Recovery potential of macrozoobenthos from dredging in shallow brackish waters

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ABSTRACT

Benthic colonization following physical disturbance was studied in shallow brackish waters at the SW coast of Finland, northern Baltic Sea. Following sand suction and periodic stagnation an annual colonization pattern is described in relation to continuous succession following channel dredging. The importance of different colonization mechanisms is discussed. The number of species recovers faster than abundance and biomass, and recovery from dredging may take as long as 5 years. Experiments show the stock of colonizing species and the immigration distance to be major structuring factors in macrozoobenthic community development.

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RÉSUMÉ

Potentiel de reconstitution du macrozoobenthos après dragage dans des régions d'eaux saumâtres peu profondes

La colonisation benthique après une perturbation mécanique a été étudiée dans trois régions d'eaux saumâtres, peu profondes, près de la côte sud-ouest de la Finlande, dans le nord de la Mer Baltique. Un modèle de colonisation annuelle après un dragage de sable suivi d'une période de stagnation est décrit en comparaison avec la succession continue intervenant après le dragage d'un chenal. Le nombre d'espèces se rétablit plus vite que l'abondance et la biomasse ; il semble que la durée de reconstitution de l'écosystème benthique après dragage puisse atteindre cinq ans. L'expérience indique que le nombre des espèces colonisatrices et la distance d'immigration sont les principaux facteurs de structuration dans le processus de développement d'une communauté macrozoobenthique.

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INTRODUCTION

Physical disturbance is known to be a major factor in shaping ecosystems (Thistle, 1981), such as marine and estuarine benthic communities (Bonsdorff, 1980; Sherman, Coull, 1980; Rainer, Fitzhardinge, 1981). In several cases the disturbance leads to complete destruction of the faunal community, and a reestablishment has to start from a zero point (McCauley *et al.*, 1977). Community development is then primarily structured by the stock of colonizing species, food supply, inter-

specific relationships (Wildish, 1977; Santos, Simon, 1980 *a*), and the structure of the sediment (Kaplan *et al.*, 1975).

Recovery from organic enrichment has thoroughly been reviewed by Jernelöv and Rosenberg (1976), Pearson and Rosenberg (1978) and Boesch and Rosenberg (1981), and a general pattern in succession has been demonstrated. For colonization following physical destruction of the benthic communities no comparative studies have been carried out, although experiments with azoic sediment have been performed in several

cases (e.g. Brunswig et al., 1976; Grassle, 1977; McCall, 1977; Scheibel, Rumohr, 1979; Arntz, Rumohr, 1982). Case studies following the recovery from dredging or natural defaunation are few, and evaluation is only seldom based on long-term studies (Rosenberg, 1977 a; Bonsdorff, 1980; Santos, Simon, 1980 b; Santos, Bloom, 1981).

In this study recolonization of macrozoobenthos was studied during 4-6 years following dredging and sand suction at three shallow, brackish water localities in southern Finland, northern Baltic Sea. As a complement to these studies a colonization experiment with defaunated sediment was carried out in 1982. The aims have been to study the recovery potential of physically damaged zoobenthic communities, and to detect similarities in different situations. Comparison is also made with data following organic pollution (e.g. Pearson, Rosenberg, 1978). The investigated areas were illustrated in Figure 1) :

1) Degersand Bay, Åland archipelago, where sand suction was carried out in 1976. Depth thus increased from 5-12 m, resulting in periodical oxygen deficiency, giving an annual colonization pattern below the summer thermocline (at 10 m),

2) Raisio Bay, SW Finnish mainland, where a 8-9 m deep channel was dredged in 1976 in a shallow bay (Bonsdorff, 1980; 1983), and

3) Gloet Bay, Åland archipelago, where a small scale dredging was performed in 1978 to prevent natural enclosing of the bay (Blomqvist, 1984). Salinity in all localities ranges from 5.5-7.5 $^o/_{oo}$, and temperature from 0-20 ºC. Thus the fauna is preadapted to environmental stress (Jernelöv, Rosenlöv, 1976), and it was expected that recovery would be fast.

MATERIAL AND METHODS

Sampling and treatment of the samples was conducted according to the recommendations given for the Baltic Sea by Dybern et al. (1976) with the following modifications : in Raisio Bay a modified Van Veen grab (0.047 m²) was used along with a 0.8 mm sieve to allow comparisions with previous studies of the area (Leppäkoski, 1975), and in the other cases an Ekman-Birge box corer (0.029 m²) was used along with a 0.5 mm sieve. In the submarine sand pit (locality 1, fig. 1) samples were taken above (9 m) and below (12 m) the summer thermocline, in Raisio Bay (locality 2, Fig. 1) samples were taken from the dredged channel and the nearby recruitment area (about 150 m off the channel), and in Gloet Bay (locality 3, Fig. 1) an inner and an outer reference were used for samples from the dredged inlet.

