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Benthic re-colonization in post-dredging pits in the Puck Bay (Southern Baltic Sea)

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Abstract

The stage of benthic re-colonization at a site formed by sand extraction was investigated some 10 years after the cessation of dredging. The examined post-dredging pit is one of five deep (up to 14 m) pits created with a static suction hopper on the sandy, flat and shallow (1-2 m) part of the inner Puck Bay (the southern Baltic Sea). The topography of the dredged area makes a specific trap for different kinds of organic matter. It is created by the small areas of post-dredging pits as compared to their depths. As a result, organic matter accumulation leads to anaerobic conditions and hydrogen sulfide formation. Macrofauna was not found to occur permanently in the deepest part (11 m) of the cup-shaped depression, which was characterized by its small area (0.2 km^2) and steep walls. However, permanent occurrence of meiofauna (max. 180 ind. 10 cm⁻², mainly Nematoda) was noted. Undoubtedly, re-colonization of benthic fauna assemblages, typical of shallow and sandy seabed of the Puck Bay, will not follow in a natural way in the area of post-dredging pits. Also, it could not be expected that the re-colonization sequence would result in the formation of a structure similar to that of the natural depression (the Kuznica Hollow). © 2006 Elsevier Ltd. All rights reserved.

Keywords: post-dredging pit; re-colonization; meiobenthos; macrozoobenthos; Puck Bay; Baltic Sea

1. Introduction

In different regions of the world, interference in the coastal environment for economic reasons is still increasing. Routine work includes the dredging of harbours, docks, channels and navigation areas, sand transport for coast protection and rebuilding, or sand extraction for building purposes. Such activity can result in mechanical devastation of physical and chemical seabed structure, either through the removal of sediment surface and/or digging deep pits, or through covering the seabed with a new layer of sediment. This results in the disturbance, or even complete degradation, of benthic habitats and feeding grounds for young fish and diving birds. As a consequence, far-reaching and often irreversible transformations

* Corresponding author. E-mail address: ocemas@univ.gda.pl (M. Szymelfenig). can be observed in ecosystem structure (Kaplan et al., 1975; Kenny and Rees, 1994, 1996; Desprez, 2000; Boyd et al., 2003). The assessment of biological effects on the areas of bottom sediments excavation (Poiner and Kennedy, 1984; Kenny and Rees. 1994, 1996; de Grave and Whitaker. 1999; Robinson et al., 2005) and their deposition (Toumazis, 1995; Harvey et al., 1998; Smith and Rule, 2001) is, therefore, commonly undertaken. First of all, macrozoobenthos have been examined (Seiderer and Newell, 1999; van Dalfsen et al., 2000; Sardá et al., 2000; Boyd and Rees, 2003). At present there are only a few works on re-colonization or reconstruction of meiobenthos assemblages after the cessation of sediment exploitation and deposition (Somerfield et al., 1995; Boyd et al., 2000; Schratzberger et al., 2000).

The Puck Bay (the southern Baltic Sea) is an exceptional area within the Polish coastal zone. It is characterized by a relatively vast, shallow-water area (ca. 104 km², average depth of ca. 3 m). In this region, especially in the inner Puck Bay, there

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are many natural shoals, channels and hollows. The biggest depression, called the Rzucewo Hollow, covers ca. 8.4 km^2 (max. depth 5.7 m). The Kuznica Hollow is ca. 5.3 km^2 in area (max. depth 9.7 m). The Chałupy Hollow is the smallest depression, ca. 0.6 km^2 (max. depth up to 4 m) (Nowacki, 1976). The abiotic diversity (water dynamics, sediment structure, water chemistry) of the Puck Bay is accompanied by different and interesting plant and animal assemblages (Korzeniewski, 1993).

As a result of several years of dredging works, five artificial pits have been formed in the Puck Bay. In contrast with natural hollows, they are characterized by small area and relatively high depth. The biggest pit is ca. 0.2 km² in area and ca. 11 m in depth. Such artificial "depths" could disturb different ecosystem functions. On one hand, they cause significant changes in abiotic conditions and destruction of biocoenoses through the ground removal over an area of several hundred m². On the other hand, physico-chemical conditions in deep pits do not favour recovery of biological resources (Wawrzyniak et al., 1993; Śmietana and Wawrzyniak, 1995; Maksymowska et al., 2003; Graca et al., 2004).

