

# Population structure of long-lived macrozoobenthic species

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## Scientific background of the indicator

The natural balances between the large and small species within the community and the large and small specimen within the population of a single species are affected by climatic changes, changes in food web structure and anthropogenic influences such as eutrophication or physical disturbance (e.g. caused by bottom trawling or sediment extraction) (Pearson & Rosenberg 1978, Hiddink et al. 2006, Westerbom 2006, Tyler-Walters et al. 2009, Basset et al. 2012). Therefore, both approaches can theoretically be used to calculate an aberration of the natural state (Jennings & Dulvy 2005). Large bodied biota are more vulnerable to benthic disturbances and have lower intrinsic rates of increase, and hence, a lower capacity to sustain elevated mortality (Kaiser et al. 2000, 2006). Indicators such as the slope of the body-size spectrum of the benthic assemblage may provide good indicators against which to measure the state of the entire assemblage in response to disturbance treatments (Duplisea & Kerr 1995, Duplisea et al. 2002, Jennings et al. 2002).

The impact of human pressure on the size-frequency distribution (i.e. population structure) of single species has mainly been described for fishes. Regional studies on macrobenthic invertebrates are rare. Amaro et al. (2003) and Witbaard & Bergmann (2003) detected bottom-trawling to be a potential reason for unbalanced population structure of bivalve species (*Mya truncata* and *Arctica islandica*) in the Frisian front. Large bivalves are in general regarded to be the most sensitive group to bottom-trawling within the soft-bottom communities whereas large, mobile gastropods, echinoderms and especially decapod species might benefit from temporal physical disturbance (Rumohr & Kujawski, 2000). Westerbom (2006) reported of changes in blue mussel (*Mytilus edulis/trossulus*) size frequency and density in different environmental conditions, including salinity and sediment content.

Food web changes, caused by altered environmental conditions like decreased salinity or eutrophication or by changes in predation pressure, have been shown to affect the benthic community (Worm & Myers 2003, Lotze & Milewski 2004) and more specifically the size-frequency distribution of single species (Westerbom 2006).

The size-frequency-distribution indicator described in this report is twofold:

- (1) Soft-bottom bivalve indicator is focused on physical disturbance or hypoxia. The response characteristics might differ between the two impacts. Large and long-living species often play key roles in the functioning of the benthic communities and the re-establishment of the population structure of those species is the most lasting step after a severe impact.
- (2) Hard-bottom mussel indicator is focused on the pressure from siltation/sedimentation of organic and inorganic matter and reflects therefore eutrophication in general (e.g. decaying blooms of phytoplankton and macroalgae), riverine run-off of organic and inorganic matter, dredging and disposal of the dredged material as well as shipping.

Both the indicators are proposed to be based on the full spectra of the size distribution and density of indicator species.

## Policy relevance

The Baltic Sea Action Plan sets a biodiversity goal 'Favorable Conservation Status of Baltic Biodiversity' and ecological objectives for 'Thriving and balanced communities of plants and animals' and 'Natural marine landscapes', which include the benthic (abiotic) habitats and associated communities.

Under the EU Marine Strategy Framework Directive, the indicator can describe either a condition of a single species population under the qualitative descriptor 1 (the criterion 1.3 of the EC Decision 477/2010), the condition of benthic habitats (the criterion 1.6) or the condition of benthic communities under the qualitative descriptor 6 (the criterion 6.2). One of the proposed indicators under the criterion 6.2 is 'Proportion of biomass/number of individuals above specified length/size' is one of the proposed indicators.

Indirectly, the indicator also reflects the impacts of hypoxic conditions on benthic fauna and therefore addresses the BSAP ecological objective 'Natural oxygen levels' and the qualitative descriptor 5 of the MSFD (especially the criterion 5.3).

