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A recent change in size distribution of blue mussels (*Mytilus edulis*) in the western part of the Gulf of Finland

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We sampled blue mussels (*Mytilus edulis*) in 1992–1996 from mussel beds that common eiders (*Somateria mollissima*) preferentially use during foraging in the Hanko archipelago, Finland. We also compared our data with an earlier study carried out in the same area. We found a consistent trend towards decreasing mussel size; the proportion of larger mussels in the population has decreased significantly. Since blue mussels are an essential part of the Baltic ecosystem, a shift in mean mussel size may have important consequences. A decrease in salinity during the last few decades may be the ultimate reason for the observed changes, as salinity affects growth, maximum size and reproduction of mussels. We also suggest that selective eider predation may be of local importance.

1. Introduction

Blue mussels (*Mytilus edulis*) dominate the animal biomass on Baltic hardbottoms (Kautsky 1981). The Baltic blue mussel is a dwarf-form of its marine counterpart and is sometimes even regarded as a semispecies (Väinölä & Hvilsom 1991). Despite its relatively small size, the Baltic blue mussel is very important in the Baltic ecosystem. On one hand, adult mussels are the staple food of common eiders (*Somateria mollissima*) and flounder (*Platichthys flesus*), while mussel larvae play a very important part in the diet of both herring larvae and other carnivorous zooplankton (Kautsky 1981, Öst 1995). On the other hand, blue mussels are very suitable as bioindicators. This is because blue mussels are virtually ubiquitous in both coastal and brackish waters; they are sessile and long-lived and thus passively experience all conditions in the water mass (Sunila 1987).

As a part of our studies of the foraging behaviour of common eiders, we have sampled blue mussels in the Hanko archipelago, SW Finland. We initially found a small mean size of mussels at some sites compared with the mussel size eiders seem to prefer (Bustnes & Erikstad 1990, Öst 1995). In the central parts of the Gulf of Finland, larger mussels seem to have disappeared altogether, with only very small mussels remaining at the bottom (Hollmén *et al.* 1996). A corresponding drastic decrease in eider population size has occurred in the area (Hario *et al.* 1992). Virtually nothing is known about the long-term population dynamics of blue mussels despite a recent upsurge in monitoring efforts for several marine invertebrates in the Baltic (Viitasalo *et al.* 1990, Viitasalo 1994).

In this paper we report on a change in mean mussel size within a short period. Because of the fundamental importance of the blue mussel in food webs, a shift in mean mussel size and, accordingly, mussel biomass may have important consequences for the Baltic ecosystem.

2. Material and methods

Using a triangular bottom scraper, mussels were sampled from mussel beds that common eiders preferentially use during foraging (own obs.). There were two main sampling areas. The first area, Hangö Västra, is situated west of the Hanko peninsula (60°N, 23°E). Here, mussels were collected in 1992 and 1996 (2 sites). Mussels were also collected near the Tvärminne Zoological Station east of the Hanko peninsula in 1994 and 1996 (8 sites). The position of sampling sites was recorded onto field maps and the same sampling sites were used every year. A map of the study area can be found in Öst (1995). The Hanko archipelago can generally be described as a fine-scaled mosaic of islands, islets and small skerries. The seashore is dominated by seaweed (*Fucus* spp. and *Cladophora* spp.). The *Mytilus edulis* mussel beds are found on hardbottoms ranging in depth from about 3–10 m (O. Mustonen, pers. comm.). The spatial segregation between these habitats is of the magnitude of a few metres. Mussels less than about 3 mm long are attached to filamentous algae in the littoral zone and are not found in the mussel fields (Sunila 1981). Our sampling sites, all of which represent typical hardbottom mussel fields frequented by foraging eiders, ranged in mean depth from 3.4–9.5 m according to the depth measurements we conducted in 1994. The salinity in the area is 6–7‰ (Sunila 1981). The mussels were sieved through a 1-mm mesh screen and the length of the mussels measured with a vernier calliper to the nearest 0.1 mm. In addition, we excluded the few mussels less than 5 mm long because these mussels are secondary food for eiders (Bustnes & Erikstad 1990), and we focused instead on the mussels that eiders utilise preferentially.

3. Results

The mussel size distribution differs between Hangö Västra and Tvärminne (Hangö Västra 1992 vs Tvärminne 1994: Two-tailed Kolmogorov-Smirnov test, $D = 0.42$, $n_1 = 560$, $n_2 = 257$, $p < 0.001$; Hangö Västra 1996 vs Tvärminne 1996: $D = 0.47$, $n_1 = 251$, $n_2 = 293$, $p < 0.001$). There are fewer of the larger mussels in Tvärminne than in Hangö Västra. These differences have probably existed for a longer period; a description of the mussel size distribution outside Tvärminne at the end of the 1970s can be found in Sunila (1980, 1981).