Biological findings from investigations carried out ca. 10 years after the cessation of dredging are presented here. Benthic fauna of a post-dredging pit was compared to the fauna of shallow-water, sandy bottom area of the Puck Bay, and the fauna of one of the natural bay depressions, i.e. the Kužnica Hollow.

2. Material and methods

Zoobenthos was collected four times: in summer 2001, autumn 2001, winter 2003, and spring 2002. The samples were taken in three characteristic regions in the Puck Bay (Fig. 1). The F station was located on a typical, shallow (1.5-2 m depth) flat bottom of the bay. The NP station was situated in a natural depression, the Kužnica Hollow (up to 9.7 m depth, 5.3 km² in area). The PP station was set up within the area of post-dredging pit (max. depth ca. 11 m, 0.2 km² in area).

The material for zoobenthos analysis was collected by a diver. At every station four sediment cores for meiofauna were sampled in cross-section using a 30 cm long Perspex tube with an inner diameter of 3.6 cm (sampling surface 10 cm^2). For macrofauna analysis, 10 samples were taken with a 210 cm² Ekman grab. The meiofauna cores were divided into 1 cm slices. In total, 120 samples of macrofauna and 48 cores of meiofauna (almost 1000 samples) were analysed.

Meiofauna samples were processed according to a standard method given in Elmgren and Radziejewska (1989). They were fixed in 4% formaldehyde solution, stained with Rose Bengale and washed over a set of sieves (the smallest mesh was 0.032 mm). Biomass (wet weight) was measured by a volumetric method (Feller and Warwick, 1988). Meiobenthos specimens were identified to major taxonomic groups. The abundance and biomass of meiofauna was expressed per 10 cm². Macrofauna samples were first washed over a 0.5 mm mesh sieve, then fixed in 4% formaldehyde solution and stained with Rose Bengale. Macrobenthic specimens were identified, where possible, to the species level. After a 3-month period of stabilization they were dried with blotting-paper and weighed (formaldehyde wet weight). The abundance and biomass of macrofauna was given per 1 m².

A non-parametric multi-dimensional scaling (MDS) ordination was applied to meiobenthos and macrozoobenthos data using the software package PRIMER v5 (Clarke and Gorley, 2001). Prior to analyses, data were transformed using square root transformation. The similarities between samples were calculated by means of Bray-Curtis index (Bray and Curtis, 1957; Clarke and Gorley, 2001).

3. Results

3.1. Meiobenthos

In the survey region of the Puck Bay, the following taxa of permanent meiobenthos were found: Nematoda, Harpacticoida, Turbellaria, Ostracoda, Acari, Gastrotricha, Tardigrada and Kinorhyncha. Temporary meiobenthos was represented by Oligochaeta, Polychaeta, Bivalvia, Gastropoda and Hirudinea. Copepoda nauplii, Cirripedia cypris and Chironomidae larvae were also observed.

Almost all of the above taxa (15 of them), except Tardigrada, occurred at the shallow bottom (F station). In the Kuźnica Hollow (NP station – 14 taxa) Kinorhyncha and Hirudinea were absent. However, in the post-dredging pit (PP station) a significant decrease in taxa number was noted (six taxa). There were only Nematoda, Harpacticoida, Turbellaria, Oligochaeta, Copepoda nauplii and Chironomidae larvae.

The post-dredging pit (PP station) was characterized by the lowest abundance and biomass of meiofauna (Fig. 2). Both parameters showed slight seasonal changes. The lowest abundance ($35.5 \text{ ind. } 10 \text{ cm}^{-2}$) was noted in June 2001, and the lowest biomass ($0.207 \text{ mg } 10 \text{ m}^{-2}$) was observed in October 2001. Maximum values of abundance ($180 \text{ ind. } 10 \text{ cm}^{-2}$) and biomass ($4.342 \text{ mg } 10 \text{ cm}^{-2}$) were found in April 2002. Meiofauna was dominated by Nematoda: from 41.1% (April 2002) to 98% (June 2001) of total abundance and 35.2% (April 2002) to 99.1% (June 2001) of total biomass (Fig. 2). Harpacticoida was also an important group. For that taxon the maximum percentage contributions of abundance (51.5%) and biomass (54.3%) were noted in April 2002.

