

## Effects of an Unusual Natural Temperature Increase on a Baltic Soft-Bottom Community

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### Abstract

The effects of a sudden, extraordinary temperature rise upon a soft-bottom community in the northern Baltic Sea were studied continuously for more than a month, during the summer of 1968. The mean abundance of the total macrofauna on the muddy bottom amounted to ca  $6 \times 10^3$  individuals  $\cdot m^{-2}$ , on the sandy bottom to  $2 \times 10^4$  individuals  $\cdot m^{-2}$ . The meiofauna, only sampled in the mud, averaged  $1 \times 10^6$  individuals  $\cdot m^{-2}$ , with nematodes, oligochaetes and ostracods as dominating groups. During this period, the redox-potential-discontinuity (RPD)-layer successively moved upwards in the muddy bottom, being relatively stable in the sand. The mud surface showed a succession of microbial communities. The initially oxidized, yellow surface film, with patches of diatoms and red *Spirula*, changed to a more grayish layer, with purple areas here interpreted as *Chromatium* and white spots of *Beggiatoa*. The latter dominated during the last part of the period, covering vast areas of the bottom like a gigantic cobweb. The endofauna was forced upwards by the emerging RPD-layer, the more sensitive components dying off, facultative anaerobes and nematodes flourishing. The described temperature increase of about 10 °C simulates the effects of a 3000 MW nuclear plant.

### Introduction

The present investigation was made during the summer of 1968 as a part of a more extensive study: "Energy flow in the Baltic ecosystem", carried out by the Askö Laboratory (Swedish marine station in the Baltic Sea). The initial aim was to define the biotic and abiotic components of the different types of soft bottoms of the area, belonging to the *Macoma*-community according to Petersen (1913). During the course of the investigation, however, the bottom-water temperature suddenly rose to around 10 °C, owing to the natural hydrodynamics of the area, offering extraordinary opportunities of studying the reactions of the bottom community to a sudden temperature rise. In view of the world-wide thermal pollution problem, the results of this "Nature's own experiment" might be of some value in the future for assessing biological consequences of cooling water from nuclear plants.

Särkkä (1969) summarizes most of the recent works on soft-bottom macrofauna in the northern Baltic Sea. The meiofauna is far less studied quantitatively: Purasjoki (1945) studied some Finnish soft-bottoms, Fenchel and Jansson (1966) a brackish-

water beach. As to temperature effects, Golikov and Scarlato (1967) regarded the average temperature as the major force in ecosystem dynamics, and Krenkel and Parker (1969) give a review of its effects on aquatic life. Fenchel (1969) presented an exhaustive study of the relationships between the microbenthos and the properties of the sediment, and Hallberg (1967) studied the physicochemical activity of the sulphate-reducing bacteria.

Elmgren (1973), in evaluating different methods of quantitative sampling on Baltic mud bottoms, found abundance figures of the meiobenthos well comparable to previous maximum values for marine meiobenthos.

### Material and Methods

The localities studied are situated in the Baltic Sea, in the vicinity of the Askö Laboratory in the Trosa archipelago, ca. 80 km south of Stockholm. The salinity of the area varies between 6 and 7‰. Two bottom types were chosen, both at 10 m depth: one muddy and more sheltered (B) and with a high organic content, the other more exposed and therefore sandy (A), rich in detritus and with irregular patches of decaying *Cladophora glomerata* algae. Sparse vegetation occurred only on the sandy locality, consisting of tufts of *Ceramium tenuicorne* and *Polysiphonia* spp.

Sampling was carried out by SCUBA diving. Cores were taken at the bottom by means of glass tubes, 20 cm long, cross-section 25 cm<sup>2</sup> (Fig. 1A). The tubes were pushed by hand into the bottom, and closed with rubber stoppers. The cores were immediately brought into the laboratory in upright position in a bucket of water, for measurement of the abiotic parameters and sampling of the fauna. All the samples except 5 were taken between 09.30 and 12.30 hrs and, generally, 5 cores were collected each time. Random sampling was carried out at Locality A in the following way. A square 10 × 10 m was marked out on the bottom with a rope. On a sheet of paper, a corresponding square was divided into 400 small squares, each representing a 0.5 × 0.5 m square; all were numbered. Squares to be sampled were chosen by simple random sample without replacement. The position of the sample squares on the

bottom was determined with a graded rope. A metal frame was placed on the surface, within which the cores, mostly 5 : 1 in each corner and 1 in the center, were taken. Unfortunately, this method could not be used at Locality B because of the easily stirred mud. Even slow movements caused clouds of particles, making it impossible to see and to take more than 1 core on the same small area. The results from the two bottoms are, therefore, not fully comparable. The temperature of the water 1 cm above the sediment surface was measured with a mercury thermometer, graded in 0.1 °C.

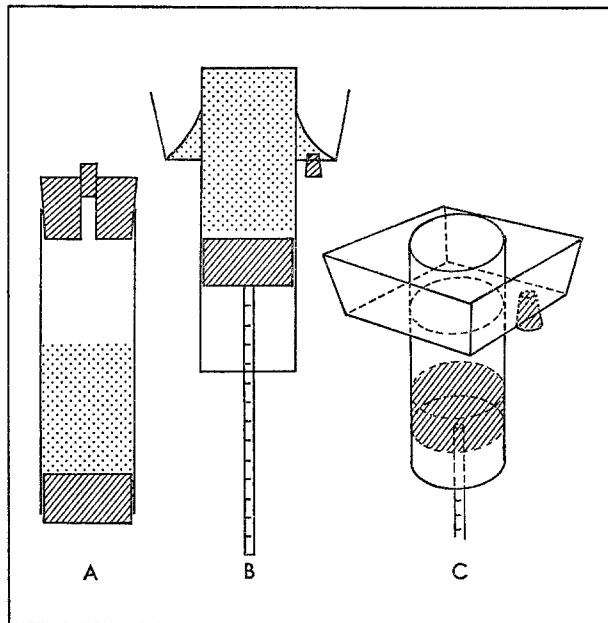


Fig. 1. The core sampler. (A) Upper rubber stopper with hole sits in the glass tube when this is pressed down into sediment, the small hole allows water to pass through when bottom stopper is pressed in, whereafter small stopper seals tube. (B) Sectioning of core is made with bottom stopper and graded stick working as piston. Overflowing material is allowed to fall down into polyethylene box (C) which functions as a collector

