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A new reality for coastal zoobenthos: long-term changes (1958–2005) in a shallow sheltered bay

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The zoobenthos in the narrow and shallow brackish-water bay Kuristenlahti in Airisto (SW Finnish archipelago) was studied in 2005, and the results were compared to unpublished data from 1958–1965 from the same area in order to analyse the long-term and spatial variability of the fauna. Observations were made at seven different stations. The length-frequency distribution was recorded for the bivalve *Macoma balthica* to study recruitment and survival in this specific environment. Significant changes in species composition, diversity, abundance and biomass, corresponding to changes in the environment, had occurred over time. After 1965 a smaller port for leisure boats had been built in the bay, and a fish farm was active for some years at the seaside of the entrance to the bay. These events, combined with severe eutrophication due to the nutrient load from the agriculture close to the bay have affected the zoobenthos negatively, and the zoobenthic assemblages of today are significantly different from and poorer than those found in the bay 40–45 years ago. This study highlights the importance and value of available reference-data for the evaluation of the present-day environmental status.

1. Introduction

The Kuristenlahti bay is a narrow and shallow inlet situated about 15 km SW of the city of Turku at the eastern coast of the island of Rymättylä (Rimito), SW Finland (Fig. 1). The length of the bay is about 3 km, greatest width 400 m and the total area 0.7 km^2. The shores are steep sloping to a depth of 3 m or less. The bottom consists of grey ooze, and is evenly flat. Near the entrance in Kuristensalmi sound, the maximum depth is 4.4 m. The bay is connected to the Airisto Sound in the west by a narrow strait, with a threshold depth of 2 m, ensuring water-exchange with the surrounding area.

We wanted to study the temporal variability of zoobenthos in Kuristenlahti, repeating a survey by Haahtela in 1958–1965 (Haahtela 1959, and unpublished material), the results of which are included in the present study. One aim was to give an indication of the present state of the bay, using zoobenthos as an environmental indicator, as done both for specific enbayments and larger areas in the Baltic Sea (Leppäkoski 1975, Voipio 1981, Bonsdorff *et al.* 1991, 1992, Jumppanen & Mattila 1994, Kraufvelin *et al.* 2001, Rosenberg *et al.* 2004).

Since 1958–1965 many physical changes have occurred in and around the Kuristenlahti bay. A minor port for leisure boats has been built, and the sound Kuristensalmi has been dredged approximately 1990. Rainbow trout (*Oncorhynchus mykiss)* was farmed between 1982–2003 at the seaside of the bay, close to the entrance. Extensive agriculture is also practiced along the shores, highly