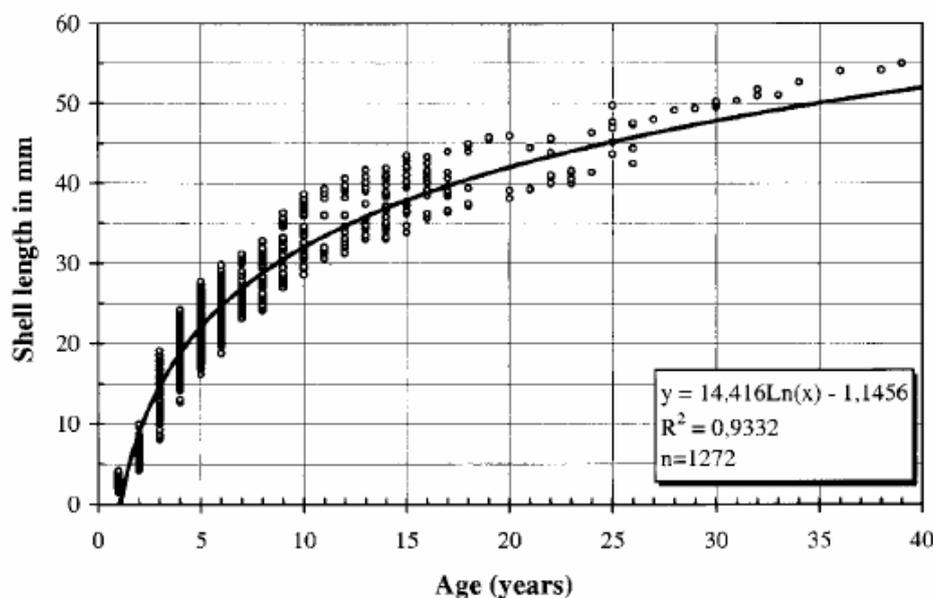
## Soft-bottom bivalves

### Selection of a method for measuring the size structure of bivalves

The indicator may be based on three alternative methods:

1. the deviation from the natural full size-spectrum,
2. the deviation from a mean size, or
3. the proportion of specimen above a certain size class.

In the first case, the basic parameter is the number of individuals per size (class). In general, size is strongly correlated with age (Figure 1) and the disturbance of the size-frequency structure can give valuable hints on the severity, frequency and longevity of impacts.



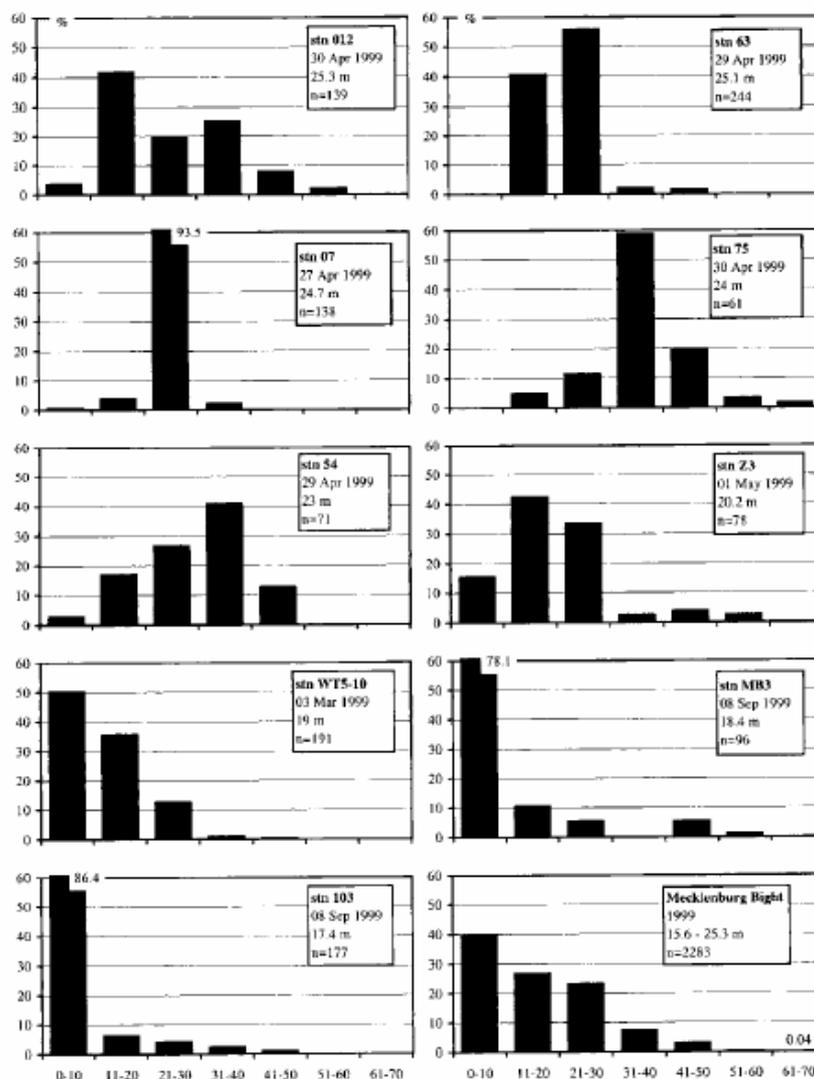
**Figure 1.** Correlation of shell-length with age in *Arctica islandica* (Zettler et al. 2001).

In principle, length-frequency distributions can only be determined using species that survive sampling relatively undamaged and are present in adequate (representative) numbers. In taxonomic terms, crustaceans, molluscs and echinoderms are suitable, but bivalve species should be preferred due to their high sensitivity. However, a careful selection of species is essential and a variety of species should be selected to improve the relevance and the reliability of the results.