In the laboratory, the cores were kept at 15 °C constant temperature during measurements. The oxygen concentration was measured *in situ* 1 cm above the bottom surface, using a galvanic oxygen analyzer (Precision Scientific Co., USA). The salinity was measured on samples of bottom water using a Wheatstone bridge (Normameter) with buzzer and earphone. The immersion cell was a Philips PR 9510. Profiles of pH, redox-potential (Eh) and oxygen availability (ODR) were recorded for each centimeter in the sediment down to 6–10 cm depth. Eh was measured by resting the reference electrode on top of the core, and successively pushing the platinum electrode down

into the sediment. The ODR measurements were performed in a similar way as by Jansson (1968). By providing the glass tubes with a collar of polyethylene (Fig 1B) it was possible to collect the substratum falling down when the lower rubber stopper was pressed upwards by means of a graded stick (Fig. 1C). The sediment was cut off along the edge of the glass tube and pH was measured with a portable pH-meter (Beckman type N 1). The substratum in the box was washed through a hole down into glass dishes. This procedure was repeated for each centimeter. The content of the dishes was then sieved through a Tyler screen of 1.00 mm mesh and the animals picked out. The sieve was inspected under a stereomicroscope. For fragments of fragile animals such as oligochaetes and polychaetes only the front part was counted, and for crushed lamellibranchs only the hinges with fresh tissue were registered.

The meiofauna was subsampled in the laboratory by pushing glass tubes of 1 cm<sup>2</sup> cross-section into the freshly taken cores. These subsamples were then cut into 1 cm high pieces by the method of Fenchel (1967). The resulting 1 cm<sup>3</sup> samples were then washed through a Tyler screen no. 200 (74 μ) and the animals sorted out under a stereomicroscope. At least two subsamples could be obtained from the same core.

## Results

The weather during the period was characterized by high air temperatures, soft winds, sunshine and practically no rainfall (45 mm during the whole period). The water temperature, nearly identical for both localities sampled, was around 6 °C until the beginning of July. During the first 2 weeks of this month the temperature increased to 15°–16 °C, and remained practically constant throughout the investigation period (Fig. 2), presenting extraordinary warm conditions at this depth for this part of the Baltic Sea.

The salinity of the bottom water fluctuated between 6.0 and 6.6‰, and was generally somewhat lower at the muddy and more sheltered locality owing to flow of fresh water into the basin.

The oxygen concentration of the bottom water was about 8 mg · l<sup>-1</sup> at the mud bottom, and between 9 and 10 mg · l<sup>-1</sup> at the sandy bottom. Similar conditions were recorded for the ODR of the sediment surface, higher values for the sand bottom — about 1.0 · 10<sup>-7</sup> g O<sub>2</sub> · cm<sup>-2</sup> · min<sup>-1</sup>, lower ones for the mud bottom — about 0.5 · 10<sup>-7</sup> g O<sub>2</sub> · cm<sup>-2</sup> · min<sup>-1</sup> (Fig. 5). In the mud, nearly anoxic conditions prevailed just underneath the sediment surface, whereas oxygen was still recorded a few centimeters down in the sandy bottom (Figs. 5–7).

The Eh-values in the sediment surface were around +50 mV throughout the investigation period at the sandy locality (Figs. 2 and 5). Negative values were attained from 1 cm depth and downwards during the

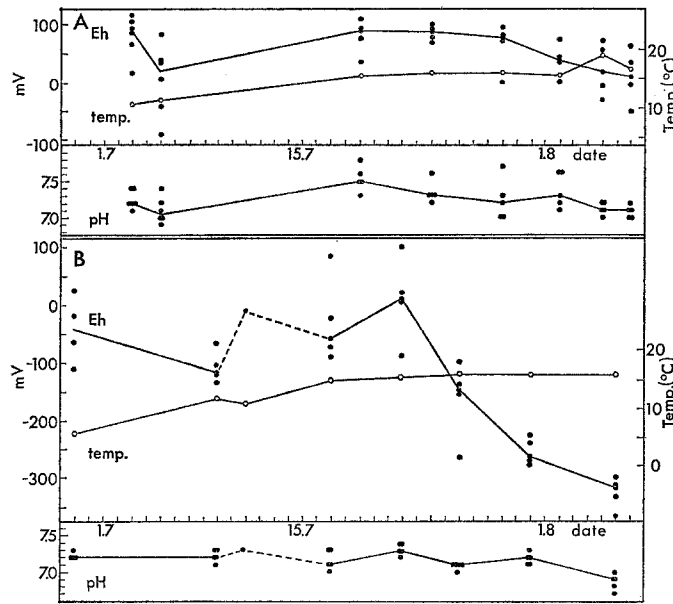


Fig. 2. Eh, pH and temperature change in sediment surface during investigation period, 1968. Values of the separate cores are indicated by black dots, when representing the same value they are somewhat displaced horizontally. The lines connect the median value of each sampling opportunity. (A) Sandy bottom; (B) mud bottom