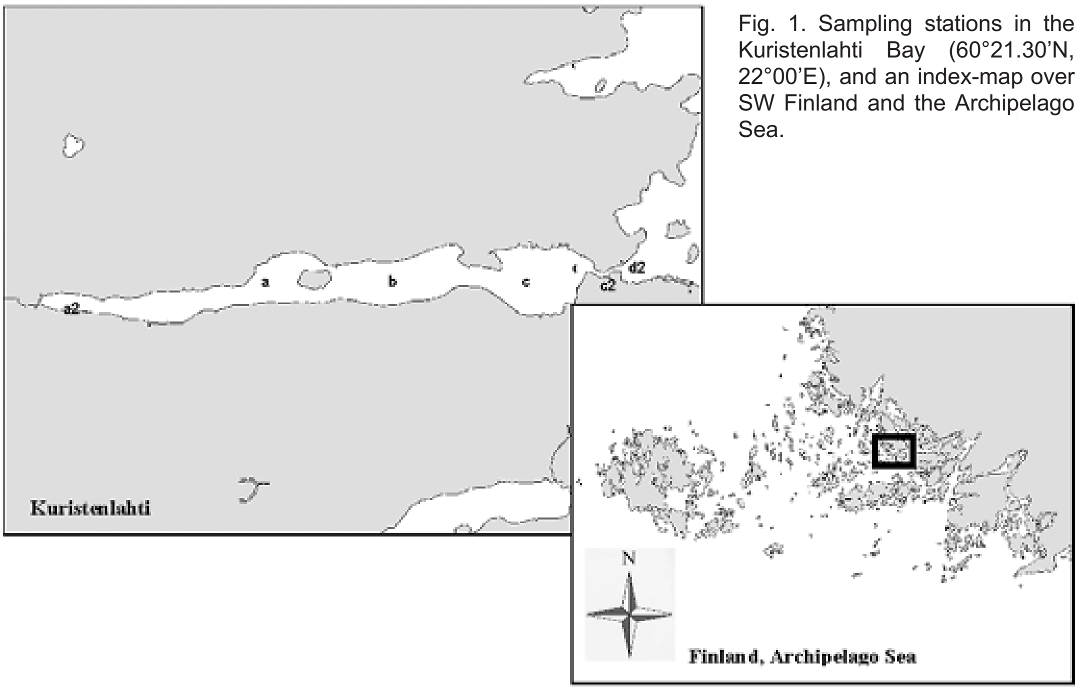

Fig. 1. Sampling stations in the Kuristenlahti Bay (60°21.30'N, 22°00'E), and an index-map over SW Finland and the Archipelago Sea.

affecting the environment due to the nutrient-load from the fields. This increase in nutrient input causes increased primary (and secondary) production, i.e. eutrophication (Bonsdorff *et al.* 1997a). The nutrient load and the increased primary productivity, among other factors, has affected the water transparency in the Archipelago Sea, and also affected zoobenthos over large areas (Bonsdorff *et al.* 1997b).

Benthic invertebrates are usually stationary and relatively long-lived (one to several years). They are thus good indicators and integrators of environmental change over time (Jumppanen & Mattila 1994). Although the present study does not verify changes of the benthic populations in Kuristenlahti over the whole time period 1958–2005, a significant change in species abundance and in dominance patterns would indicate environmental change between what we consider to be reasonably pristine conditions in the late 1950's and early 1960's, and the relatively stressed environment of today.

2. Material and methods

Sampling of zoobenthos in 2005 was carried out at seven stations of which *a2, a, b, c* and *d* were taken in the Kuristenlahti bay proper, station *c2* in the westernmost part of the Kuristensalmi sound and station *d2* at the seaside of the sound (Fig. 1). The samples were taken in late July with an Ekman-Birge hand-operated box corer (18x18 cm). Stations *a, b, c* and *d* are the same that Haahtela studied in 1958–1965 (the raw data for this study, 1958–1965, are stored on CD-ROM at the Archipelago Research Institute, University of Turku). At stations *a2, c2* and *d2* sampling was carried out in 2005 only (Fig. 1). In 1958–1963 five replicate samples were taken at each station, and in 2005 five samples at stations *b, d* and *d2*, four at station *a*, and one at stations *c* and *c2*. At station *a2* only visual observations were made since the bottom was covered with a dense mat of the yellow-green algae *Vaucheria dichotoma*.

In 1958–1963 sieves with a mesh size 0,7 mm and 1,0 mm were used. In 2005 a mesh size of 0,5 mm was used in order to collect as many organisms as possible, and in order to allow comparisons with other modern studies often using 0.5 mm