The proposed metric would be a comparison of the actual population structure with a (theoretical) natural population structure resulting in a value for the “degree of naturalness” of the population structure. No such metric is known for marine benthic species.

The definition of a mean reference size or biomass integrates all size classes and may become a valuable indicator if all size classes are impacted equally or mainly large specimens are exposed. This is not true e.g. in case of the exposure of

*A. islandica* to hypoxia. In this case young (small) specimens are more sensitive than old (large) specimen potentially leading to a wrong assessment (Figure 2). That is seen in Figure 2 between the stations above and below 20 meters.



**Figure 2.** Size-frequency distribution of *Arctica islandica* at different stations in the Mecklenburg Bight (Zettler et al. 2001). The four upper graphs are from >20 m depth where anoxic events were found and the recruitment of young failed. The four lower graphs are from <20 m depth where recruitment of the species was successful.

Because of the contradictory responses of bivalves to different predominant pressures, it is recommended to use the full size/ biomass spectra instead of concentrating on a ratio of individuals/biomass above specified length/ size as information on the full state of the population and a potential recovery might be lost by ignoring smaller size/biomass classes. See also the section ‘Strengths and weaknesses’ for discussion of depths and food supply.

## Hard-bottom communities: mussels size-frequency and density

### Description of the blue mussel indicator

Blue mussel (*Mytilus edulis/trossulus*) is a keystone species in the Baltic Sea. It is the main food source of many invertebrate, fish and bird predators and, as a sedentary organism, it indicates well the state of the local marine

ecosystem. Blue mussel is a habitat-building species, creating biodiversity hotspots for tens of invertebrate and fish species. In the Northern Baltic Proper 12 of the 22 species found in the mussel beds were not found outside the mussel bed (Norling & Kautsky 2008). In Kattegat, a total of 45 species of macrofauna, 23 species of macroalgae and 33 meiofaunal species were found associated with the mussel beds (Norling & Kautsky 2007). Koivisto (2011) reported of 39 macroinvertebrate species associated with mussel beds in the Finnish Northern Baltic Proper.

In this indicator, blue mussel size-frequency distribution – coupled with information of density and lower depth limit – is intended to reflect the state of hard-bottom biotopes in coastal areas and specifically the pressure from increased sedimentation/siltation due to various anthropogenic sources. In addition to that, the indicator describes:

- state of biodiversity in hard substrata biotopes,
- state of a main prey species for several predatory species, and
- effects of climatic variations (salinity, temperature, pH) on benthic biodiversity hotspots.

### Main factors affecting the blue mussel density and population structure

The blue mussel density and size-frequency distribution in the Baltic Sea are mainly affected by hydrographic variables (salinity, wave exposure, temperature, water flow, and likely pH), oxygen deficiency (mainly local events), inputs of organic and inorganic matter, food (phytoplankton) and predation (Figure 3).

Salinity is the major factor affecting the distribution of the species and in the margins of the distribution area affects the size of the individuals (Westerbom 2006). Climate change has been predicted to decrease salinity in the Baltic Sea.

Hypoxia occurs in the blue mussel beds mainly as local events due to decaying drifting algal mats. It kills entire mussel beds but mainly in the scale of tens of meters.

Temperature is a major stressor for large mussel individuals whose energetic costs are high. Periods of warm water temperatures (>17 °C) have been suggested to cause mortality of large mussels. Dead/dying large mussels detach easily from the substrate, as their byssus production ends/weakens, and entire communities may detach with them.

Predation by birds (e.g. Common eiders, Long-tailed ducks), fish (e.g. flounder, roach) or invertebrates (e.g. common sea star *Asteria rubens*) can effectively reduce mussel density or numbers of certain size class. See the next chapter for more information.

Increase of food enhances mussel growth to a certain extent, after which the abundant plankton disrupts filter feeding. High phytoplankton abundance leads also to high sedimentation rate of organic matter (when the bloom dies).

Organic and inorganic matter is a stressor that can disturb mussel feeding (when suspended in water) but its most negative impact is the falling on hard substrata and failing the settlement of mussel (and algal) recruits. This occurs mainly in sites where wave exposure is low. As the effect of waves depends also on depth, this stressor should be observed also in mussel beds at deeper depths.