The abundance and biomass of meiofauna on the flat bottom and the natural hollow covered very broad ranges (Fig. 2). Total abundance in the natural depression was between 97.3 ind. 10 cm^{-2} (April 2002) and 941.3 ind. 10 cm^{-2} (June 2001), and total biomass ranged between 1.860 mg 10 cm⁻² (April 2002) and 39.567 mg 10 cm⁻² (June 2001). The lowest total abundance (271.8 ind. 10 cm⁻²) and biomass (6.441 mg 10 cm⁻²) on the shallow bottom were found in March 2003 and June 2001, respectively, whereas the highest total abundance (1386.8 ind. 10 cm⁻²) and biomass (58.683 mg 10 cm⁻²) were observed in April 2002. Nematoda



Fig. 1. Location of sampling stations in the Puck Bay.

was the most abundant group in both regions, however, its dominance was less pronounced compared to the post-dredging pit (Fig. 2). The percentage contribution of Nematoda ranged from 49.6% (June 2001) to 85.1% (April 2002) in the Kuznica Hollow, and from 48.5% (March 2003) to 68.7% (April 2002) on the flat bottom. The abundance of the second most important taxon, Harpacticoida, was considerable on the shallow bottom (13.9-30.6%), however, its percentage contribution in the natural hollow was markedly lower and remained at almost constant level (5.4-9.5%). Although among meiofauna, Nematoda showed the highest biomass in the natural hollow as well as on flat bottom, their percentage in total biomass was lower as compared to their percentage in total abundance (Fig. 2). Their contribution to total biomass was between 23.1% (June 2001) and 81.4% (April 2001) and between 41.9% (April 2002) and 50.7% (March 2003) at the NP and F stations, respectively. The percentage of Harpacticoida biomass was more or less constant at both stations, i.e. 11.3-14.8% (F station) and 1.7-1.8% (NP station). The percentage

contributions of Turbellaria (max. 10.3%), Oligochaeta (max. 7.1%) and Ostracoda (max. 8.3%) in total meiofauna abundance were distinctly lower at both stations than the percentage of those taxa in total biomass. It was accompanied by considerably greater fluctuations in percentage contributions of Turbellaria (5.1-29.5%), Oligochaeta (0.8-29.5%) and Ostracoda (0-19.4%) in total meiobenthos biomass as compared to the fluctuations in total abundance. A significant Bivalvia contribution in the abundance and total biomass of meiofauna was noted in June and October 2001. In June 2001 values ranged between 2.5% (F station) and 14.2% (NP station) for abundance and between 9.6% (F station) and 12.1% (NP station) for biomass.

Meiobenthos abundance considerably decreased with an increase in sediment depth (Fig. 3). Such pattern was observed at all the examined stations. Meiobenthos occurred only to 8 cm depth in the post-dredging pit, to 18 cm in the natural hollow, and as far as 24 cm on the shallow bottom (Fig. 3). Irrespective of the study area, the deepest penetration was



Fig. 2. Abundance, biomass and number of meiobenthos taxa at the sampling stations in the Puck Bay.

shown by Nematoda. In June 2001, in the Kuźnica Hollow, Turbellaria and Oligochaeta were observed down to 18 cm depth, and Harpacticoida to 10 cm depth. At the flat bottom station, the above taxa were noted even in deeper layers, Turbellaria and Oligochaeta at 24 cm, and Harpacticoida at 10 cm.

The highest taxa number at the investigated stations was found in the surface sediment layer of 2 cm thick (Fig. 3). In the post-dredging pit, a maximum of three taxa were observed at up to 3 cm sediment depth. Three taxa were still noted at the 10-15 cm layer in the natural depression and up to five taxa were found at the same depth at the flat bottom station.

The percentage contribution of Nematoda in total meiofauna abundance increased up to 100% with an increase in sediment

depth. Such a pattern was most distinct in the post-dredging pit where Nematoda percentage contribution reached 100% at 2 cm sediment depth. A similar tendency was observed in the natural depression. However, a 100% contribution of Nematoda was already noted at a depth of 4 cm. The situation at the flat bottom station showed significant seasonal differentiation. Only in June 2001 was the maximum Nematoda contribution (100%) found below 4 cm of sediment depth.

