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Short-term study on the early succession stages of fouling communities in the coastal zone of Puck Bay (southern Baltic Sea)

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Abstract

The aim of this study was to distinguish the early succession stages of the fouling community in Puck Bay at depths of 3–7 m, to evaluate its biodiversity and to find the point at which the biodiversity of the assemblages achieved similarity. The depth at the study site was 8 m. The investigation lasted from 24 July to 22 September 2008 (61 days) when the colonisation and succession process of fouling communities is most intensive. During this period five sets of samples were collected. The investigations were focused on sessile organisms that established themselves on 105 PVC settlement panels (15 × 15 cm, 0.2 cm thick), 21 panels being deployed at each of five depths – 3, 4, 5, 6 and 7 m. A total of twelve sessile taxa and eight mobile (accompanying) taxa were identified over the course of the experiment. The panels became overgrown with fouling organisms in a characteristic manner - a layer of barnacles became covered with a layer of mussels. This type of community development created a double-layered

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structure (multi-strata growth). Assemblages reached a thickness of 2 cm as a result of the stratified fouling process. The species diversity was highest on 12 August (the first sampling day) at 7 m depth. Biodiversity differences during the study indicated that communities from all examined depths in Puck Bay became similar after a two-month colonisation period. By the end of the study *Balanus improvisus* and *Mytilus trossulus* were dominant in the communities at all depths.

INTRODUCTION

The classical theory of ecological succession propounded by Clements (1928) points to the climax state as the final stage of this process. Clements assumed that a climax community was not a static, homogenous community but rather a dynamic mosaic. Nowadays, however, this concept is viewed as an idealised description (Vance 1988, Qvarfordt 2006). Although the term 'succession' was originally applied to plant communities, the development of fouling assemblages is also a classic example of this process. Our study focused on succession at different depths and, therefore, on shallow-water zonation. Biofouling is a serious problem affecting hydro-engineering structures and ships' hulls. The most significant problems, however, relate to the colonisation and fouling of water pipelines (Shevtsova 1994). A range of acoustic, optical and electrode sensor technologies have been developed worldwide to cope with hull fouling and the corrosion of submerged objects (Alliance for Coastal Technologies 2003).

Macrobenthic zonation has the capacity to change much more rapidly than on land, owing to natural changes in population cycles, massive recruitment and seasonal cycles (O'Brien et al. 2003). Studies on benthic zonation usually cover a wide range of depths. Comparisons concentrate on the pelagic zone (0–30 m) and the sea bed, which enrich knowledge of benthic-pelagic interactions and hypoxia studies (Olenin 1997). However, other studies have shown that there are significant differences between biomass and structure in shallow waters, although the factors driving benthic zonation are not so strong there (Qvarfordt et al. 2006). According to Kiirikki (1996), the three factors usually regarded as causing the zonation pattern in Baltic rocky shore communities are ice scraping, irregular sea level changes, and light. In Puck Bay, light conditions are the main factor, since there are no natural rocky shores in this environment.

The aim of the present study was to distinguish early succession stages in the fouling community at depths from 3 to 7 m, during the season when the colonisation and succession process is most intensive, in order to evaluate its biodiversity, to find the point at which assemblages achieve biodiversity similarity, and to examine the relationship between the organisms making up these assemblages in Puck Bay.

MATERIALS AND METHODS

Study area

Puck Bay is a section of the Gulf of Gdańsk, which is in turn a part of the southern Baltic Proper (Majewski 1990). Long-term studies have shown that the water temperature amplitude during the course of the year is around 16°C (summer mean 18°C; winter mean 2°C) (Piliczewski 2004). The salinity of the surface water ranges between 6.70 and 8.31 PSU. The surface water salinity is subject to seasonal changes: it is lowest during summer, and highest during spring (Nowacki 1993).

The experiment took place in Puck Bay, off the Hel Peninsula (Poland), about 350 m from the shore (Fig. 1). The depth at the study site was 8 m. The seabed at the study site is dominated by natural sandy substrata and man-made constructions (harbour, coast reinforcement).