The quality of the sediment was qualitatively described by the ignition loss (used as a rough estimate of the organic content). The ignition loss was determined as the difference between the dry weight (100 ºC, 24 h) and ashfree dry weight (500 ºC, 3 h), and is given as per centage of the sediment.

In the experimental study 10 boxes (30 × 40 × 11 cm) filled with defaunated (deepfrozen) natural sediment were placed at the bottom at 1.5 m depth in Gloet Bay (locality 3) in May 1982, and recovered 1-2 times per month. Simultaneously samples were taken from the surrounding sediment. The data presented here are part of a larger experiment to be presented separately.

Recolonization is described by species-abundance-biomass (SAB) curves, as presented in Pearson and Rosenberg (1978), by changes in the size-frequency distribution of Macoma balthica (L.), and by the Czekanowski coefficient of similarity (Bray, Curtis, 1957) :

$$C_z = \frac{2 \times \Sigma n_i \, (\min)}{N_a + N_b},$$

where

N_a is the total number of individuals at locality a, and
N_b is the total number of individuals at locality b, and
n_i is the number of individuals of species i.

RESULTS

Annual recovery from oxygen deficiency due to sand suction

In Degersand Bay the zoobenthic community is structured mainly by the type of sediment (fine sand, ignition loss 0.5-3.5 % in the disturbed area, and 0.3-0.5 % in the reference area), and the fauna of the recruitment area. The natural community is dominated by Bathyporeia pilosa Lindström, Pygospio elegans Claparède Macoma balthica, Prostoma obscurum Schultze, and Nereis diversicolor O. F. Müller. Total abundance is high (6 000-9 000 ind./m²), species number ranges from 10-15 (30 species have been recorded), and biomass values are low (below 15 g wwt/m²). Variation in com-
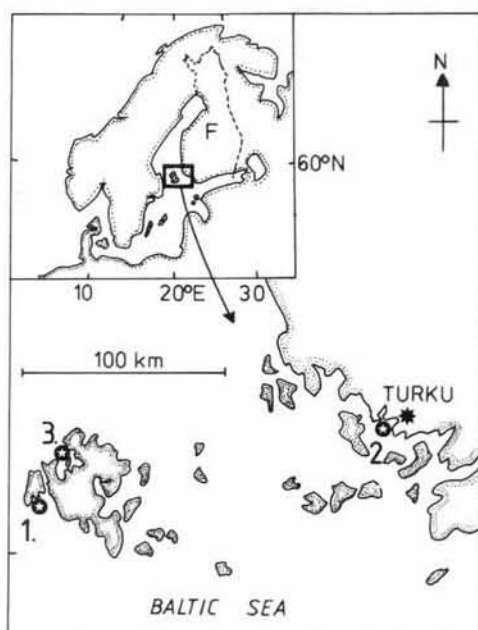

Figure 1

The investigated localities in the SW archipelago of Finland, Northern Baltic Sea. F = Finland; 1 = Degersand Bay (sand suction 1976); 2 = Raisio Bay (channel dredging 1976); 3 = Gloet Bay (small scale dredging 1978).

munity composition is small, and changes are due to seasonal recruitment. In the disturbed area hydrographical conditions follow a distinct seasonal pattern. A strong thermocline develops at 10-12 m leading to oxygen deficiency at 11-12 m, thus defaunating the bottom. At 9-10 m in the sand pit a stable community has evolved during 1976-1982, enabling rapid, annual recolonization of the deeper parts (Fig. 2), when the thermocline breaks, and the bottom is reoxygenated. This primary recruitment pool has the same dominance pattern as the outer reference (4 000-6 000 ind./m²). At 12 m the number of species follows the oxygen content of the water (Fig. 2), giving an annual recovery pattern with highest diversity in early summer, decreasing towards late summer. Similarity between 12 and 9 m reaches 40-45 % in May, but is reduced to 0 within 2-3 months.