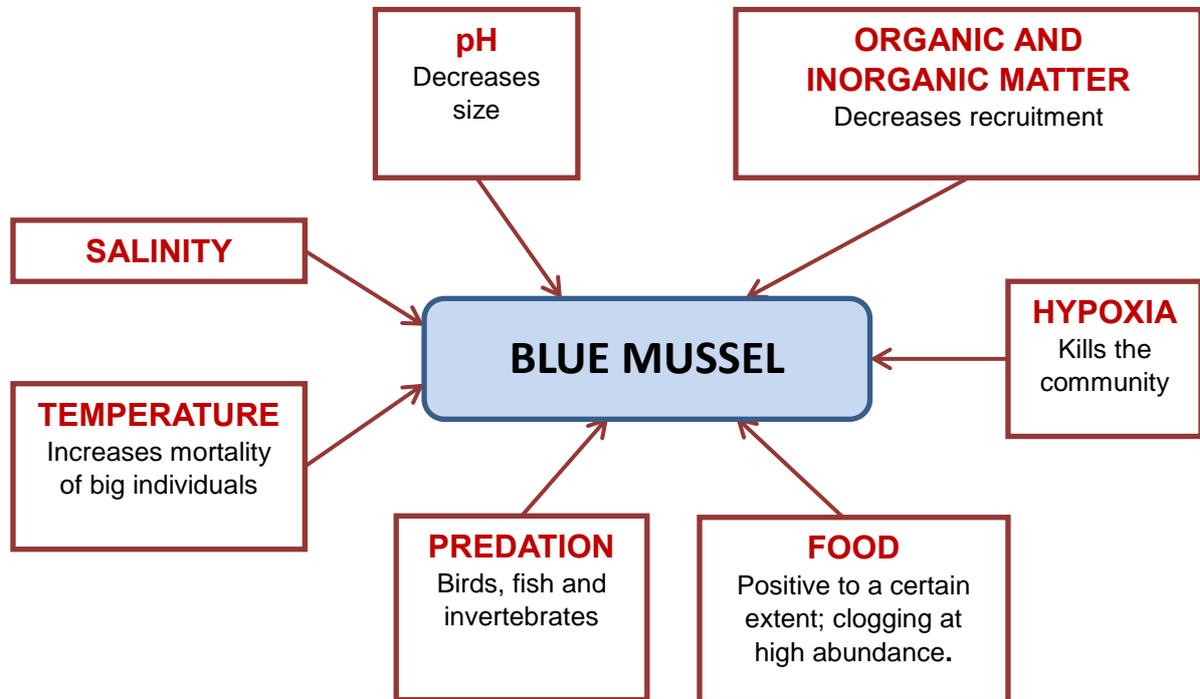


Figure 3. Factors affecting the blue mussel density and size frequency distribution.

### Parameters to follow in the blue mussel indicator

#### 1. Size-frequency distribution of blue mussels:

Blue mussel size is affected by several environmental factors (Figure 3) and therefore the parameter should be used at sites where environmental conditions are known and size-frequency distribution can be followed over time. Coupled with density information, the mussel sizes can show success of recruitment and, hence, the condition of hard-bottom biotope over longer time periods. The indicator is especially focused on the impacts of siltation of hard substrata, which cannot be measured directly by single measurements. Failure of recruitment is seen as ‘flattening’ of the size-frequency curve and repeated failure will lead to a mussel bed with weigh towards older mussels (Figure 4). See Metadata for a suggested method to measure the size classes.

#### 2. Density of blue mussels:

Density of 1+ year-classes of blue mussels in a healthy mussel bed is in the order of 20 000 – 100 000 ind. m<sup>-2</sup> (Westerbom 2006, Koivisto 2011). Recruitment failures decrease mussel density in a couple of years to 10– 5 000 ind. m<sup>-2</sup> as most of the individuals in a healthy mussel bed are 1-year-old recruits (fresh recruits are not suggested to be counted).

#### 3. Lower depth limit of blue mussels:

The depth distribution of a mussel bed is constrained at deeper depths by the amount of free hard substratum to settle. Because the amount of silt/organic matter increases as a result of eutrophication, dredging, shipping and

riverine run-off from agricultural lands, the monitoring of the extent of mussel beds is an indicator for human impacts and shows how much benthic biotope is lost.

It is suggested that the blue mussel indicator would be monitored at intervals of 1–3 years and be coupled with monitoring of macroalgal depth distribution. It is further suggested that a new measured parameter ‘density of *Fucus* recruits’ would be included in the monitoring of macroalgae as this parameter would give additional support to the assessment of the impacts of siltation (organic+inorganic) on hard-bottom substrata.