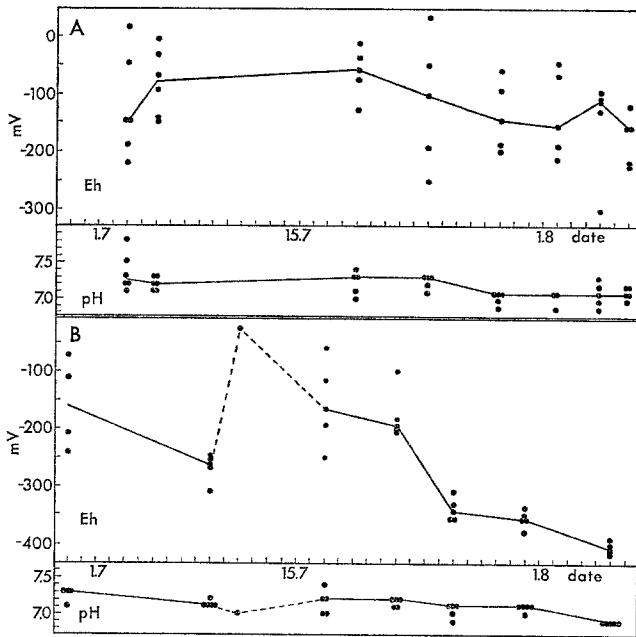


Fig. 3. Eh and pH changes at 2 cm depth in (A) sandy bottom; (B) mud bottom. For further explanations see Fig. 2

whole period of investigation (Figs. 3—5). The mud bottom, however, showed a more dynamic picture, and negative values already at the surface (Figs. 2 and 5). The Eh-curves for the surface, 2 and 5 cm depth were similar, although successively displaced towards

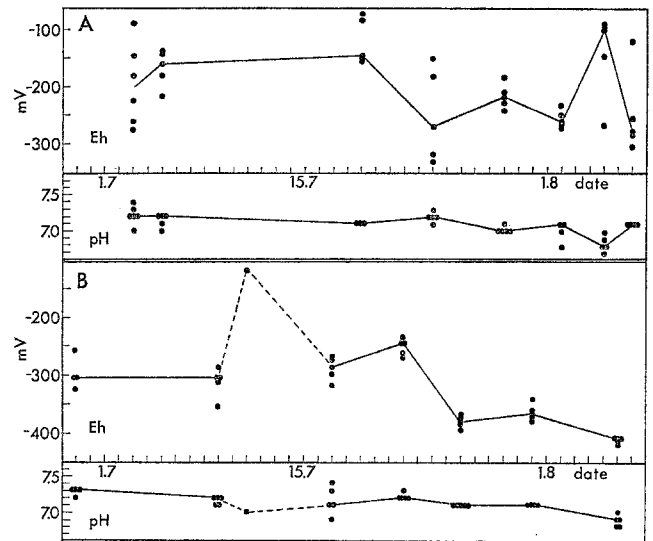


Fig. 4. Eh and pH changes at 5 cm depth in (A) sandy bottom; (B) mud bottom. For further explanations see Fig. 2

the very low part of the Eh-scale (Figs. 2—5). From a dubious maximum value on 11 July (only 1 set of measurements was made), the values dropped and attained their minimum at the end of the investigation period. The range of Eh-values was considerable in the surface layers (Figs. 2—5, and 7) of the muddy bottom, whereas the sandy bottom showed less difference between the samples. The dispersion of the Eh-

values decreased with increasing depth. Duplicate measurements, 2 cm apart in the same core, showed a mean difference of 27 mV on the surface and at 1 cm depth, compared with 6 mV at 5 to 6 cm depth.

The entire pH-range varied at Locality A between 6.7 and 7.8, but the mean values had only small varia-

successively downwards from 16.5% for the top centimeter to 21.3% for 5 to 6 cm depth.

The weekly inspection of the bottoms by diving gave a good visual knowledge of the bottom surfaces. While the sandy bottom (Locality A), of morainic origin (sand mingled with gravel and stones), had a thin layer of fine detritus, irregularly distributed both in space and time, the muddy bottom (Locality B) showed a clear succession of different microbial communities. Until the middle of July, the mud surface was covered by a continuous brownish-grey, slimy layer of bacteria (unidentified), dark brown patches of diatoms, and irregular areas of red *Spirula* (blue-green algae). This rather brightly coloured surface successively adopted a more uniform, greyish appearance, here and there broken by purple patches of *Chromatium* and white stripes of *Beggiatoa*. The latter bacteria expanded more and more; the sediment surface showed numerous cracks, with white margins of *Beggiatoa*, which finally covered large areas of the bottom like a vast cob-web. During the first half of July, the bottom water became very turbid and remained so for at least 10 days, with a visible sedimentation on the bottom surface.

The macrofauna — here defined as the animals left on a sieve of 1 mm mesh, disregarding the body length — are represented by at least 22 faunal components on the more sandy bottom (Table 1), compared with 11 on the mud bottom (Table 2). The corresponding abundance was  $2 \times 10^4$  and  $6 \times 10^3$  individuals  $\cdot$  m $^{-2}$ , respectively. Most abundant at both localities were the oligochaetes, with a maximum at 1 to 2 cm depth. The numbers on the sandy locality amounted to  $6.2 \times 10^3$  individuals  $\cdot$  m $^{-2}$ , and on the muddy and more sheltered bottom to  $3.6 \times 10^3$  individuals  $\cdot$  m $^{-2}$ . Other dominating species, (individuals  $\cdot$  m $^{-2}$ ) on the sandy bottom were *Pygospio elegans* ( $1.8 \times 10^3$ ), *Corophium volutator* ( $2.0 \times 10^3$ ), *Hydrobia* spp. ( $3.1 \times 10^3$ ), *Mytilus edulis* ( $3.0 \times 10^3$ ) and *Macoma baltica* ( $1.9 \times 10^3$ ). *M. baltica* was also common on the mud bottom with numbers of  $1.5 \times 10^3$  individuals  $\cdot$  m $^{-2}$ . The specimens were smaller on the mud bottom, average size 2.5 mm, than on the sandy bottom, where their mean size was 7.0 mm.