The mussel size distribution at Hangö Västra differed significantly between 1992 and 1996 (Sample 1: Two-tailed Kolmogorov-Smirnov test, $D = 0.35$, $n_1 = 260$, $n_2 = 70$; $p < 0.001$; Sample 2: $D = 0.32$, $n_1 = 300$, $n_2 = 181$, $p < 0.001$). At both sampling sites the trend was similar: in 1996, the largest mussels had more or less disappeared, and the proportion of the smallest mussels had corre-

Table 1. Median length, maximum length and sample size of mussels sampled from Tvärminne and Hangö Västra. At Tvärminne, mussels were collected in 1994 and 1996 and at Hangö Västra in 1992 and 1996 (median values were used instead of means because some samples were not normally distributed).

		Median (mm)		Max. (mm)		*n*	
Site	Sample	1992/94	1996	1992/94	1996	1992/94	1996
Tvärminne	1	11	11	29.7	27	30	44
	2	18.9	21	29.5	29	33	21
	3	11.1	7	37.2	33	14	33
	4	19.9	7.1	29.1	25.2	30	47
	5	8.9	8.4	18.4	22.7	30	39
	6	13	7.6	35.3	16.1	30	32
	7	10.4	7.8	17	15.8	30	44
	8	11.2	7.6	15.1	22.1	30	33
Hangö Västra	1	18.6	10.7	46.2	34.3	260	70
	2	21.4	15.5	40.2	31.1	300	181

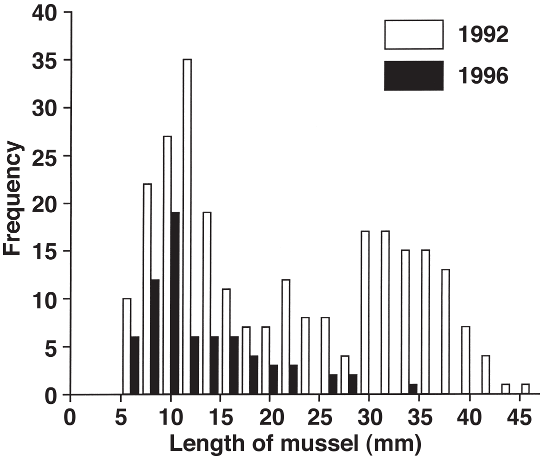

Fig. 1. The mussel size frequency distribution at Hangö Västra, Sampling Site 1, in 1992 ($n = 260$) and 1996 ($n = 70$). The data is grouped in 2-mm size classes.

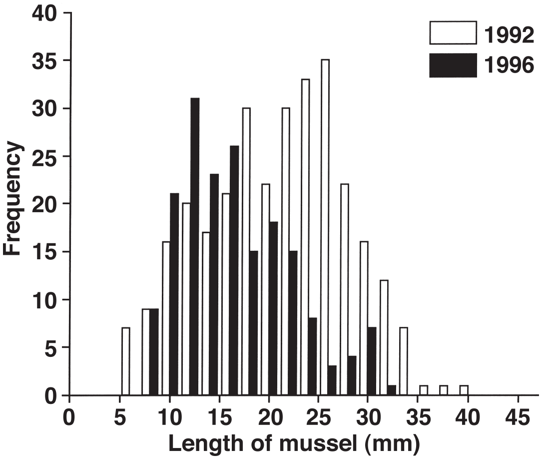

Fig. 2. The mussel size frequency distribution at Hangö Västra, Sampling Site 2, in 1992 ($n = 300$) and 1996 ($n = 181$). The data is grouped in 2-mm size classes.

spondingly increased, compared with the situation in 1992 (Table 1, Figs. 1 and 2).

The mussel size distribution outside Tvärminne differed between 1994 and 1996 (all samples pooled: Two-tailed Kolmogorov-Smirnov test, $D = 0.42$, $n_1 = 227$, $n_2 = 293$, $p < 0.001$). In 1996, there were fewer large mussels than in 1994 and, correspondingly, the proportion of the smallest mussels had increased compared with 1994 (Fig. 3). The mussel size distributions differed quite consistently between 1994 and 1996, even after the material was subdivided into samples (Table 1). In four of the eight sampling sites from Tvärminne, the mussel size distribution differed significantly between the two years: the proportion of large mussels had decreased and the proportion of small mussels increased in 1996 compared with 1994 (Two-tailed Kolmogorov-Smirnov tests, $p < 0.001$ in all these cases). The size distributions were equal in three cases and the number of mussels in Sample 3 was too small to analyse by statistical procedures. It is noteworthy that none of the samples showed a trend towards increasing mussel size.