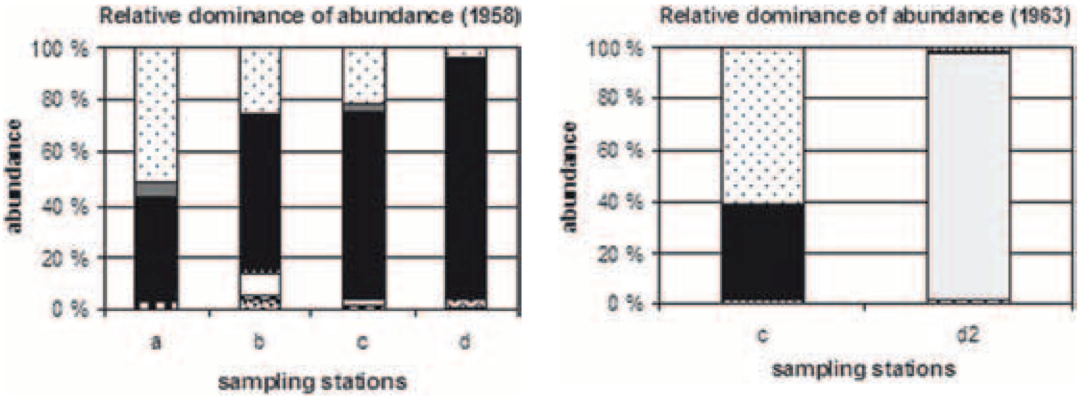

Fig. 2. Relative dominance of abundance (ind/m^2) for stations a, b, c and d (1958), and stations c and d2 (1963) respectively. For species-legends, see Fig. 4.

mesh as a standard in coastal monitoring. We also wanted to ensure a conservative estimate in case of a decline in the fauna. The samples were collected in large plastic boxes, one sample in each, after which they were sieved in the field and then instantly preserved in 70% alcohol-solution. The parameters studied were species composition and diversity, species-level and total abundance and biomass, and size class distribution of the bivalve *Macoma balthica*. Whenever possible, all benthic animals were identified to the species level. Chironomid larvae were identified to the family level, with the exception of *Chironomus plumosus*. The larval and pupal developmental stages were recorded for all chironomids. All sorting and identification was done in the laboratory under a microscope. The wet weight of each subsample was measured to 0,01 g level, as was done in the study 1958–1965. The length of the bivalve *M. balthica* was measured to the nearest mm. In 2005, depth, temperature and conductivity were recorded with a CTD-probe (Sea-Bird Electronics Inc. USA, SBE 19-03) from the surface to 0,5–1 m above the bottom. The data collected in 2005 and the unpublished data from 1958–1965 were analysed using the PRIMER software-package. The similarities within and between the sampling stations of 2005 are analysed as well as the similarities between the years 1958, 1965 and 2005. Similarity percentages and species contributions were also calculated. The results are further illustrated by hierarchical cluster analysis in order to find natural groupings of the stations and years, and a NMDS ordination which constructs a configuration of the samples (Clarke & Warwick 1994).

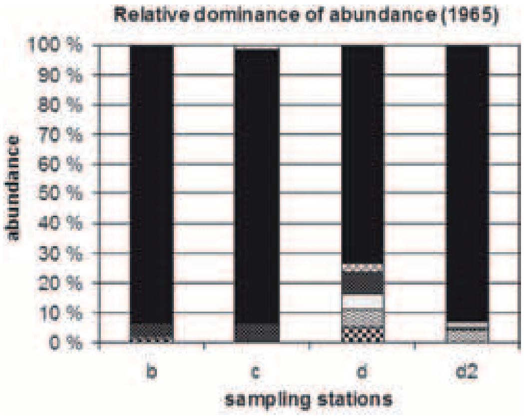

Fig. 3. Relative dominance of abundance (ind/m^2) for stations b, c, d and d2, 1965. For species-legends, see Fig. 4.

3. Results

The sampling stations were 2–5 m deep, and in 2005 the salinity was 5,8 psu in the entire inlet. Oxygen conditions were good (6,8–8,3 mg/l). Transparency was 0,7–0,8 m, compared to 0,9–1.6 m in the early 1960's, i.e. a reduction in Secchi depth had taken place. The years 1958 and 1965 are most similar with regard to zoobenthos, with an average dissimilarity of only 50,99%. When comparing 2005 to the earlier years, 2005 is most similar to