The meiofauna was only sampled on the mud bottom. Fig. 7 and Table 3 show the animals retained on a sieve of 74  $\mu$  mesh. All groups except the nematodes (20/8:  $1.3 \times 10^6$  individuals  $\cdot$  m $^{-2}$ ) and the ostracod *Candona neglecta* (20/8:  $3.5 \times 10^4$  individuals  $\cdot$  m $^{-2}$ ) had higher mean values during the first sampling period: the nauides *Amphichaeta sannio* and *Nais elinguis* (27/7: 9.1,  $7.6 \times 10^4$  individuals  $\cdot$  m $^{-2}$  respectively), unidentified oligochaetes (27/7:  $1.4 \times 10^5$  individuals  $\cdot$  m $^{-2}$ ) and turbellarians (mostly small acellans, 27/7:  $5.8 \times 10^4$  individuals  $\cdot$  m $^{-2}$ ).

The vertical distribution of both the macrofauna and meiofauna shows a maximum for most species in the uppermost centimeter of the bottom sediment for

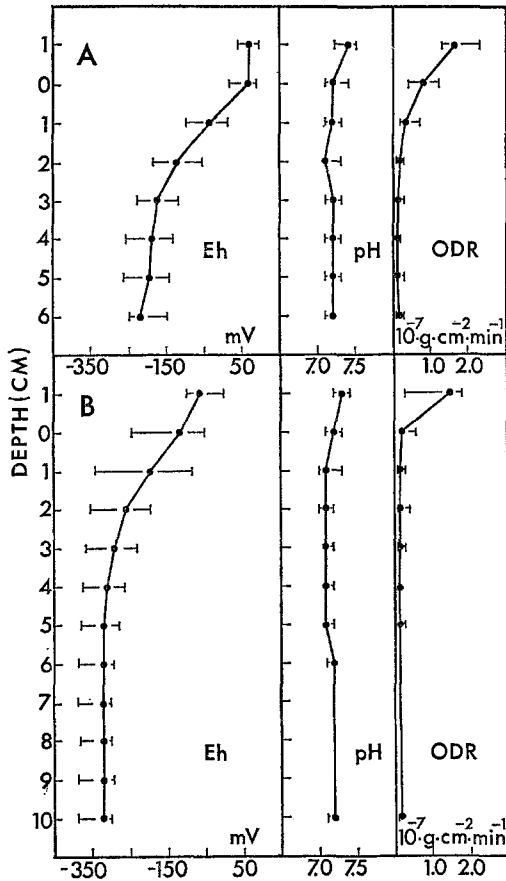


Fig. 5. Vertical distribution of redox-potential (Eh), pH and oxygen availability (ODR) in sandy bottom (A) and mud bottom (B) for the whole period investigated. Median values are connected by solid lines, horizontal bars unite limits for 25th and 75th percentiles (which means that 50% of the values lie between these limits). Number of measurements of Eh and pH was for (A) 42, for (B) 25. Number of ODR-determinations 18 and 10, respectively

tions, and decreased slightly towards the end of the investigation period. On the mud bottom, the total range was 6.8 to 7.4, with a clear decrease during the first week of August (Figs. 2–5). Vertically, pH generally decreased with depth, but showed sometimes an irregular distribution (Figs. 5–7).

The organic content in % dry weight of Locality B was determined according to Jansson (1969) during the investigation period as loss by ignition. It increased

Table 1. Vertical distribution of macrofauna components in sandy bottom, standard error of mean, and coefficient of dispersion (CD). Figures represent individuals · m<sup>-2</sup> expressed as mean values of 42 cores taken during investigation period

Species	Depth (cm)							Total individuals · m <sup>-2</sup>	Standard error of total individuals · m <sup>-2</sup>	CD
	0-1	1-2	2-3	3-4	4-5	5-6	6-7			
<i>Turbellaria</i>	10							10	10	
<i>Laomedea loveni</i>	x									
<i>Laomedea flexuosa</i>	x									
<i>Prostoma obscurum</i>	10							10	10	
<i>Nereis diversicolor</i>	257	295	181	114	38	10		895	87	0.9
<i>Fabricia sabella</i>	114							114	50	
<i>Pygospio elegans</i>	1067	591	143					1801	158	1.4
Oligochaeta	1391	1971	1457	933	343	95	29	6219	519	4.4
<i>Nais elinguis</i>	391	10						401	95	
<i>Neomysis vulgaris</i>	19							19	13	
<i>Jaera ischiosetosa</i> ♂	76							76	28	
<i>Jaera</i> spp.	152							152	63	
<i>Pontoporeia affinis</i>	48	10						58	22	
<i>Gammarus</i> spp.	181							181	70	
<i>Gammarus oceanicus</i>	181							181	95	
<i>Corophium volutator</i>	1952	95	10	10				2067	298	4.4
<i>Crangon vulgaris</i>	10							10	10	
Acarina	19							19	13	
Chironomidae	505	10	10					525	228	
<i>Hydrobia</i> spp.	2848	152	57	19				3076	342	4.3
<i>Mytilus edulis</i>	2933	19						2952	633	13.8
<i>Cardium glaucum</i>	10							10	10	
<i>Macoma baltica</i>	371	448	562	419	76	19	10	1905	139	1.0
<i>Electra crustulenta</i>	x									
Total individuals · m <sup>-2</sup>	12545	3601	2420	1495	457	124	39	20681	1424	10.2