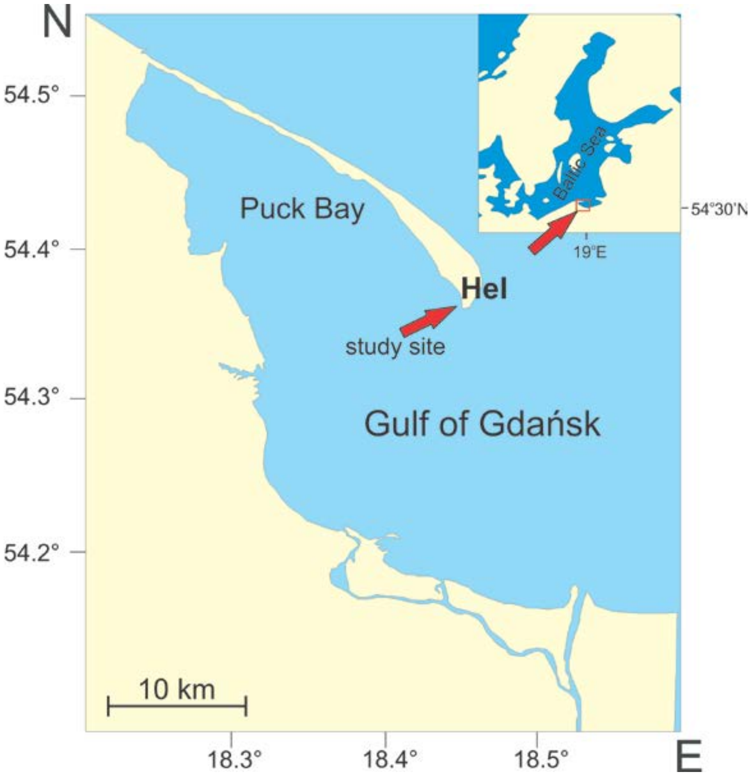

Fig. 1. Location of the set-up.

Sampling procedure and analysis

The study was carried out between 24 July and 22 September 2008, a total of 61 days. During this period five sets of samples were collected. Investigations were focused on sessile organisms that had established themselves on artificial substrata (PVC panels) at five depths: 3, 4, 5, 6 and 7 m. The presence of mobile (accompanying) organisms was also noted. The set-up consisted of 105 PVC settlement panels (15 × 15 cm, 0.2 cm thick), with 21 panels deployed at each depth. The panels had been previously roughened with sandpaper to facilitate settlement. The set-up was suspended from buoys such that the top of it was submerged at a depth of approximately 3 m (Fig. 2).

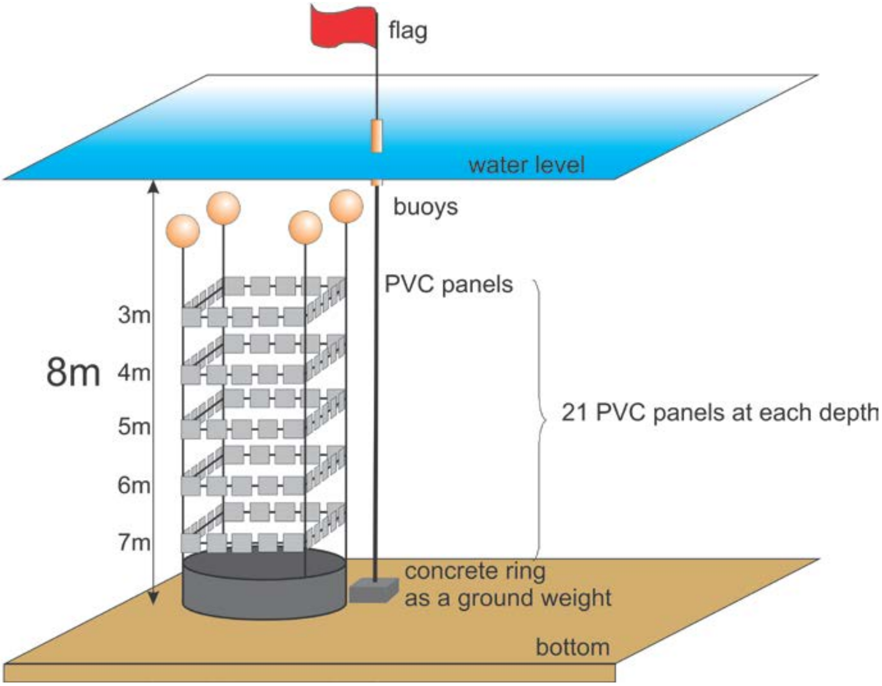

Fig. 2. Construction of the set-up.