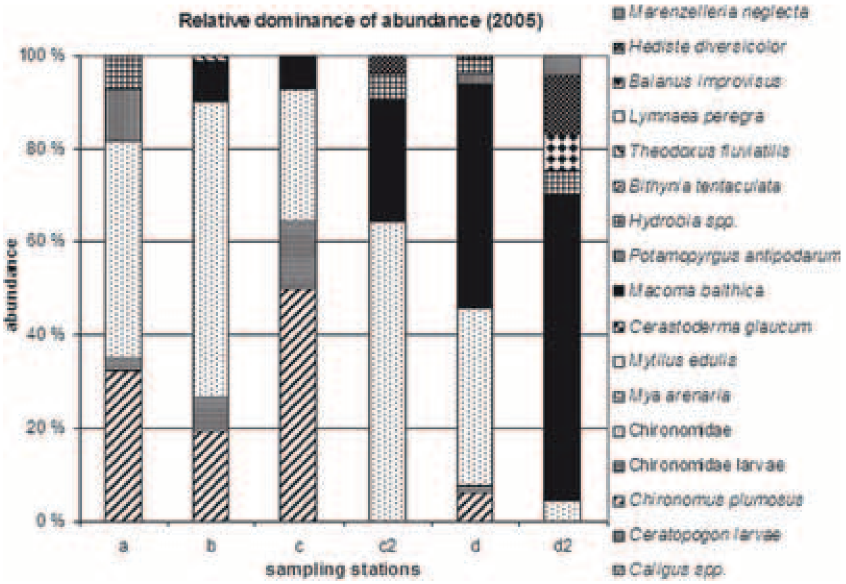

Fig. 4. Relative dominance of abundance (ind/m^2) for stations a, b, c, c2, d and d2, 2005 (incl. legends).

1958 with an average dissimilarity of 51,84% (average dissimilarity between 2005 and 1965: 65,93%). There is a gradient of decreasing abundance of Chironomidae from the innermost station *a* to the outermost stations *d* (1958) and *d2* (2005), and a gradient of increasing abundance of *Macoma balthica* in the same direction. The pattern was generally similar in 1958 and 2005, although in 1958 the abundance of *M. balthica* (mean: 226,25 ind/m^2) was lower than in 2005 (mean: 273,50 ind/m^2), although the difference was not significant. At station *c, M. balthica* was the dominant species in 1958. In 1963 the station was dominated by Chironomidae-larvae although *M. balthica* was still abundant. At station *d2* the bivalve *Mytilus edulis* was the dominant species in 1963, but in 1965, only two years later, this position was taken over by *M. balthica*. In 2005 *M. edulis* was not found at all in the bay. *M.edulis* is described as an oligosaprobic species (species sensitive to pollution, see Leppäkoski 1975). This would indicate that the environmental conditions in 1963 in the Kuristenlahti bay were still good. A positive change in environmental parameters seemingly occurred sometimes between 1958 and 1963, followed again by a negative change between 1963 and 1965, unless the finding of *M. edulis* in 1963 was a chance-event (Figs 2, 3 & 4).

Two species which were not recorded in 1958–1965 were found in 2005: the cirriped *Balanus improvisus* and the polychaete *Marenzelleria neglecta* (Bastrop & Blank 2006). Because *B. improvisus* is a sessile organism, it is only accidentally recorded in samples from soft bottoms. It is very common in the Airisto sound and thus evidently not a new species to the study area. However, *M. neglecta* was not introduced to the Baltic Sea until in the beginning of the 1980s. Since then it has rapidly spread throughout the continent, including the northern parts of the Baltic Sea (Bick & Buckhardt 1989, Norkko *et al*. 1993, Bastrop & Blank 2006). It favours coastal eutrophicated areas (Kotta *et al.* 2003). Species present in 1958–1965 not found again in 2005 include larvae of the Dipteran family Ceratopogonidae, the pulmonate gastropod *Lymnaea peregra,* prosobranciate gastropod *Bithynia tentaculata,* the bivalves *Mya arenaria* and *Mytilus edulis* and the polychaete *Polydora redeki*. *P.redeki* was first found in Kuristenlahti 1965 (Eliason & Haahtela 1969). Some copepods (e.g. *Caligus* spp.) were recorded in 2005, but they are not considered as zoobenthos. The bivalve *Cerastoderma* spp., named as *Cardium lamarcki* in 1958–1965, nowadays *Cerastoderma glaucum* (White 2002, www-document) was abundant at station *a2* intertwined in the alga *Vaucheria dichotoma*. This alga was not recorded in the Kuristenlahti bay in 1958–1965 and the specimens of *Cerastoderma* then found, were recorded in the box-corer samples. For a complete