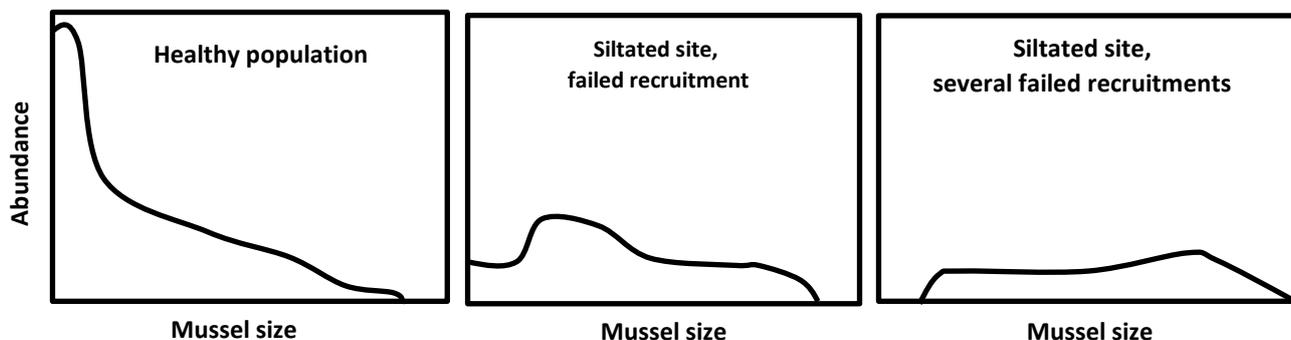


Figure 4. Size-frequency curves of blue mussels in a healthy population and two stages of disturbed population

## Impacts of predation on the size distribution of blue mussels

### Blue mussel size-frequency distribution

The blue mussel growth is tightly linked to its age (Figure 5) but varies at different depths, probably due to differences in salinity, temperature and food availability.

The blue mussel size-frequency distribution in the Archipelago Sea shows that the abundances of different-sized individuals are depth specific (Antsulevich et al. 1999). Populations in general show great proportion of small

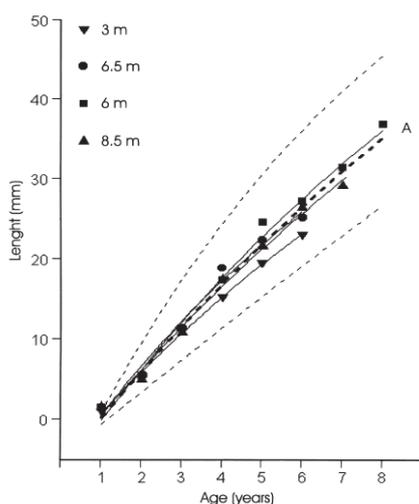
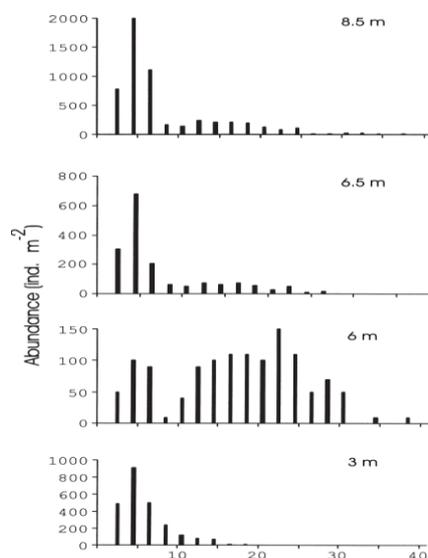


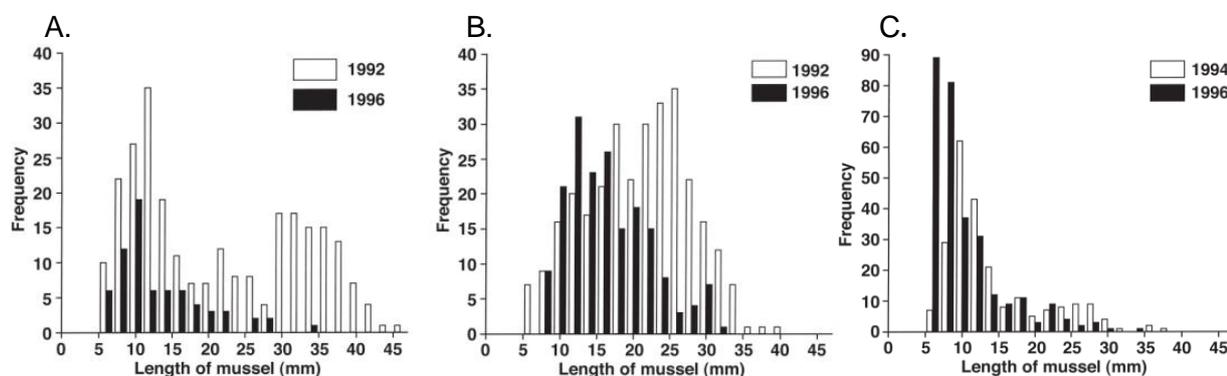
Figure 5. Correlation of shell-length with age in blue mussel at depths of 3, 6, 6.5 and 8.5 meters (Antsulevich et al. 1999). Outer lines represent range of growth rate and solid lines show average shell length during the winter stop-of-growth period at different depths.

individuals (Figure 6), but at 6-meter's depth large individuals form a considerable share of the population. Antsulevich et al. noted that the blue mussels grew faster in deep than shallow water.