Table 2. Vertical distribution of macrofauna components in mud bottom, standard error of mean, and coefficient of dispersion (CD). Figures represent individuals · m<sup>-2</sup> expressed as mean values of 39 cores taken during investigation period

Species	Depth (cm)						Total individuals · m <sup>-2</sup>	Standard error of total individuals · m <sup>-2</sup>	CD
	0-1	1-2	2-3	3-4	4-5	5-6			
<i>Pelmatohydra oligactis</i>	10						10	11	
<i>Halicryptus spinulosus</i>		10					10	11	
<i>Prostoma obscurum</i>	10						10	11	
Oligochaeta	1344	1651	369	144	82	10	3600	671	11.8
<i>Nais elinguis</i>	349	72					421	105	2.5
<i>Idothea viridis</i>	10						10	11	
<i>Chironomus</i> spp.	72		10	10	21	31	144	43	
<i>Hydrobia</i> spp.	144	21					165	49	
<i>Potamopyrgus jenkinsi</i>	72						72	30	
<i>Limapontia capitata</i>	51						51	26	
<i>Macoma baltica</i>	513	472	339	62	51	31	1468	283	5.4
Total individuals · m <sup>-2</sup>	2575	2226	718	216	154	72	5961	768	9.6

both localities. On the sandy bottom, many of the captured animals are in fact epifauna members — *Laomedea*, *Jaera*, *Gammarus*, *Crangon*, *Mytilus*, or hemipelagic as *Neomysis*. Also, the true infauna shows a definite concentration to the sediment surface, more pronounced in the mud bottom than in the sand bottom (Tables 1 and 2).

Table 3. Abundance in  $10^4 \times m^{-2}$  of meiofauna components in mud bottom on two sampling occasions (cf Fig. 7)

Species	Date (1968)		Mean
	27 July	20 Aug.	
Turbellaria	5.8	1.7	3.8
Nematoda	27.9	125.0	76.5
Rotatoria	0.0	0.3	0.2
Oligochaeta	13.9	5.7	9.8
<i>Nais elinguis</i>	7.6	0.7	4.2
<i>Amphichaeta sannio</i>	9.1	3.8	6.5
<i>Candona neglecta</i>	1.8	3.5	2.7
Cyclopoida	1.3	0.0	0.7
Harpacticoida	1.3	0.2	0.8
Chironomidae	0.0	0.2	0.1
<i>Macoma baltica</i>	1.5	0.0	0.8
Total	70.2	141.1	105.7

### Discussion

In most bottom investigations, some kind of grab has been used for the evaluation of the quantity and quality of the bottom fauna. This method has several drawbacks, often pointed out (Hopkins, 1964). We have mostly no idea of how deep in the sediment the grab has dug; it may have dug obliquely, so that the different strata have not been sampled in due proportion, or some material might have slipped out during transport through the water. Digging efficiency is also strongly dependent on the consistency of the material, the grab taking more sediment in a soft bottom than in a sandy one. Furthermore, the stratification is mostly disturbed and thereby unfit for defining the vertical distribution of biotic and abiotic factors. The SCUBA-diving technique, however, makes it possible, with small financial cost, both to visually register the characteristics of the sediment surface, and to take undisturbed cores by hand.

The question arose as to what might happen during measurement in the laboratory. In the present investigation, the last measurements were sometimes not finished until 12 h after the samples were taken. To define the magnitude of the possible changes in pH and Eh, the means of the first two measured samples were compared with the means of the last two from the same sampling batch (usually consisting of 5 cores), and expressed as the difference to the mean value of all the samples from the same sampling location. In the 0 to 1 cm and 5 to 6 cm strata, pH was unchanged

in both bottom types. The Eh-values in the mud bottom, however, were on the 0 to 1 cm level about 40 mV lower, on the 5 to 6 cm level about 20 mV higher, in the last measured cores. In the sandy bottom, corresponding values were generally about 20 mV lower in both layers in the last measurements. The reason for these discrepancies is probably the activity of various bacteria. This stresses the importance of carrying out measurements as soon as possible.

Negative effects of sampling upon the vertical distribution of the animals are difficult to evaluate. The first core could mostly be sectioned within 1 h after sampling, and no difference between this and the last sectioned core could be traced.

The representativity of the macrofauna number depends wholly on the practical definition used — the animals retained on a 1 mm sieve. To test the validity of this statement, 5 sand cores were sieved both through a 1 mm and a 250  $\mu$  sieve. The number of animals retained on the finer sieve, expressed as percentage of the total number of respective groups of the macrofauna fraction was, for some critical groups: *Nereis diversicolor*, 57%; *Pygospio elegans*, 38%; Oligochaeta, 38%; *Nais elinguis*, 200%; *Corophium volutator*, 194%; Chironomidae, 40%. This means an underestimation of the total numbers of these groups as presented in Tables 1 and 2. This is also obvious if we compare the abundance figures for some species or groups from the mud bottom, appearing as macrofauna (Table 2) and meiofauna (Table 3). For Oligochaeta, the corresponding figures are  $3.6 \times 10^3$  and  $9.8 \times 10^4$ , for *Nais elinguis* 420 and  $4.2 \times 10^4$ , for chironomids 140 and  $1 \times 10^3$ , and for *Macoma baltica*  $1.5 \times 10^3$  respectively  $8.8 \times 10^4$ . This stresses the need for sampling the meiofauna and the macrofauna when estimating the productivity of marine bottoms (Wieser, 1964; Fenchel, 1969 p. 165ff; Elmgren, 1972).