During initial recovery *Macoma balthica* was the most successful colonizer due to its resistance to periods with lowered oxygen saturation, while mobile crustaceans and polychaetes accumulated above the thermocline. In the affected area *M. balthica* does not seem to reach maturity, however, and is thus depending on annual input of larvae. As the internal recruitment pool has become more complex, the annual colonization of the deepest parts has become more diverse (Fig. 2), although the abundance is constantly much lower (in 1982 from 1 200 ind./m² to 0 within two months). The benthic community of the area affected by the sand suction in 1976 is thus permanently altered from natural conditions.

Recovery following channel dredging

In Raisio Bay (mud, ignition loss 5-8 %) the macrozoobenthic community is affected by municipal waste water, and dominated by *Macoma balthica*, *Nereis diversicolor*, *Corophium volutator* (Pallas) and tubificide oligochaetes. Changes in environmental conditions are highly seasonal, but only slightly modify the benthic assemblage. The initial recolonization was fast and dominated by *N. diversicolor* and oligochaetes, and later followed by *C. volutator* and finally *M. balthica* (Bonsdorff, 1980; 1983). As compared to the recruitment area variation in the SAB-parameters were consi-

derable (Fig. 3). A peak in community development was recorded two years after the dredging when 17 species, 2 270 ind./m² and 129 g wwt/m² were found (mean values for the bay 1975-82 are 10-12 species, 800-1 200 ind./m², 50-100 g wwt/m²). Stabilization of the macrozoobenthos followed a decrease in species number and abundance, while biomass continued to rise another year (Fig. 3). As compared to the nearby recruitment area the community stabilized on a somewhat lower level. This is partly explained by irregular periods of low oxygen content (2-5 mg O_2/l) at the deeper locality, which leads to increasing mortality and flight of the fauna (Rosenberg, 1977 b).

Faunal similarity (Fig. 4) between the dredged and the reference areas, however, show a peak value 5 years after the dredging. Only 4-6 years after dredging is a stabilization evident in similarity between these nearby localities !

The seemingly stable species composition (the S-curve in Fig. 3) shows considerable structural variations. In early colonization some species (*e.g. Harmothoe sarsi* Kinberg, *Halicryptus spinulosus* v. Siebold and *Pontoporeia affinis* Lindström) that had not occured in the area prior to dredging, were recorded. Following the peak in recovery in 1978 these species disappeared, presumably due to growing competition (new immigrants, as *Pygospio elegans*, *Polydora redeki* Horst and *Prostoma obscurum*, have become more important instead). The number of immigrating and emigrating species is still considerable (to 75 % of the species present can be exchanged between samplings), even though the number of species is stable (10-12). These changes were more denoted at the dredged site than in the surrounding environment.

Macoma balthica is the main structuring component of the community, and *Corophium volutator* shows opportunistic traits in that it becomes abundant when its major competitors are reduced in numbers. The population of *M. balthica* showed a rapid increase in numbers, biomass and age classes due to larval settling, active and passive migrations of post-settled juveniles and adults (Bonsdorff, 1980; 1983). Within two years the population in the dredged area was similar in structure to that of the reference area, but in 1979 low oxygen saturation inhibited larval settling in the channel.
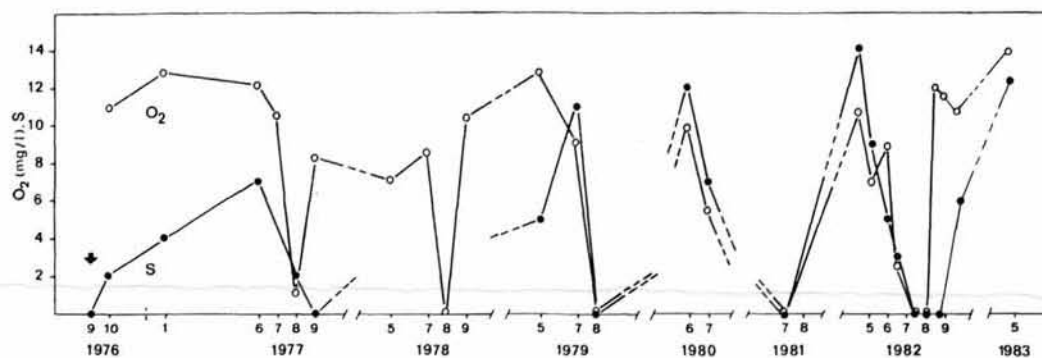