Table 1. All benthic species recorded in the Kuristenlahti Bay in the years 1958, 1963, 1965 and 2005.

	1958				1963		1965				2005					
Species /Station	a	b	c	d	c	d2	b	c	d	d2	a	b	c	c2	d	d2
Marenzelleria neglecta																x
Hediste diversicolor		x				x	x	x	x	x				x	x	x
Balanus improvisus																x
Lymnaea peregra		x	x						x							
Theodoxus fluviatilis									x			x				
Bithynia tentaculata		x														
Hydrobia spp.										x	x			x	x	x
Potamopyrgus antipodarum					x	x				x	x				x	
Macoma balthica	x	x	x	x	x		x	x	x	x		x	x	x	x	x
Cerastoderma glaucum	x	x	x	x			x		x							
Mytilus edulis						x	x									
Mya arenaria				x		x			x	x						
Chironomidae	x	x	x	x	x			x			x	x	x	x	x	x
Chironomidae larvae											x	x	x		x	
Chironomus plumosus											x	x	x		x	
Ceratopogon larvae	x		x													
Caligus spp.							x									

list of species recorded in 1958–1965, and in 2005, see Table 1.

Since 1965 the number of species has decreased at all stations except at the outermost station *d2*. However, the number of individuals per m^2 has increased (mean 1965: 156 ind/m^2, 2005: 170 ind/m^2), except at station *d2* (Fig. 5). I.e. the gradient of increasing abundance follows the same pattern for both time periods from station *b* to station *c*, then decreases from *c* to *d* (even though the decrease is more drastic for 1965 compared to 2005). A significant change in the gradient for abundance between station *d* and *d2* has occurred since 1965. Total biomass has decreased significantly (mean 1965: 33 g wwt/m^2, 2005: 2 g wwt/m^2: Fig. 6). The decrease is mainly due to the decrease in biomass of one species, *M. balthica*, which in 1965 consisted of individuals of several size-classes and in average 86.5% of the whole biomass. In 2005 the great majority of *M. balthica* were < 1 mm, and constituted only 25,9% of the total biomass. This indicates failed recruitment in the previous years.

The majority were less than 1 mm in size. The sediment in the inlet is soft mud, containing various amounts of algal material, such as *V. dicho-*

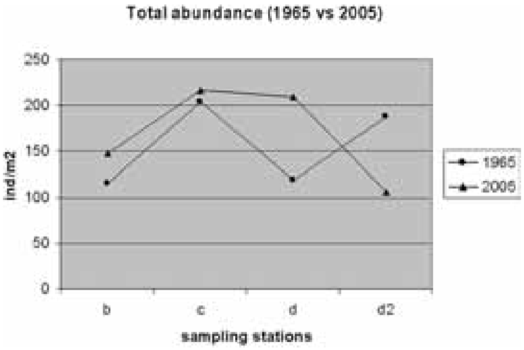

Fig. 5. Total abundance (ind/m^2) for stations b, c, d and d2 (1965 vs. 2005).