Analysis of seasonal similarity revealed that only in June 2001 and in April 2002 could three distinct meiofauna groups corresponding to individual stations be distinguished (Fig. 4). Such groups were not found in the other seasons, i.e. in October 2001 and March 2003.

3.2. Macrozoobenthos

In the investigated region of the Puck Bay the following taxa were identified: Bivalvia with Cerastoderma glaucum, Macoma baltica, Mya arenaria, Mytilus edulis; Gastropoda with Hydrobia spp., Potamopyrgus antipodarum, Lymnaea peregra, Theodoxus fluviatilis; Crustacea with Idotea chelipes, Cyathura carinata, Bathyporeia pilosa, Gammarus salinus, Gammarus oceanicus, Gammarus zaddachi, Corophium volutator, Oligochaeta; Polychaeta with Hediste diversicolor, Pygospio elegans, Streblospio benedicti, Alkmaria rominji, Marenzelleria viridis; Prlapulida with Priapulus caudatus; Nemertini with Prostoma obscurum; Chironomidae larvae (non det.) and unidentified larvae of other Insecta.

The number of taxa in the Kuźnica Hollow (23) was only somewhat higher than that of the shallow bottom station (20). However, it was almost two times higher as compared to the post-dredging pit (12 taxa).

The highest macrozoobenthos abundance (20 847 ind. m⁻²) and biomass (1081 g m⁻²) were noted in the natural depression (Fig. 5), irrespective of the season. Bivalvia was the most abundant group, 39.5-61.9% (Fig. 5). The following taxa showed lower but also significant contribution in abundance: Gastropoda (to 39% in October 2001), Oligochaeta (to 40.3% in March 2003) and Polychaeta (to 15% in March 2003). In that area, macrofauna biomass (Fig. 5) was constituted mainly by Bivalvia (93–95.2%). This group was represented by *Cerastoderma glaucum*, *Macoma baltica*, *Mytilus edulis* and *Mya arenaria*. The last species showed the highest percentage of abundance (54.7–91.1%) and biomass (71.3–79.2%), with maximum values of abundance (10 327.9 ind. m⁻²) and biomass (725.5 g m⁻²) noted in October 2001.

The highest abundance of macrozoobenthos on the flat bottom (10053.4 ind. m⁻², October 2001) was lower than the lowest value found in the natural hollow (Fig. 5). The highest macrozoobenthos biomass at the flat bottom station (121.4 g m⁻², June 2001) was almost nine times lower than the lowest biomass in the natural depression (Fig. 5). Oligochaeta, represented mainly by small specimens, were the most abundant group at the flat bottom station, ranging from 36.5% to 80.2% (Fig. 5). However, as in the Kuznica Hollow, biomass was dominated by Bivalvia, and varied



Fig. 3. Vertical profiles of meiobenthos abundance, expressed as percentage contribution, at the sampling stations in the Puck Bay.

from 36.4% to 81.9% of total macrofaunal biomass (except for March 2003, 13.5%). Mya arenaria dominance was not as high as in that area as a result of an increase in Macoma haltica and Cerastoderma glaucum abundance. At the flat bottom station Polychaeta showed a considerable contribution to total abundance (13-64.5%) and biomass (3.7-26.3%), whereas Crustacea – only to total abundance (2.6-26.1%).

Generally, the abundance and biomass of macrozoobenthos in the post-dredging pit were distinctly lower as compared to the Kuźnica Hollow and flat bottom stations (Fig. 5). The only exception was noted in June when the highest abundance (7555.6 ind. m⁻²) in the post-dredging pit was close to the lowest value at the flat bottom station (6261 ind. m⁻²). Biomass in the post-dredging pit ranged between 0.2 g m⁻² (October 2001) and 51.0 g m⁻² (June 2001). As Chironomidae were the most abundant group (69.1–100%) in the post-dredging pit (Fig. 5), they contributed either significantly (16.2– 95.1%) or totally (100%) to macrozoobenthos biomass. However, in June 2001, the biomass was largely made up by Polychaeta (78.7%), mainly *Hediste diversicolor*, and in April 2002 by Polychaeta (43.5%), mainly *H. diversicolor*, and Bivalvia (36.5%), mainly *Macoma baltica*.