Nematodes, turbellarians and *Beggiatoa* spp. — all true representatives of the sulphide biome (*sensu* Fenchel and Riedl, 1970) — were found. There is some difference in the vertical distribution of the animals between the two localities, however. A comparison between Tables 1 and 2 reveals the deeper penetration of animals into the more sandy sediment. This is made possible by the better oxygenation of the upper layers. However, some members of the macrofauna, e.g. Chironomidae, Oligochaeta and *Macoma baltica*, were found rather deep in both localities. The mud-bottom chironomids consisted of red *Chironomus* spp., known for their great resistance to anaerobic conditions. The oligochaetes, although well represented in the mud bottom, were less numerous than on the sandy bottom. *M. baltica* penetrated deeper into the mud than into the sand. The lack of oxygen in the deeper layers hardly affects the clam, as oxygenated water is pumped down to the gills from the sediment surface. However,

vertical penetration into the sandy bottom is limited by the length of the siphon. In experiments carried out in the laboratory with different size classes of *M. baltica*, the length of the protruded siphon was estimated to about 4 times the length of the shell. This limited the penetration into the sandy sediment, as the tip of the siphon was always level with the sediment surface to keep the opening free from falling sand grains. In the jelly-like mud, however, a hole once made through the surface remained open, allowing water to pass to the siphon tip, situated deeper down.

*Hydrobia* spp. (mostly *H. ventrosa*) were found so deep in the sandy sediment that experiments were made to clarify whether they had been forced down by the tube walls upon sampling, or whether they really dig into the substrate. The snails were kept in glass tubes (the same as for the investigation) with sand and mud substrates, respectively, for 48 h, at a temperature of 24 °C. Half of the tubes were kept in the dark, the remainder were exposed to light. After counting the specimens on and above the bottom surface, the sediment was sectioned in the same way as described before. Both in mud and sand, *Hydrobia* spp. were found 1 to 2 cm deep (which shows that they are able to penetrate to such a depth). There were more specimens on the surface in the dark tubes (83%

on mud, 91% on sand) than in the illuminated ones (73% on mud, 27% on sand), which might indicate that the vertical distribution may change during day and night. Oxidizing processes caused by photoautotrophic organisms exposed to light force the RPD layer a little down (Fenchel and Riedl, 1970), thus allowing the oxygen-demanding fauna to migrate deeper.

The horizontal distribution of the macrofauna was evaluated by computing standard error and dispersion coefficient from the distribution numbers. As is apparent from Tables 1 and 2, some animals show a standard error nearly as high as the total mean value. Some, occurring in small numbers, are hardly typical for respective bottoms, e.g. *Prostoma obscurum*, *Fabricia sabella*, *Neomysis vulgaris*, *Jaera* spp., *Acarina*, and were found mainly because of the heterogeneity of the bottom: stones, algal tufts etc. Others, such as *Crangon vulgaris*, were collected in so few cores because of their flight reaction. The dispersion coefficient (CD) was estimated for the most abundant species. A CD value >1 indicates an aggregated distribution in time and/or space, CD 1 a random, and CD < 1, an even distribution (e.g. Wieser 1964; Kosler, 1968). On the mud bottom, *Macoma baltica* and *Oligochaeta* show patchiness, which may be caused by migration from unfavourable microhabitats,

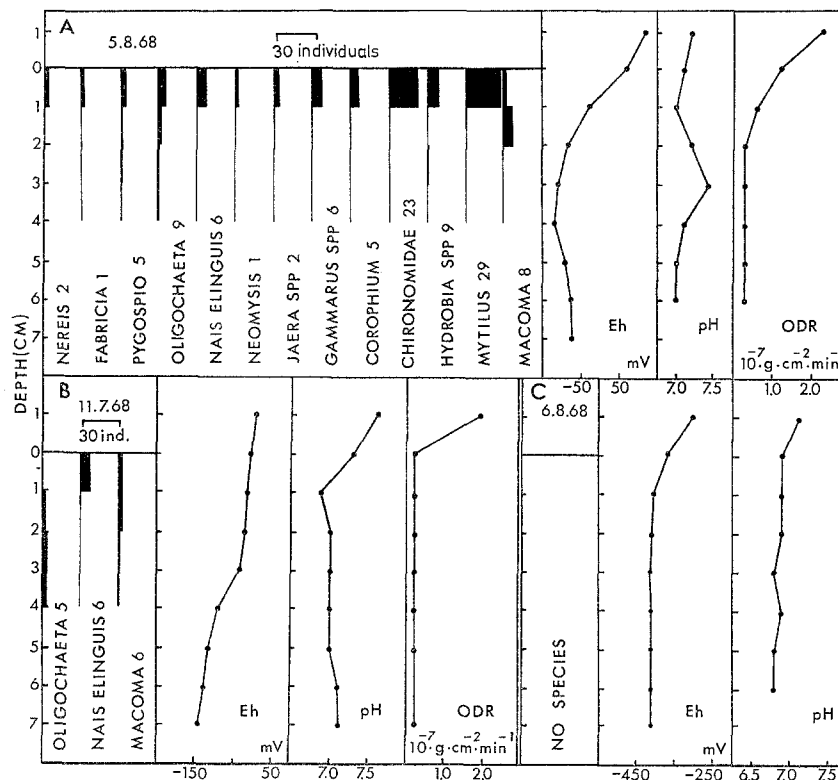


Fig. 6. Vertical distribution of macrofauna and some environmental parameters in 3 representative cores, from sandy bottom (A) and mud bottom (B), (C). Core B is from beginning, C from end of investigation period

deaths due to passed tolerance limits, or attraction to favourable microhabitats. This patchiness is already indicated by the heterogeneity of the Eh-values, probably reflecting unevenly distributed debris of algae. On the sandy bottom, the aggregated distribution of Oligochaeta, *Corophium volutator*, *Hydrobia* spp., and the random distribution of *Nereis diversicolor* and *Macoma baltica* are in agreement with the results of Kosler (1968) for the shallow bottoms around Hiddensee in the southern Baltic Sea. This is in good agreement with the better homogeneity of the Eh-values on the sandy bottom. The distributional aggregation of the total fauna is of almost the same order in both localities.