Panels were collected randomly every ten days by scuba divers. The qualitative analysis was non-destructive, each panel being carefully examined with the naked eye and under a stereoscopic microscope. The sessile organisms present on the panels were identified to the lowest possible taxonomic level. A margin of 1 cm around the panel was ignored to prevent the sampling of edge effects; a PVC frame was used to mark the relevant area. The abundance of the communities was measured as the percentage cover of each taxon. Visual estimation of the percentage cover of sessile organisms was standardised by placing a grid on each panel to divide it into four sub-squares (6.5 × 6.5 cm), and using a 5% interval-step scale (5%, 10%, 15%, etc.). Exceptions were made for single individuals of some taxa that were visible but occupied less than 5% of the substratum (e.g. *Cerastoderma glaucum*). In this case, abundance was assessed as 1%. In the case of organisms forming layers and growing on top of one another (multi-strata growth), such as *Balanus improvisus* and *Mytilus trossulus*, the percentage cover reached much more than 100%. After each sampling, the organisms (all taxa) were scraped off the panels and the community dry mass was obtained for each panel. To standardise the procedure, the panels were stood vertically for one minute to allow the adhering water to run off before removing organisms from the panels. The material was desiccated at a temperature of 60°C to constant mass. Biomass was expressed in g m^{-2} DM (including shells).

Qualitative and quantitative changes in the macrobenthic communities were assessed on the basis of percentage cover data. The appearance of single specimens of a given taxon was considered to be the beginning of settlement. The mean abundance of each taxa on single panels was used to estimate quantitative changes in the fouling community. Confidence intervals were assessed at a significance level of $\alpha = 0.95$. The succession process was divided into phases defined by changes in the dominant organisms (Aleem 1957). Species diversity was assessed on the basis of the Shannon Index (Shannon, Weaver 1949). To define community evenness, the Pielou Index was used (Pielou 1966).

The normality test (normal probability plot) was performed to check whether data were distributed normally. The variation in percentage cover and biodiversity with respect to depth were compared using one-way ANOVA. T-test was used to determine whether there was a significant difference between group means.

RESULTS

Appearance of taxa

A total of twelve sessile taxa and eight mobile (accompanying) taxa were distinguished during the course of the experiment (Table 1). In the latter group Gammaridae were most common (Table 1). Larval stages of organisms residing temporarily in the fouling communities were also found. Two sessile species – *Balanus improvisus* and *Mytilus trossulus* – were dominant; they, along with

Table 1

Taxa of sessile and mobile organisms present (+) at different depths.

Depth Taxa	3 m	4 m	5 m	6 m	7 m
Cyanobacteria					
Spirulina rosea	+	+	+	+	+
Phaeophyta					
Pilayella littoralis	+	+			
Chlorophyta					
Enteromorpha intestinalis	+				
Cladophora glomerata	+				
Ciliata					
Peritrichia	+	+	+	+	+
Cnidaria					
Laomedea loveni		+			+
Cordylophora caspia					+
Arthropoda					
Balanus improvisus	+	+	+	+	+
Gammarus oceanicus	+	+	+	+	+
Gammarus salinus	+	+	+	+	+
Gammarus tigrinus	+	+	+	+	+
Gammarus zaddachi	+	+	+	+	+
Gammarus duebeni	+		+		
Sphaeorma hookeri	+	+	+	+	+
Idotea chelipes	+	+	+	+	+
Mollusca					
Mytilus trossulus	+	+	+	+	+
Cerastoderna glaucum				+	
Mya arenaria			+		
Tentaculata					
Electra crustulenta					+
Others					
megalopa *Rhitropanopeus harrisii*	+				
Chironomidae larvae	+	+			+

Peritrichia, a subclass of Oligohymenophora (Ciliata), were the first to colonise the free surface. These taxa appeared twenty days after the set-up had been submerged and were present at every sampling until the end of the study (Fig. 3, 4). Single specimens of *Mya arenaria* (6 m) and *Cerastoderma glaucum* (5 m) were also present. Polyps of the hydrozoans *Laomodea loveni* and *Cordylophora caspia* settled at 4 and 7 m. Bryozoan colonies (maximum diameter = 1 cm) were observed at 7 m (Table 1). Both the hydrozoans and the bryozoans appeared in September (Fig. 3).