The indices of species richness, evenness and diversity (Table 1) showed that macrobenthos diversity in the postdredging pit was distinctly lower than that in the natural depression and on the flat bottom. Although species richness and diversity were slightly higher at the NP station, the indices at the NP and F stations were comparable.

Based on the results of MDS ordination and cluster analysis using Bray-Curtis similarity comparing macrofauna densities of the studied sites, three groups corresponding to particular stations were distinguished (Fig. 6). The results obtained at the PP station differed from the others at ca. 20% similarity level, except for June 2001.

4. Discussion

The selected study areas in the Puck Bay differ significantly in meio- and macrofauna assemblages. Two of them, i.e. the shallow (1-2 m) coastal zone and the Kuznica Hollow (ca.



Fig. 4. Similarity of meiobenthos assemblages: MDS plot and clustering of meiobenthos communities at the sampling stations in the Puck Bay.

10 m), represent stabilized ecosystems with low and relatively constant number of macrobenthos species and typical meiobenthos taxa. Despite considerable depth and size differences between the Kužnica Hollow and shallow coastal zone, oxygen conditions were fairly similar in both areas in every season (Graca et al., 2004). Therefore, it is most likely that differences in species composition depend on sediment type. In the Kužnica Hollow, sediments consist of sandy mud and organic silt with a small fraction of muddy sand, whereas the shallow coastal zone includes medium-grained sand (Musielak, 1984; Jankowska, 1993; Jankowska and Łęczyński, 1993; Łęczyński, pers. comm.). Low organic matter content in the shallow zone (0.3-0.5%) stands out against that of the Kužnica Hollow (3.9-4.8%) (Graca et al., 2004).

The post-dredging pit (max. depth ca. 11 m) is almost 27 times smaller in area (ca. 0.2 km^2) than the Kuznica Hollow (5.3 km², max. depth ca. 9.7 m). Contrary to the gently-sloping seabed of the Kuznica Hollow, the pit slopes are very steep. Due to "terrace" configuration of pit slopes, a decrease in depth could even reach 4–7 m per 4 m (Smietana and Wawrzyniak,

1995). The sediment surface layer is defined as fine-grained material: from fine-grained muddy sand (Łęczynski, pers. comm.) to silty sand and silt (Maksymowska et al., 2003). It was found that organic matter content changes significantly (1.9-36%) at high rate of organic matter mineralization (Graca et al., 2004). Although oxygen concentration in the upper-bottom water is only slightly lower than at the surface, persistence of hydrogen sulfide in the interstitial water (Graca et al., 2004) does not promote zoobenthos development. However, Nematoda, which are relatively resistant to unfavourable environmental conditions (Higgins and Thiel, 1988), constitute a permanent but not very abundant (36-74 ind. 10 cm⁻²) element of meiobenthos in the post-dredging pit. Very high abundance of Chironomidae larvae (ca. 5 thousand per m²) also indicates deterioration of environmental quality (Stanczykowska, 1986). It is difficult to estimate the persistence of Polychaeta (Hediste diversicolor), Bivalvia (Macoma baltica) or Crustacea (Corophium volutator) in the post-dredging pit since they appear sporadically and in small numbers. Since macrofauna species were not noted in autumn, except for low abundant Chironomidae larvae (245

25000 20000 abundance [ind. m²] NP F 15000 10000 5000 0 VI IV ш vi x IV vi iv х ш 2001 2001 2002 2003 2001 2001 2002 2003 2001 2001 2002 2003 station FF station NF station VI, X, IV, III - months PP, NP, F - stations Rivalvia Insecta larvae Oligochaela olhers 1200 1000 800 biomass [g m⁻²] 600 400 200 ۵ VI х IV 111 ٧Ľ IV vi IV 2001 2001 2002 2003 2001 2001 2002 2003 2001 2002 2003 2001 station PP station NP station E VI, X, IV, III - months PP, NP, F - slabons 🛛 Insecta Iarvae Oligochaela olhers 📕 Biyatvia

Fig. 5. Abundance, biomass and number of macrozoobenthos taxa at the sampling stations in the Puck Bay.