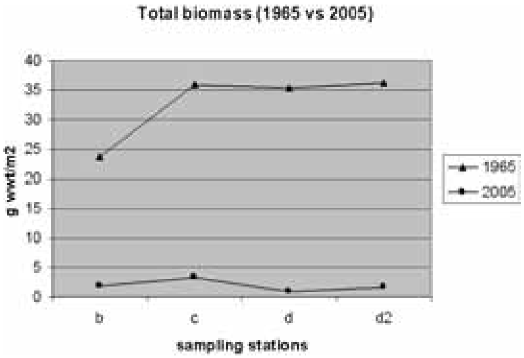

Fig. 6. Total biomass (g wwt/m^2) for stations b, c, d and d2 (1965 vs. 2005).

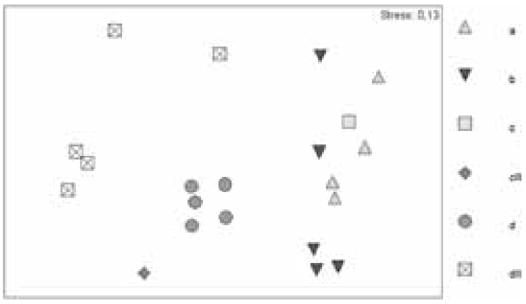

Fig. 7. NMDS ordination of sampling stations, 2005 (data presented for individual grabs).

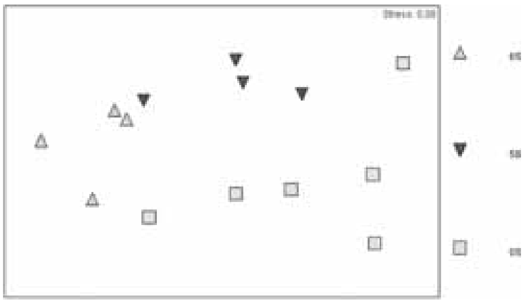

Fig. 8. NMDS ordination of all stations for the years 1958, 1965, 2005.

toma which was not present in 1958–1965. The statistical analysis for 2005 (ANOSIM) shows that stations *a–d* and *a–d2* differed significantly (p<0,008), *b–d* and *b–d2* as well as *d–d2* also had significant dissimilarities (p<0,008, Fig. 7). For most stations Chironomidae and *M. balthica* were the main contributors of the dissimilarities. The years 1958 and 2005 were more similar than 1965 and 2005 (Figs. 8 and 9; % transformation). However, when analysing these figures, notice the differing number of replicates (1958 and 1965: all five replicates, 2005: *b, d, d2* five replicates, *a* four replicates and *c* and *c2* one sample each).

4. Discussion

Analysing the studies conducted in the period 1958–1965 and on the other hand in 2005, we cannot tell exactly when and why the changes recorded have taken place, but we can show significant changes in the zoobenthos between "then" and "now", just as has been shown for other archipelago-regions (see e.g. Hänninen & Vuorinen 2001, Perus & Bonsdorff 2004). Changes in a restricted area, such as the Kuristenlahti bay, may not have more significant implications than simply that of an environmental shift on a very local scale (Bonsdorff *et al.* 1991). We cannot tell whether the changes have been ongoing for a longer period, or if the results of 2005 only represent a shift in the environmental state, or if eutrophication has reached its peak in the region (Jumppanen & Mattila 1994, Bonsdorff *et al.* 1997 a, b). Perhaps the state of the Kuristenlahti bay will improve, although the probable future is the opposite due to the magnitude and diversity of environmental stress. We can only conclude that the differences in numbers of species, abundances and in total biomass in 1958–1965 and 2005, are most likely results of this ongoing stress (e.g. nutrient run-off from extensive agriculture surrounding the bay, dredging, fish farming and the port) which has occurred over the years in this area. The presumed