Depth zonation and biodiversity

The percentage cover of the dominant organisms displayed a tendency to decrease with depth. This relationship was found statistically significant for *M. trossulus* but was not significant for *B. improvisus* (Table 2). Only at 6 m was the percentage cover of *B. improvisus* and *M. trossulus* greater than at 5 m,

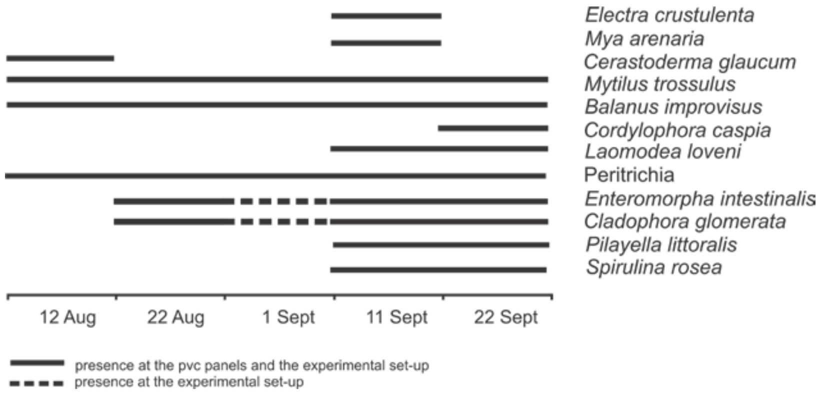

Fig. 3. Order of taxa appearance during the study (24 July – 22 September 2008), including all depths.

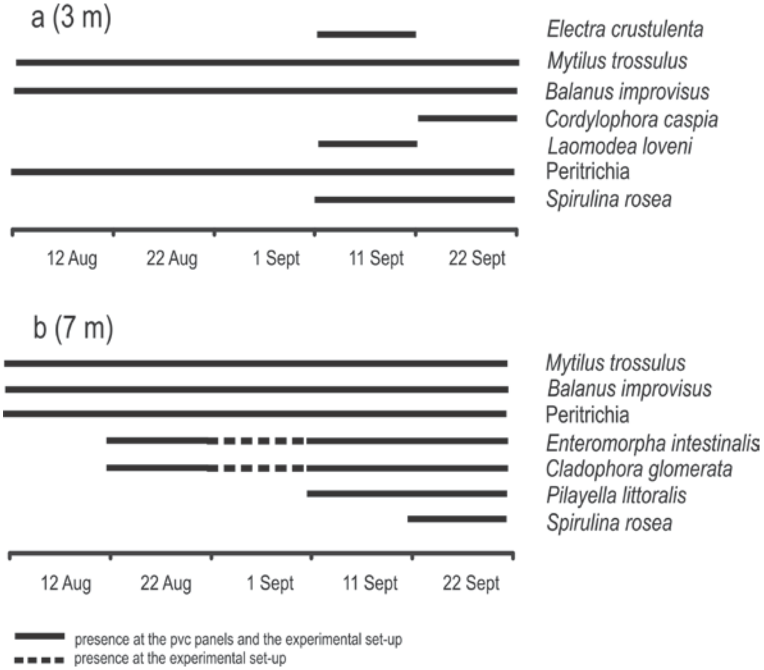

Fig. 4. Order of taxa appearance at (a) 3 m and (b) 7 m during the study (24 July – 22 September 2008).

Table 2

One-way ANOVA for the percentage cover of *B. improvisus*, *M. trossulus* and biodiversity indices (Shannon, Pielou).

Effect	SS	df	MS	F	p
***Balanus improvisus* (percentage cover)**					
intercept	**416194.30**	**1**	**416194.30**	**417.724**	**0.000000**
depth	6589.00	4	1647.30	1.653	0.170669
error	69743.70	70	996.30		
***Mytilus trossulus* (percentage cover)**					
intercept	**266531.20**	**1**	**266531.20**	**319.212**	**0.000000**
depth	**10222.20**	**4**	**2555.50**	**3.061**	**0.022036**
error	58447.60	70	835.00		
Shannon Index					
intercept	**50.69**	**1**	**50.68**	**4681.001**	**0.000000**
depth	**0.16**	**4**	**0.04**	**3.533**	**0.011019**
error	0.76	70	0.01		
Pielou Index					
intercept	**36.81**	**1**	**36.81**	**2534.379**	**0.000000**
depth	**0.22**	**4**	**0.06**	**3.713**	**0.008479**
error	1.02	70	0.01		