ind. m⁻²), it could be presumed that strong spring storms drift macrozoobenthos organisms together with the heaps of seagrass (*Zostera marina*) and brown algae (Ectocarpaceae) from the adjacent shallow areas of the Puck Bay. Śmietana and Wawrzyniak (1995) studied an adjacent pit two years after the cessation of sand extraction. They observed a decrease in the number of macrozoobenthos species (from 9 to 1) with an increase in postdredging pit depth and the occurrence of seagrass on shallow terraces (36–74 ind. 10 cm⁻²). Bivalvia were very abundant on sandy seabed up to 4 m depth (*Cerastoderma glaucum* – ca. 32680 ind. m⁻²). Total abundance of the other taxa (Polychaeta, Gastropoda, Amphipoda and Isopoda) did not exceed 1000 ind. m⁻². Presumably, only this area was recolonized by

Table 1

The values of macrozoobenthos diversity indices in the investigated region of the Puck Bay, S = total number of species; N = total abundance; d = Margalefs species richness index; J' = Pielou's evenness index; H' = Shannon-Wiener's species diversity index; C = Simpson's species diversity index

Year	Month	Station	S	N	d	ſ	H'	С
2001	VI	PP	9	7555.6	0.9	0.5	1.1	0.5
2001	VI	NP	14	16 393.3	1.3	0.6	1.5	0.7
200 I	VI	F	19	8312.8	2.0	0.6	1.8	0.8
2001	Х	PP	1	244.7	0.0		0.0	0.0
2001	Х	NP	17	20846.9	1_6	0.5	1.4	0.7
2001	Х	F	18	10 055.4	1.8	0.5	1.4	0_6
2002	IV	PP	7	1603.9	0.8	0.4	0.7	0.3
2002	IV	NP	20	10832.2	2.0	0.5	1.6	0.7
2002	IV	F	17	9871.2	1.7	0.5	1.5	0.7
2003	111	PP	5	2916.7	0.5	0.3	0.5	0.2
2003	111	NP	15	11 577.9	1.5	0.6	1.8	0.8
2003	m	F	14	6261.6	1.5	0.3	0.9	0.3

macrofauna. It could be supposed that physico-chemical conditions in deeper parts of post-dredging pits do not favour the colonization process. Neither within 2 (Smietana and Wawrzyniak, 1995) nor within 10 years after the cessation of aggregate extraction did colonization occur favourably. Meiobenthos is also poorly developed and inhabits only the surface (1-2 cm) sediment layer. Nematoda are scarce, whereas Turbellaria and Harpacticoida appear occasionally.

Restoration of zoobenthos assemblages after cessation of bottom sediment extraction proceeds at very different rates. Re-colonization depends, among others, on seabed topography, hydrodynamic regime, transport of water masses and sedimentary characteristics, area size and depth, the way and period of aggregate extraction, the degree of biocoenosis disturbance, the changes in sediment structure and biological features of adjacent habitats (Newell et al., 1998). According to Boyd et al. (2003), while assessing "recovery" rate it is important to draw a distinction between re-colonization, which is the settlement of new recruits from the plankton or immigration of adults from outside the area (i.e. the start of the process of restoration), and restoration, which can be considered as the return of community structure.

The investigations on the impact of dredging on marine benthos show that the process of re-colonization and recovery in commercially exploited sand borrow sites is a complex one involving initial colonization by pioneer and opportunistic fast-growing species (van Dalfsen et al., 2000; Desprez, 2000; Sarda et al., 2000; Robinson et al., 2005). It was also found that initial colonization occurred within months of cessation, but the restoration of species richness and biomass took even several years (Kenny and Rees, 1994, 1996; Newell et al., 2004). Many authors suggest that distinct progress in macrozoobenthos restoration could be observed within 2-4 years following cessation of marine sand and gravel extraction (van Dalfsen et al., 2000; Desprez, 2000; Sardá et al., 2000; van Dalfsen and Essink, 2001). However, Boyd et al. (2005) concluded that the above period is too short, and at least 9 years are required for the complete erosion of dredged tracks in the disturbed area. The authors



Fig. 6. Similarity of macrozoobenthos assemblages: MDS plot and clustering of macrozoobenthos communities at the sampling stations in the Puck Bay.