**Figure 6.** Size-frequency graphs of blue mussels in the Archipelago Sea at four depths. After Antsulevich et al. 1999.

Sunila (1981) described the size distribution of blue mussels in the Tvärminne area, NW Gulf of Finland, in 1978–79. The size distribution showed significantly larger individuals in late-70s than in early 90s, and even greater difference against the mid-90s situation (Öst & Kilpi 1997).

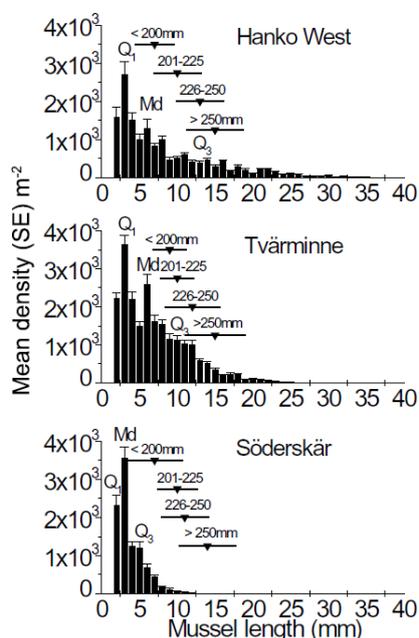


**Figure 7.** Size-frequency distribution of blue mussels at two sites in the western part of the Hanko Peninsula (A-B) and one site in Tvärminne (C), NW Gulf of Finland, in 1992 and 1996. The figure shows how the size-frequency distributions can be used to detect temporal changes in an indicator species. After Öst & Kilpi (1997).

### Predation by birds

Predation by birds affects the size distribution of blue mussels (Hilgerloh 1997). Hilgerloh noticed that bird predation on blue mussels on a sandy shore in the southern North Sea caused a gap in the size-frequency distribution of blue mussels (Figure 8). Hilgerloh estimated that 165 metric tonnes of blue mussels were consumed by oystercatchers, herring gulls and common eiders in one year. In the Baltic Sea, the ecological consequences of the decreased mussel size have been suspected to be linked with the strong decline of the common eider population (Hario et al. 1992, Holmen et al. 1996, Westerborn 2006). Common eiders consume 0.5-2.5 kg mussels daily (Hario & Öst 2002). Öst & Kilpi (1997) estimated that the population of 1000 female eiders and 2000 ducklings consume roughly 130 metric tons of blue mussels in selected mussel beds in the Tvärminne area. Based on the high predation pressure, they suspected that the bimodal size distribution in Figure 7A was caused by eider predation. Although salinity is likely the ultimate

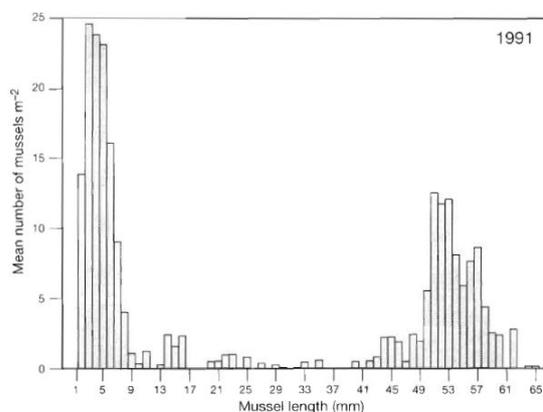
reason for the decline of mussel size, the eider predation may have contributed significantly and this can be seen locally in the size-frequency graphs (see also Westerborg 2006). Common eiders prefer mussels of 16-17 mm in size in the Northern Baltic Proper (Öst 1995).



**Figure 8.** Size-frequency distribution of blue mussels in southern North Sea in 1991. The figure shows how the shape of the size-frequency distribution can reveal significant impacts of predation on an indicator species. From Higerloh (1997).

### Predation by fish

Blue mussels are a key prey species for a number of fish species in the Baltic Sea, e.g. flounder, plaice and roach. In the northern Baltic Sea, the freshwater species roach (*Rutilus rutilus*) has increased greatly in the mid- and outer archipelago since 1990s (Lappalainen et al. 2000, 2004, 2005). Roach preys readily on blue mussels, the species being locally a dominant prey item (Lappalainen et al. 2004). Moreover, roach is able to feed on the entire size range of blue



**Figure 9.** Density of blue mussel size classes in three areas in the Gulf of Finland (Söderskär being the easternmost area). The quartiles and the median of the length classes are shown as well as the size class of the mussels being prey to roach of four size sizes. From Westerborg (2006).

mussels (Figure 9). The strong predation pressure on blue mussels, particularly on the margins of its distribution, leads also to an indirect negative effect on the blue mussel recruitment as the mortality of young is higher in the absence of refuge among the large individuals (Westerbom 2006).