Surely, the greater sensitivity of sediments of high organic content to temperature changes is responsible for the size difference between mud and sand-bottom populations of *Macoma baltica*. The smaller specimens on the mud bottom represent only a few age classes compared with the sand-bottom population, indicating similar temperature-induced reductions in population size during preceding years.

Unfortunately, no biomass determinations were

made, so it is impossible to say anything about the relations between the specific area of activity (surface area/dry weight animal) of different species (Wieser, 1964). However, *Macoma baltica* displayed almost the same abundance on the two bottoms, and the size differences (smaller-sized individuals on the mud bottom) show that there must be a greater value for the specific area of activity of the mud-bottom population than for the sand-bottom population, although the organic content was greater on the mud bottom. In this case, the specific area of activity will not reflect the nutrition potential of the bottom, but other characteristics of the biotope, such as environmental stress.

The good accordance between the vertical distribution of Eh, ODR and the macro- and meiofauna (Figs. 6 and 7) is further supported if we summarize the total dynamics evolved during the investigation period. The rising temperature started a successively increasing bacterial activity, which was pronounced on the mud bottom with its greater amount of organic material and lesser exchange of freshly oxygenated water. Whereas the sandy sediment surface showed no

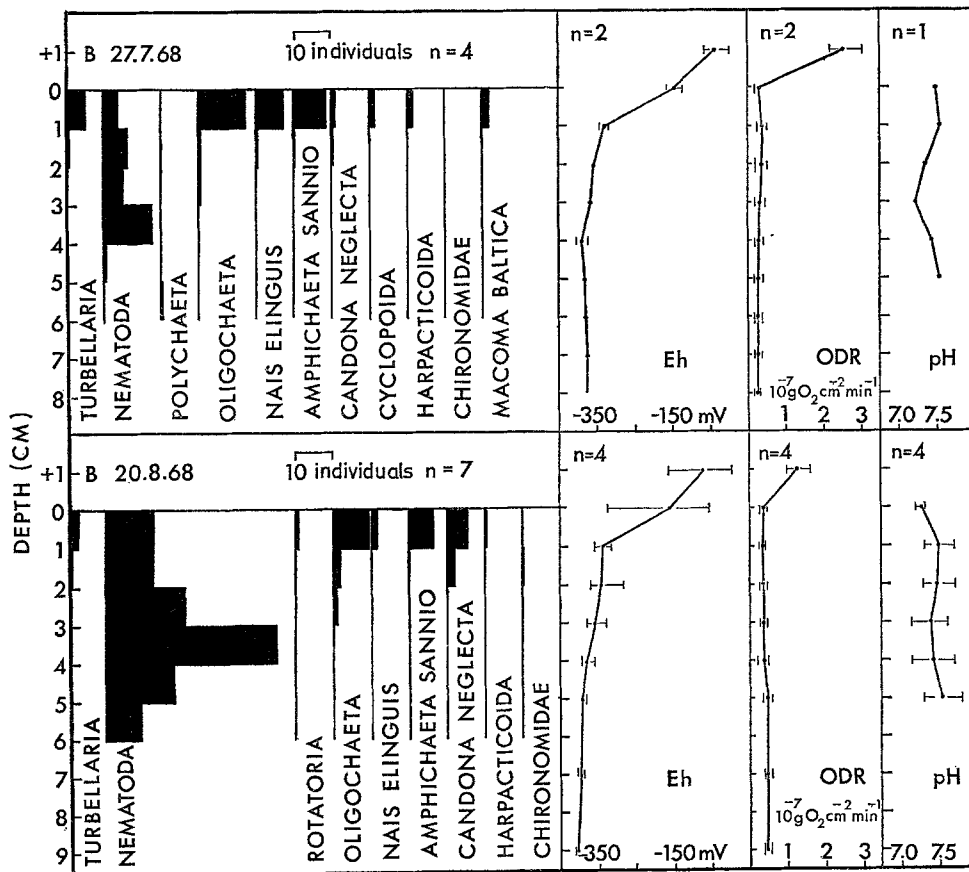


Fig. 7. Vertical distribution of meiofauna and some environmental parameters in mud bottom (B) on two occasions. Histograms: mean values of fauna collected on a 74  $\mu$  sieve. Mean values are connected by vertical lines, horizontal bars unite maximum and minimum values



Table 4. *Macoma baltica* (>1 mm). Numbers (individuals · 25 cm<sup>2</sup>) and vertical distribution from both mud and sand bottoms during investigation period. n: number of samples

## LOCALITY A

Depth (cm)	Date (1968)								Total	Mean
	3 July	5 July	19 July	24 July	29 July	2 Aug.	5 Aug.	7 Aug.		
0—1	0.7	0.7	0.0	1.0	0.6	0.8	2.4	1.4	7.6	1.0
1—2	1.0	0.7	0.8	0.6	0.8	1.2	2.2	1.8	9.1	1.1
2—3	0.7	0.8	1.0	1.8	1.4	1.4	2.0	2.4	11.5	1.4
3—4	1.0	0.7	1.2	0.8	1.2	1.4	1.4	0.8	8.5	1.1
4—5	0.2	0.5	0.6	0.0	0.0	0.0	0.2	0.0	1.5	0.2
5—6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.05
6—7	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.03
Total	3.6	3.4	3.6	4.4	4.0	4.8	8.2	6.8	38.8	4.9
n	6	6	5	5	5	5	5	5	42	