Figure 2

Long-term changes in the number of species (S) and oxygen content (mg O_2/l) at 12 m depth in Degersand Bay. Arrow indicates the sand suction. 1978 no macrofaunal samples were taken.
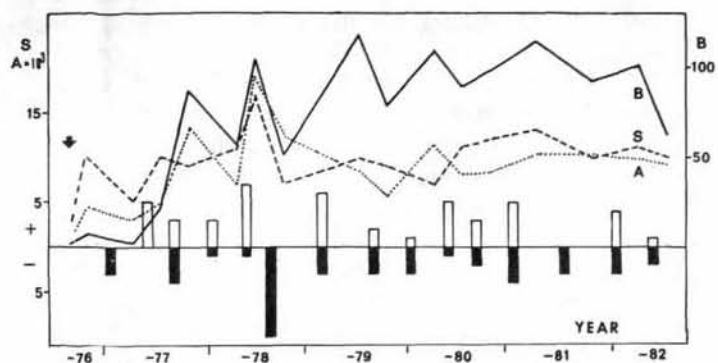
Figure 3

Long-term changes of macrozoobenthos in the dredged channel of Raisio Bay. Arrow indicates the termination of dredging. Number of species (S), total abundance (A, ind./m²) and total biomass (B, g wwt/m²), Bars indicate the numbers of immigrating (+, open bars) and emigrating (−, black bars) species between samplings.
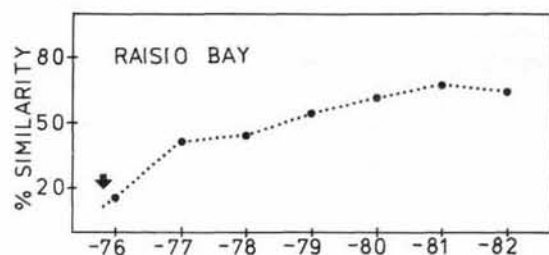

Figure 4

The development of similarity (Czekanowski's coefficient) between the dredged channel and the reference area in Raisio Bay 1976-1982. All samplings carried out in October/November each year. Arrow indicates the termination of dredging.

From November 1980 onwards (4 years after dredging), however, no significant differences have been recorded between the two populations (Bonsdorff, 1983). In August 1982 growth curves (mean individual length *versus* mean individual wet wight) were almost identical in the dredged channel and the reference site ($y = 0.115\,6\,X^{3.028}$, $r = 0.989$ *versus* $y = 0.073\,1\,X^{3.181}$, $r = 0.998$). Life history data for the individual species are presented elsewhere (Bonsdorff, 1980; 1983; and in prep.).

In Gloet Bay (mud/sand, ignition loss 2.5-5 %) the defaunated area was small (5 × 100 m), and thus the immigration distance short. Recovery was rapid, and the community established gained a composition intermediate to the inner (littoral) and outer (sublittoral) recruitment pools. In July 1982 14 species, 9 600 ind./m² and 69 g wwt/m² were recorded in the dredged area (outer reference: 12 species, 3 300 ind./m², 135 g wwt/m², inner reference: 14 species, 12 700 ind./m², 59 g wwt/m²). Abundance was dominated by *Corophium volutator*, *Macoma balthica*, Hydrobidae and chironomid larvae, and biomass totally by *M. balthica* (13-70 %). Full stabilization has not yet occured, as abundance and biomass have grown continuously. *M. balthica* has a similar growth pattern to that of the population in the dredged channel in Raisio Bay, and an increased biomass can be expected, as maximum size (about 20 mm)

has not yet been reached in Gloet Bay (Fig. 5). Thus even a small scale physical destruction of the infaunal community demands several years to fully recover.

Experimental community succession

During an exposure period of 14 weeks colonization was rapid, and within one week 7 macrofaunal species were recorded (Fig. 6). Two weeks later species number and abundance approached the surrounding sediment, but biomass was low (4 g wwt/m²). After 5 weeks a primary abundance maximum was noted, due mainly to massive import of chironomid larvae (80 % of total abundance). The number of species reached the recruitment pool within 8-11 weeks. Simultaneously *M. balthica* immigrated by settling larvae (5 000-6 000 ind./m²), and biomass of the community rose (Fig. 6). This
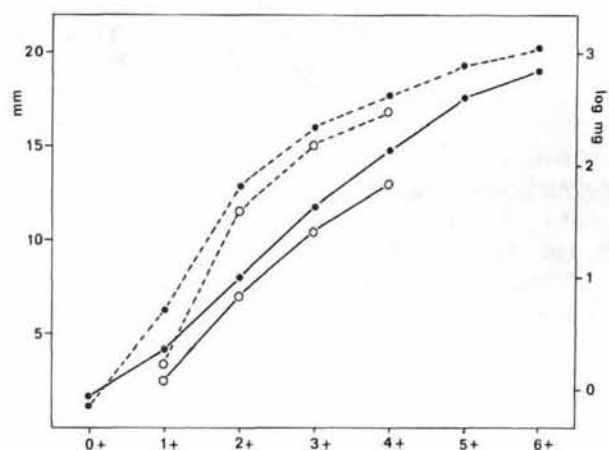