In addition to decreased salinity, also increased eutrophication is favouring roach (Lappalainen 2002) and to a certain extent also blue mussels after which the secondary effects of eutrophication (increased sedimentation) begin to disturb the blue mussel recruitment (Westerbom 2006).



**Figure 10.** A photograph of *Asteria rubens* preying on a blue mussel bed.

## Impacts of demersal trawling on the size frequency distribution

Exposure of non-disturbed seabed to trawling causes high mortality rates of large-bodied species and individuals already at the first trawling event (Dinmore et al. 2003); mortality rates as high as 90 % have been recorded for sea urchins and 30–40 % for large bivalves (Bergman and van Santbrink 2000). Dinmore et al. (2003) suggest that the recovery time for the biomass of large macrofauna, even after just one trawl pass, is about 5 years. The global meta-analysis by Kaiser et al. (2006) showed that the recovery of the benthic habitats is habitat specific. For sand habitats that are dominated by physical processes, habitat restoration is relatively rapid (days to a few months), whereas in muddy sand habitats that are mediated by a combination of physical, chemical and biological processes, habitat restoration is much longer (months or >1 yr). It is therefore not surprising that the projected recovery time for annelids in sand habitats subjected to intertidal dredging was up to 98 d and that for muddy sand habitats was up to 1210 d. According to Kaiser et al. (2006), full recovery in terms of biomass of the molluscs can take much longer than that for smaller-bodied fauna such as annelids.

Due to the long-term recovery of trawled sites, the size-frequency –based indicator is considered a robust method to assess the level of pressure in the assessed area.

## Metadata

### Remarks on the monitoring of the core indicator

Currently we are not aware of any regular European monitoring programme measuring size frequencies of benthic organisms. Therefore data for testing and operationalization are missing.

The CORESET expert group recommended that the monitoring could be arranged in co-operation with the existing monitoring on soft and hard bottoms.

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#### Suggested monitoring on soft bottoms

Presumably it will principally be possible to record this parameter using the samples taken within the framework of many standard benthos monitoring programmes as long as the species involved occur in an adequate density. To reach this prerequisite, it may be necessary to expand the sampling scope. The additional effort and expense for implementation of size-based benthos parameters are expected to be low, even though additional time is needed for size or biomass measurements.

When working with size-based metrics, one has to take into account that they are less suitable for an annual assessment, but rather lead to suitable results for management on a time scale of > 5 years (Jennings & Dulvy 2005). Although this statement is based on the application of such metrics to fish communities, it principally applies to marine seafloor animal communities as well.

#### Suggested monitoring on hard bottoms

Monitoring of blue mussel beds is currently done for contaminant monitoring in southern HELCOM sub-basins (Sweden, Poland, Germany and Denmark), for biomarkers under research projects also in the northern sub-basins and for blue mussel cover at least in Sweden.

The monitoring of blue mussel beds should be placed in a gradient from coast to offshore (2-3 stations) in order to get a reliable overview of the factors affecting the indicator. It is recommended to avoid exposed sites as at those sites siltation/sedimentation is washed away and only the lower depth limit could be reliably assessed.

Size-frequency distribution of blue mussels can be measured by using a series of sieves to get an initial classification and then the total number of individuals per sieve is counted and X number of individuals (a sub-sample) per sieve are measured (1 mm accuracy). The sub-sample is used to estimate the size-frequency of the entire sample.

It is suggested that the blue mussel indicator would be monitored at intervals of 1-3 years and be coupled with monitoring of macroalgal depth distribution. It is further suggested that a new measured parameter 'density of *Fucus* recruits' would be included in the monitoring of macroalgae as this parameter would give additional support to the assessment of the impacts of siltation (organic+inorganic) on hard-bottom substrata.

#### Determination of GES

The GES is reached when the size-distributions of all indicator species are within the range of natural variability in the assessment unit. For individual populations, GES requires locally adapted values for the 'non-impacted' populations.

