 mm) were only observed in high abundance in the inner part of the Mecklenburg Bight (Fig. 8). Köhn (1989) pointed out that only individuals >20 mm are reproductive. In the White Sea *A. borealis* reaches sexual maturity in sizes >17 mm (Matveeva 1977). The maintenance of the stock in the Mecklenburg Bight depends on few adults and/or probably on drifting of lecitothrophic (non-pelagic) larvae from regions nearby. In areas with strong currents, longer immigration distances are imaginable (Rasmussen 1973). In the Kiel Bight and in Russian Arctic waters however, the population structures are more balanced (Werner et al. 1974; Gagaev 1989).

Meat Yield

The mean wet meat yield of *A. borealis* of 14.5% in the present study is similar to reported values of Köhn (1989). He found organic contents (wet) between 9% and 30% for a population in the Mecklenburg Bight. Ansell (1975) observed a soft tissue content for *A. elliptica* of 14.3–23.5% and dry tissue weights of 3–5% in British waters depending on the reproductive cycle. In the Mecklenburg Bight, in the present study, the mean individual ash free dry weight of *A. borealis* decreased from 9.1% to 5.6% with increasing size classes. The increasing mean wet yield and the decreasing ash free dry weight with increasing shell length indicates relatively higher water content of bigger bivalves. The length specific wet weight (shell length – wet weight relationship) in this study was similar to that reported for *A. borealis* of the Kiel Bight and Russian Arctic waters. In the Mecklenburg Bight, the calculated wet weight for an individual of 25 mm shell length was 3.42 g. The wet weight of *A. borealis* in the East Siberian Sea reported by Gagaev (1989) was 3.49 g and in Kiel Bight 4.22 g (Schaefer et al. 1985). According to Köhn (1989) the meat wet weight of a 25-mm specimen of *A. borealis* is 534 mg compared with 572 mg in the present study.

In conclusion, the present study shows ecological and morphological features of *Astarte borealis* in the Mecklenburg Bight near its eastern distributional boundary within the Baltic Sea. Further investigations must deal with growth rates and morphology of *A. borealis* within the Baltic and adjacent waters. The causes of the decline of this cold-adapted arctic-boreal species in much of the Baltic remain unclear. The comparative population dynamics at different water depths and/or within different sediment structures and the dispersion and settlement patterns of the larvae in this "border" area are of special interest.

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