Figure 5

Growth pattern for Macoma balthica *in Raisio Bay (filled circles) and Gloet Bay (open circles) 1982. Solid lines = age (years after settling) versus mean individual length (mm), broken lines = age versus mean individual weight (log mg wwt).*
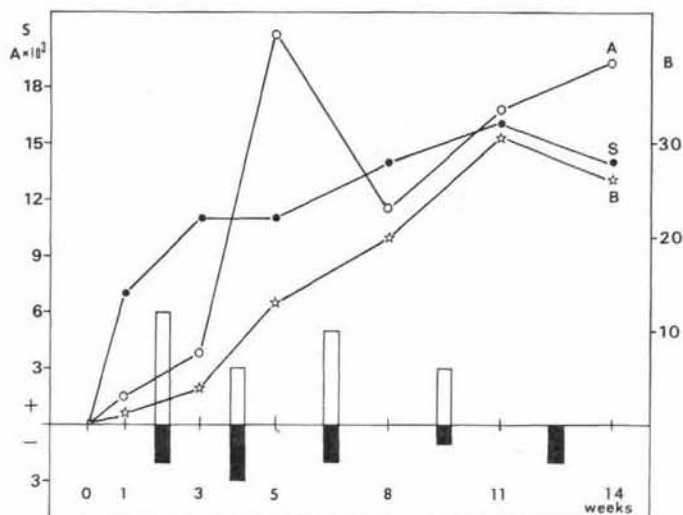

Figure 6

Establishment of the macrozoobenthic community in Gloet Bay (1.5 m depth) during 14 weeks of experimental exposure (May-September 1982). Number of species (S), total abundance (A, ind./m²) and total biomass (B, g wwt/m²). Bars indicate the number of immigrating (+, open bars) and emigrating (−, black bars) species during the community succession.

peak in immigration was followed by a massivie immigration of newly hatched *C. volutator* (11 000 ind./m²), which compensated for a reduction in abundance of chironomids (90 % reduction) and juvenile *M. balthica* (40 % reduction after settling). The number of species and abundance values are expected to remain stable, whereas biomass will continue to grow for a long time in accordance with the results from Gloet Bay. This experiment shows that the recovery potential for macrozoobenthos is high following mechanical disturbance, as also demonstrated by McCall (1977) and Sherman and Coull (1980).

DISCUSSION AND CONCLUSIONS

Comparing the different case studies, it seems evident that the recovery potential of shallow brackish water following mechanical destruction is high. Recolonization can be delayed or altered by secondary effects, as periodic oxygen depletion. Generally the species composition recovers faster than the interspecific dominance patterns. Simon and Dauer (1977) found that major faunal groups have different colonizing strategies. Thus some polychaetes (as *Nereis diversicolor*) are able to inhabit a defaunated area rapidly by active adult immigration, whereas others (*e.g. Manayunkia aestuarina* (Bourne)) are slow colonizers due to their entirely tubiculous lifecycle. Bivalves mainly colonize by settling larvae, and migrations among the post-settled. Opportunistic colonization behaviour is shown by *Corophium volutator* and *Bathyporeia pilosa*. This may lead to

drastic oscillations in abundance numbers, as demonstrated experimentally by Arntz and Rumohr (1982).

A shift from r — to K-strategists occured in Raisio Bay and Gloet Bay, where *Macoma balthica*, with a life span of several years, slowly became dominant, replacing the typically short lived r-strategists.

In Degersand Bay (Fig. 2) *M. balthica* never spawns, and thus species with short life cycles (*Pygospio elegans, B. pilosa*) dominate. Although initial recovery is rapid, it may take 5 years or more for a shallow water benthic community to stabilize, as shown by the similarity curve in Figure 4.

The intensive experiment conducted confirms that the stock of colonizing species and the distance they have to move are of vital importance in structuring the macrozoobenthic ecosystem. These case studies and experiments, as well as other studies (Arntz, Rumohr, 1982; Éleftheriou *et al.*, 1982) demonstrate the usefulness of recovery studies in trying to answer ecological problems at population — and community level.

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