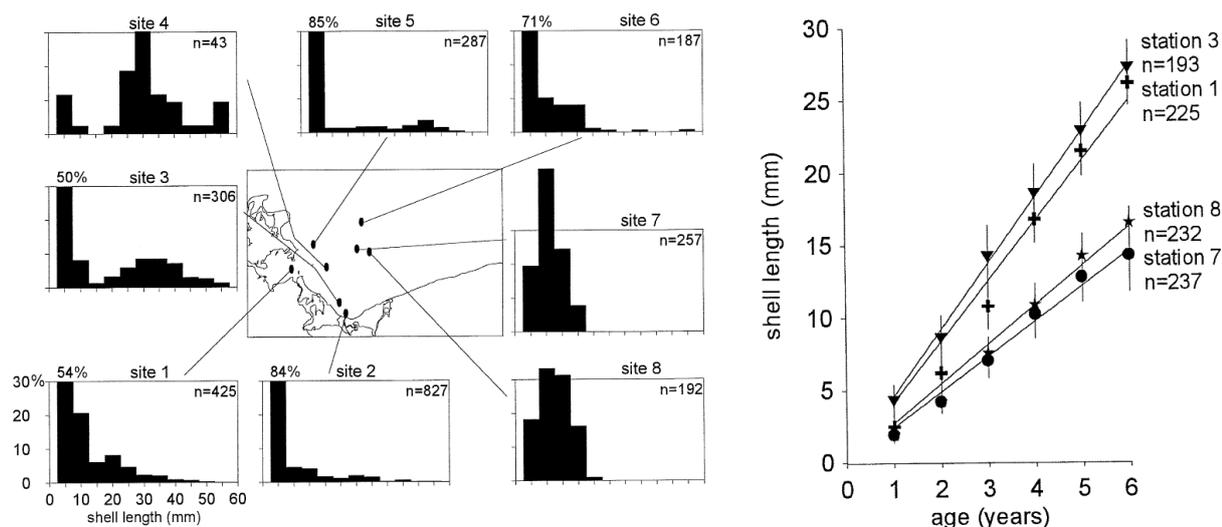
The ultimate aim is to develop the indicator towards quantitative assessment with a method to evaluate good environmental status by specified target values.

#### Strengths and weaknesses of data

One of the main tasks for implementation of this indicator is the appraisal of the natural variability which is influenced by biological processes like spawning success, growth and mortality rates which are mainly driven by environmental conditions (e.g. salinity, food supply, physical forcing). Kube (1996) for example investigated the population structure of the soft shell clam *Mya arenaria* in the Pomeranian Bight and described quite different population structure within his investigation area (Figure 8). He was able to show that especially the different maximum size-classes were a result of natural processes, mainly physical forcing and food supply leading to different growth rates and to a lesser extent predation by birds. Kube detected that the specimens on the Odra bank (stations 7 and 8 in Figure 8) grow much slower than in the deeper parts of the Pomeranian Bight - especially close the Odra mouth (stations 2 and 3) and at the ridge towards the Greifswald lagoon (station 1). (Note the similarity with the growth rate of blue mussels in shallow and deep water (Antsulevich et al. 1999). The result was that those six-years-old specimens were twice as large at station 3 than at station 7. The reasons for these large differences in the growth-rate within a relatively

narrow area are the much better food supply supported by the Rivers Odra and Peene and the much more stable sediments at the bottom of the Pomeranian Bight than on the top of the Odra bank. In the latter area more energy is needed by the bivalves to re-burrow and less energy is available for growth. Additionally, the predation by wintering bird is much higher in the shallow parts of the Odra Bank which might also reduce the number of large specimen. But this effect is most probably of minor importance. Thus, for assessment of the state of the population by size-distribution one should be careful to compare different sites e.g. to use the population in one undisturbed area as reference for other impacted areas. Alternatively, one might directly measure the age of the specimens that considerably increase the effort.

As a result, the indicator has to be developed on a regional scale with respect to the local environmental conditions.



**Figure 8.** Size distribution (left panel) and growth rates (right) of *Mya arenaria* at different stations in the Pomeranian Bight (from Kube 1996).

The second task is to define the natural state of a population. It is very unlikely to be found in the field as most areas are already impacted. Additionally, the not-impacted area has to be environmentally comparable to the impacted area (see above). Historical data are also very rare as size-measurements have not been part of the standardized protocol in most monitoring programs. Most probably, the natural condition therefore will have to be defined using population dynamic models which have up to now rarely been applied in marine benthic ecology.

### Further work required

The next step with the indicator is to acquire Baltic data and start testing its applicability as an impact indicator against disturbances from bottom trawling, hypoxia and other pressures (soft bottoms) and siltation (hard bottoms). After that the indicator requires setting of GES boundaries in different areas of the Baltic Sea.

The blue mussel indicator requires also further investigation as regards the impacts of waves on the siltation in different sites and in the scale of the entire Baltic Sea.

It may also be useful to consider the Condition Index of bivalves by following the length/weight ratios (see Pierścieniak et al. 2010 for results in Guld of Gdansk).

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