Good data exist on the size distribution of mussels in a mussel field outside Tvärminne in 1978–79 (Sunila 1980, 1981). Hence it is possible to make a long-term comparison of the mussel size distribution of this area by comparing our data with this data set. We chose only those sites that were from the same area as the the sampling sites studied by Sunila (1980). We also excluded mussels less than 5 mm long from the data set of Sunila (1980) in order to make this data homogeneous with ours. The mussel size distributions in 1978–79 and 1994 differed significantly from each other (Two-tailed Kolmogorov-Smirnov test, $D = 0.37$, $n_1 = 1\ 008$, $n_2 = 120$, $p < 0.001$). The proportion of small mussels was higher and the proportion of large mussels smaller in 1994 than in 1978–79. Naturally, these differences in mussel size distribution are even more extreme when the data from 1996 are compared with the data

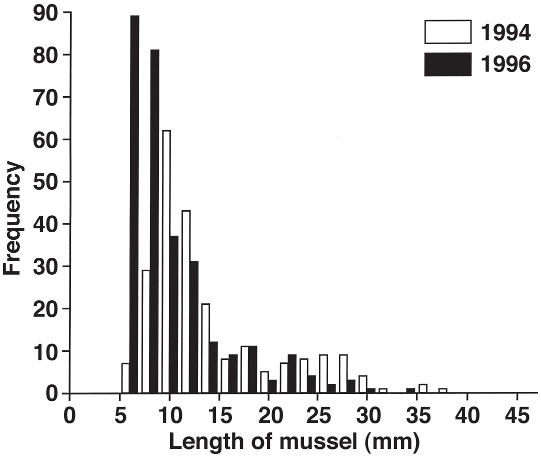

Fig. 3. The mussel size frequency distribution at Tvärminne, all samples pooled, in 1994 ($n = 227$) and 1996 ($n = 293$). The data is grouped in 2-mm size classes.

from 1978–79 (Two-tailed Kolmogorov-Smirnov test, $D = 0.48$, $n_1 = 1\,008$, $n_2 = 148$, $p < 0.001$). Thus, it is plausible to assume that the change in mussel size distribution has continued for longer, at least in Tvärminne.

4. Discussion

The populations of blue mussels in the Baltic have traditionally been described as stable, extremely dense populations living near the carrying capacity of the area with regard to food and space availability (Kautsky 1981, 1982ab). The total number of mussels in a mussel bed has been considered as rather constant during the year, and this constancy applies especially well to the larger (≥ 2 mm) mussels (Kautsky 1982a). Because of the lack of predatory pressure in the Baltic, dead adult mussels have been found to accumulate on the bottom, which is why they have even been called a "dead end" in the food web (Kautsky 1981).

There are, however, some indications that the situation described above has begun to change. Changes have occurred in both central and more marginal parts of the range of Baltic blue mussels. In 1994, a tendency towards both decreasing coverage and biomass of blue mussels was found at most of the sampled sites in the Baltic Proper (Kautsky 1995). However, the changes have been even more obvious in areas closer to the lower salinity tolerance limit of mussels (4.5‰, Sunila 1981). Here, decreasing coverage and biomass of blue mussels as well as a decrease in mean mussel size have been observed. At Söderskär, in the central parts of the Gulf of Finland, larger mussels are virtually non-existent, and only very small mussels remain at the bottom (Hollmén *et al.* 1996). At the same time the population size of common eiders at Söderskär has decreased drastically (Hario *et al.* 1992, and pers. comm.). Possibly the misfortune of the common eiders in the area may be related to the contemporary disappearance of mussels suitable as food: eiders prefer mussels with a mean size of 16–17 mm (Öst 1995).

The present work demonstrated a shift in mussel size distribution in the archipelago of Hanko: the proportion of larger mussels in the population has decreased. The time interval in our studies was relatively short, only 2–4 years, but probably the forces governing the changes in the mussel populations have been working for a longer period. By comparing our data from Tvärminne with the data of Sunila (1980, 1981) from the same sites, we were able to show that a continuously diminishing trend of mussels may be true from the end of the 1970s to the present.

The smaller mean size of mussels may have important consequences for the population dynamics of mussels. For example, the reproductive output of the population may be reduced. Since gamete biomass increases strongly with size, the maximum contribution to reproduction in the population is from the mid-sized mussels of about 10–25 mm length, while mussels smaller than 10 mm contribute very little, despite their dominance in numbers (Kautsky 1982b). Mid-sized mussels have become scarce in the populations (Figs. 1–3). In the long run, reduced recruitment may result in lower densities and biomass of blue mussels. Unfortunately, nothing is known about changes in population density in our study area, as we did not measure mussel density at the sampling sites.