## LOCALITY B

Depth (cm)	Date (1968)								Total	Mean
	29 June	9 July	11 July	17 July	22 July	26 July	31 July	6 Aug.		
0—1	1.6	0.0	3.2	0.2	1.6	2.8	0.4	0.2	10.0	1.3
1—2	3.2	0.4	1.8	0.4	1.2	1.8	0.4	0.0	9.2	1.2
2—3	3.4	0.2	1.8	0.2	1.0	0.0	0.0	0.0	6.6	0.8
3—4	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	1.2	0.2
4—5	0.8	0.0	0.0	0.0	0.2	0.0	0.0	0.0	1.0	0.1
5—6	0.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.6	0.1
Total	9.8	1.0	7.2	0.8	4.2	4.6	0.8	0.2	28.6	3.6
n	4	5	5	5	5	5	5	5	39	

visual change during the investigation, the mud surface strikingly reflected the effects of the increased temperature. The slimy bacterial film spotted on diatoms and red *Spirula* at the beginning of the period, successively changed, and the reducing phases of the sulphur cycle at the decreasing Eh-values started to work intensively even in the surface layers of the mud. In a middle phase, the still good supply of oxygen and light in the bottom water favoured the growth of purple sulphur bacteria, but the increasing steepness of the Eh-gradient between the more oxygenated mud surface and the increasing SH<sup>-</sup>-activity in the sediment beneath, favoured a typical gradient organism such as *Beggiatoa* (Pringsheim, 1964; Wood, 1965, p. 135) which began to flourish (cf Fenchel, 1969, p. 152). The increasing content of gases such as CH<sub>4</sub> and H<sub>2</sub>S in the mud first make the sediment increasingly thixotropic, the minute gas bubbles unite, expand, and cause the conspicuous cracks on the sediment surface. The significance of these crevices for the oxygenation of the sediment is proved by the presence of *Beggiatoa* growing in the fresh gradients in new cracks. The increasing anaerobiosis in the sediment forces the fauna upwards, wiping out the less

resistant components, and favouring the facultative anaerobes such as the nematodes, which flourish vigorously (Fig. 7).

Let us choose *Macoma baltica* as a typical representative for the Baltic mud bottom with fairly stable populations owing to its long generation time. The dynamics of the macrofauna then appear as in Table 4. Whereas the sandy bottom (Locality A) shows little difference in the vertical distribution during the investigation period, the mud bottom (Locality B) reflects great changes. Not only are there less animals during the last period, but the lower limit for the vertical distribution of the organisms is successively moved towards the surface. At the last sampling, all specimens were concentrated in the topmost centimeter. This was further supported by visual observations during the last dives, when many animals, still alive, could be seen lying on the sediment surface.

The properties of the mud bottom responsible for the decrease of oxygen and upward migration of the RPD-layer are: (a) low turbulence; (b) increasing temperature; (c) high organic content. This is in good agreement with the findings of Fenchel and Riedl (1970, p. 259).

The sandy locality, characterized by high turbulence and low organic content, shows less response to increasing temperatures and also higher macrofauna populations than the mud locality.

### Summary

1. The effects of a sudden, natural temperature rise upon a soft-bottom community in the northern Baltic Sea was followed continuously at 2 localities of 10 m depth, one sandy, the other muddy.

2. The mean abundance of the macrofauna was on the sandy bottom  $(2.1 \pm 0.1) \times 10^4$ , on the muddy bottom  $(6.0 \pm 0.7) \times 10^3$  individuals  $\cdot$  m<sup>-2</sup>. Most abundant on both localities were the oligochaetes, most of them falling into the meiofauna category. Dominating species on the sandy locality were: *Pygospio elegans* (1,800), *Corophium volutator* (2,100), *Hydrobia* spp. (3,100), *Mytilus edulis* (3,000) and *Macoma baltica* (1,900). *M. baltica* was also common on the mud bottom, with numbers of 1,500 individuals  $\cdot$  m<sup>-2</sup>.

3. The meiofauna, only sampled on the mud bottom, averaged  $1.1 \times 10^6$  individuals  $\cdot$  m<sup>-2</sup>. In this figure are also included some macrofauna specimens; however, their number is very restricted owing to the small sample surface (1 cm<sup>2</sup>). The dominating meiofauna representatives (individuals  $\cdot$  m<sup>-2</sup>  $\times 10^4$ ) were the nematodes (77), the ostracod *Candona neglecta* (2.7), the oligochaetes *Amphichaeta sannio* (6.5) and *Nais elinguis* (4.2), unidentified oligochaetes (9.8) and turbellarians (3.8).

4. The redox-potential-discontinuity (RPD)-layer was rather stationary in the sand, but moved gradually upwards in the mud, owing to the increased bacterial activity in this bottom. The mud surface reflected the changes of decreased oxygen availability (ODR) and redox-potential (Eh) in the sediment. The initially oxidized, yellowish surface layer of bacteria coloured by diatoms and red *Spirula*, gradually transformed to a greyish film with areas of purple bacteria (*Chromatium*) and the filamentous white sulphur organism *Beggiatoa*. During the latter part of the investigation, large areas were covered by these whitish filaments, like a gigantic cob-web.

5. The fauna in the mud bottom was forced upwards by the emerging RPD-layer; the animals — revealing symptoms of stress, but still alive — were found in a thin layer at the sediment surface. The abundance of *Macoma baltica* (individuals  $\cdot$  25 cm<sup>2</sup>) during the earlier part of the period ranged between 0.8 and 9.8, and decreased to 0.2 during the last week. All the specimens were then concentrated in the top centimeter of the mud.

6. The sandy bottom was hardly affected by rising temperature as to Eh, pH, ODR, and fauna.

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