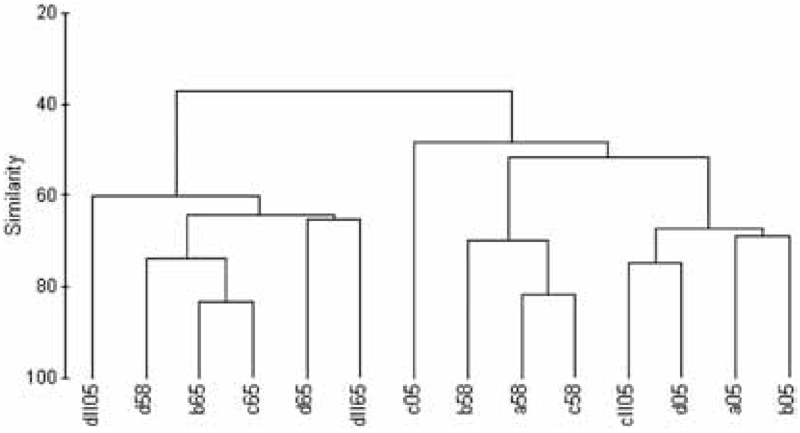

Fig. 9. Dendrogram over hierarchical cluster analysis of years and sampling stations.

negative changes in areas close to the Kuristenlahti bay have further strengthened the negative effects of eutrophication. Unfortunately this narrow inlet has not been regularly studied since 1965. The importance of studying coastal shallow areas was largely recognized as late as the 1980's (Bonsdorff *et al.* 1991). The coastal areas are usually highly productive and are also the first ones to be affected by eutrophication (Cederwall & Elmgren 1980, Larsson *et al.* 1985, Elmgren 1989, Bonsdorff *et al.* 1991).

The size-structure of *Macoma balthica* may reflect adaptive responses to a significantly changed environment, at least at population level (Bonsdorff *et al.* 1991). Boesch & Rosenberg (1981) showed that species which are last eliminated from an environment due to environmental stress, are also the first to re-colonize the area. These organisms act as opportunists in the different successional stages and, hence, often characterize the whole recovery process. These species are not superseded until the niches are again made available through additional environmental stress (Peterson 1979, 1980, Ambrose 1984). Chironomidae and Oligochaeta are recognized as opportunists which thrive in eutrophicated areas (Loch *et al.* 1996). In addition, the chironomid *Chironomus plumosus* indicates eutrophication (Perus & Bonsdorff 2004). Chironomidae and *M. balthica* were the most abundant species in the Kuristenlahti bay 2005. *M. balthica* is one of the most successful species in the northern Baltic, because it can resist environmental stress in a very wide range and has only few competitors.

Eutrophication causes changes in the fish populations which, in turn, can increase the predation pressure on *M. balthica*. This bivalve is a typical food source for several fish in the Baltic (Segerstråle 1960). E.g. bream (*Abramis brama*) and roach (*Rutilus rutilus*) feed on *M. balthica*. The roach is favoured by eutrophication (Haahtela 1959, Bonsdorff *et al.* 1997 a, b). This food chain link most likely serves as an explanation to the lack of larger individuals of *M. balthica* in the outer parts of the bay.

Unfortunately the length-frequency distribution of *M. balthica* was not recorded in 1958–1965, which makes a direct comparison difficult. The maturation of *M. balthica* occurs at a length of approximately 6 mm (Budd & Rayment 2001, www-document). This would imply that only a few specimens at stations *d, c2* and *d2* would be of adult size and hence would be able to reproduce locally. Most of the individuals were, however, of a size < 1 mm, which indicates that they are litter of 2005. Most *M. balthica* do not survive over the winter in the inner parts of the bay, possibly due to oxygen-deficiency, which partly explains the large difference in biomass from the early 1960's until 2005.

We can conclude that in the Kuristenlahti bay the species composition and the abundance has changed since 1958. Especially the biomass has decreased drastically in forty years. The locations of the sampling stations were less exact in 1958–1965 than in 2005, but we believe that this has not had any major effect on the results. Studies of this kind have their value in that reliable background-information, often unpublished and forgotten, can give us a clue to what has happened to the sedimentary organism-assemblages in our coastal bays over the last three to five decades, i.e. since eutrophication in a larger scale started with the use of artificial fertilizers.

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