suggest that the differences resulted from the period and intensity of dredging as well as the size of dredging area. Marine aggregate extraction is made by trailer or static dredging. Although both methods cause severe disturbance in macrozoobenthos assemblages (Desprez, 2000; Sardá et al., 2000; Boyd et al., 2003), the differences between dredged and surrounding areas are more significant after static dredging (Boyd and Rees, 2003). Generally, as a consequence of dredging by trailer suction hopper dredgers, shallow furrows of 1-3 m width and 0.2-0.5 m (ICES, 2001), and sometimes up to 5 m depth (Desprez, 2000) are formed. Undisturbed deposits are formed between the furrows. Their size and number depend on the intensity and period of exploitation. Undisturbed deposits between dredged furrows provide an important source of colonizing species (Newell et al., 1998), and re-colonization proceeds more rapidly in less heavily dredged sediments than in areas of intensive dredging (Newell et al., 2004; Boyd et al., 2005). However, Robinson et al. (2005) observed only slight differences between dredged and control areas. They explain the high speed of re-colonization by a highly dynamic environment, which is continuously subjected to disturbance. The macrofaunal community is represented there by a high proportion of mobile opportunistic species that are capable of rapid recovery following an episodic disturbance.

In the Puck Bay, static dredging led to the formation of deep cup-shaped depressions with very steep slopes. This has resulted in quite different physico-chemical conditions compared to the adjacent area (Graca et al., 2004). In an experimental area of seabed off the English east coast (ca. 1.4 km² some seven times greater than the pit in the Puck Bay) dredged by a commercial suction-trailer, re-colonization by opportunistic species proceeded at relatively high speed (Kenny and Rees, 1994, 1996). Within seven months macro-zoobenthos abundance was similar to that of pre-dredging state. However, seabed destruction was manifested there by

the formation of shallow (0.3-0.5 m) and narrow (ca. 1-2 m) furrows, whereas in the Puck Bay deep pits were observed. Undoubtedly, a new and quite different habitat was formed as a result of deep pit dredging. The investigations of those post-dredging pits, carried out almost 10 years after the cessation of aggregate exploitation, indicate very few signs of re-colonization in their deepest parts. According to Desprez (2000), on the area with large deep furrows (up to 5 m) separated by crests of shingles, species richness has been fully restored as early as 16 months, while density and biomass were still 40% and 25%, respectively. However, it was due to the large natural transport of sediment, produced by the strong tidal currents occurring in the area (1 m s⁻¹ during spring tides). In the Puck Bay, the current velocity is several cm s⁻¹, and it rarely exceeds 10 cm s⁻¹ (Nowacki, 1993). Therefore, the pits of 10-14 m depth, situated in shallow area (1.5-2 m), could not be filled up in natural way, even within tens of years. So, it could be most certainly stated that the restoration of macrozoobenthos assemblages, typical of shallow sandy seabed of the Puck Bay, will not happen in the nearest future (several or even tens of years). Also, it should not be expected that re-colonization would tend towards the formation of a structure similar to that of natural pits, such as the Kuznica Hollow. The pit topography makes it a specific trap for different types of organic matter. This results from small area of post-dredging pits in relation to their depth. As a consequence, the sediment is enriched with organic matter which decomposes leading to anoxic conditions and hydrogen sulfide formation (Graca et al., 2004).

Thus, there is limited information on the rate and course of recolonization on post-dredging areas by meiobenthos. This group of organisms does not possess pelagic larval forms providing easy expansion in water. However, those small-sized animals could be readily transported with sediment (Giere, 1993). Moreover, the dominating meiobenthos group, Nematoda, includes many species which are highly resistant to environmental disturbance. Therefore, Nematoda could be recognized as pioneer species that inhabit defauned area. However, such an assumption requires appropriate further study.

Generally, the pits dredged in the Puck Bay are some five times deeper than the average bay depth (1-2 m). New ecosystems formed in those pits are characterized by low biodiversity and they are limited only to the pit areas. Therefore, the deep pit dredging seems to be of no importance for the Puck Bay as a whole. However, the above method of aggregate exploitation should be ceased in shallow areas since the natural reconstruction of the disturbed environment is unlikely.

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