The main factor affecting growth rate and maximum size of mussels in the Baltic is salinity (Kautsky 1982a, Kautsky *et al.* 1990). Salinity also affects the reproduction of mussels by influencing the percentage of fertilisation and survival of mussel larvae (Kautsky 1982b). Differences in salinity may account for the initial differences in mussel size between Hangö Västra and Tvärminne. The larger size of mussels at Hangö Västra may be explained by slightly higher salinity levels because of a more western and less sheltered location compared with Tvärminne. Perttilä *et al.* (1995) found a significant decrease in salinity in the Gulf of Finland during the period 1975–1992, which corresponds to the trend found for other Baltic Sea areas as well (HELCOM 1990). This decrease is due to the lack of any major saline seawater inflow through the Belt Sea and the Danish Straits into the Baltic Sea (Perttilä *et al.* 1995). Accordingly, the within-site changes in mussel size between years may be explained, at least in part, by decreasing salinity levels.

Growth and maximum size of mussels are controlled not only by salinity, but also by temperature, food supply, wave exposure, light and population structure (Kautsky 1982a). Several of these factors may interact with each other. For example, a long heat-wave in 1994 was one possible explanation for the high mortality of mussels in the Baltic Proper (Kautsky 1995). The food supply may have been insufficient to meet the increasing energy demands of mussels because of high respiration rates due to elevated water temperatures. Consequently, the mussels may have starved to death (Kautsky 1995). An alternative, but less likely explanation for the mussel decline in the Baltic Proper in 1994 was an accumulation of algal mats on the mussel beds, resulting in the death of mussels due to a lack of oxygen (Kautsky 1995). In shallow areas in the Archipelago Sea and the Åland Islands, drifting algal mats have become more common as a result of increasing primary production, thereby representing a serious threat to the biota since they induce severe hypoxia (Norkko & Bonsdorff 1996, Sandberg 1996). However, it seems that drifting algal mats are less common in the Gulf of Finland (J. Lehtonen & O. Mustonen, pers. comm.).

The Baltic eider populations increased rapidly during this century until the mid 1980s (Hario *et al.* 1992), and in the archipelago of Hanko no decline has been observed so far (own obs.). Although the predation on mussels by an increasing eider population cannot be the ultimate reason for the altered mussel size distribution we observed, it can locally still have a major impact. According to the calculations of Kautsky (1981), eiders and flounders both consumed only about 1% of the whole standing stock of adult mussels in the research area of the Askö Laboratory about 70 km south of Stockholm. However, the predation is highly concentrated to a few of the most preferred mussel beds that are utilised by eiders every year (Kilpi *et al.* 1990). To demonstrate the significance of eiders, we can estimate the magnitude of eider predation on mussels at Tvärminne. In a good production year, such as in 1995, 1 000 pairs of eiders nested in the area, rearing about 2 000 fledglings (own obs.). The energy demand of an eider is approximately 555 kcal/day (Nyström & Pehrsson 1988, Bustnes & Erikstad 1990) and the energy content of mussels is ca. 4.9 kcal/g dry weight (Thompson 1985). Taking into consideration the special properties of Baltic blue mussels, an eider therefore consumes about 0.7 kg of mussels per day to meet its daily requirement of food (Öst 1995). Consequently, a population of 1 000 females and 2 000 ducklings staying an average of 60 days in the Tvärminne area annually consumes about 130 metric tons of mussels! Moreover, this predation is concentrated on the larger size classes of mussels, which are numerically a minority in the population (Kautsky 1982a). Of course these are only very rough estimates, but the point is that eiders are able to substantially influence the mussel populations at preferred foraging sites. Observations from scuba-divers also support our theoretical suggestion: outside Tvärminne, signs of heavy eider predation can be seen in the mussel fields (J. Lehtonen & O. Mustonen, pers. comm.). Thus it is possible, for example, that the observed bimodal size frequency at one of the sampling sites at Hangö Västra (Fig. 1) could be explained by selective eider predation (preferred size 16–17 mm, Öst 1995). At Söderskär, the high density of nesting eiders, 2 300 nesting pairs, may similarly have contributed to the rapid decline of larger mussels in the area.

To conclude, we believe that the ultimate reason for the observed change in mean mussel size may be long-term salinity changes affecting the growth rate, maximum size and recruitment of mussels. We find other explanations less probable, e.g. a decrease in food supply or elevated water temperatures possibly combined with an accumulation of algal belts on the bottom. Eider predation is very unlikely to be the primary reason, although it may have a locally modifying effect on the size distribution of mussels. It is uncertain how permanent these changes will be. Some vague signs of a recovery can be discerned in the data from Tvärminne: the high proportion of mussels ranging from 5–10 mm in length in 1996 suggests a high colonization rate of young mussels (Fig. 3). Nevertheless, more long-term studies of the population dynamics of blue mussels are certainly needed. It would be especially important to study changes in population density and recruitment.

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