Bold denotes a significant result at p=0.05 or less

which slightly perturbed the general stepwise decrease (Fig. 5a). These changes were not statistically significant, however. Macrophytes were also important components of these communities: two species of green algae (*Cladophora glomerata* and *Enteromorpha intestinalis*) and one of brown algae (*Pilayella littoralis*). The green algae appeared only at 3 m and on the buoys supporting the set-up (1.5 m) (Fig. 5b). *C. glomerata* appeared on the panels on 22 August 2008 (nearly one month after the submergence of the set-up) and was ever-present until 11 September 2008 (Fig. 4a). *E. intestinalis* had also started to colonise the panels on 22 August and was recorded continually until the last sampling day (22 September 2008, Fig. 4a). The brown alga *P. littoralis* appeared in September and colonised panels at 3 and 4 m (Fig. 5b). Peritrichia were recorded at each sampling at all depths, but were most abundant at 3 and 7 m. The highest variability in their percentage cover was observed at 3 m (Fig. 5c). *Spirulina rosea,* a red-coloured cyanobacterium, also settled at all depths. It was most abundant at 7 m (Fig. 5d); its colonisation at that depth started earlier (11 September 2008) than at 3 m (22 September 2008) (Fig. 4a, b).

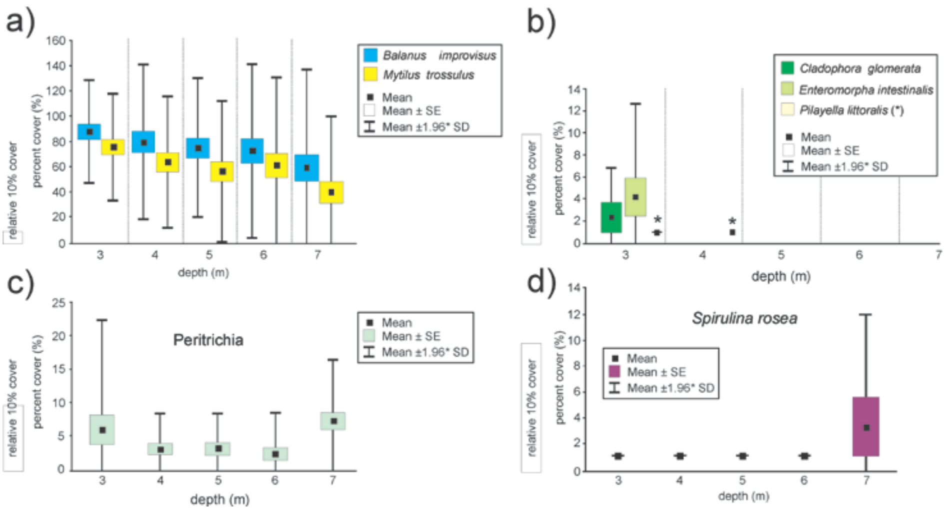

Fig. 5. Changes in percentage cover of (a) *B. improvisus* and *M. trossulus*, (b) macroalgae, (c) Peritrichia, (d) *S. rosea* at different depths, during the course of the study (24 July – 22 September 2008).

Fouling organisms grew over the panels in a characteristic manner, the layer of barnacles became covered with mussels. This type of community development created a double-layered structure (multi-strata growth). Assemblages reached 2 cm as a result of the stratified fouling process (Fig. 6). Community biomass varied during the study and was found to decrease with depth. The greatest disproportions in biomass were apparent on the last day of the study, the differences between 3 and 7 m (Fig. 7) being statistically significant ($p < 0.05$).

The Shannon Index provides data on species diversity. This revealed that biodiversity was the highest on 12 August (the first sampling day) at 7 m depth (H’ = 1.1) (Fig. 8a). The most evenly distributed abundance among the taxa (Pielou Index) was also recorded on 12 August at the same depth; this was reflected by the highest possible value of the Pielou index (J’ = 1) (Fig. 8b). In both cases this was the effect of three coexisting taxa (*B. improvisus*, *M. trossulus*, Peritrichia), each with a percentage cover of 5%. Biodiversity differences during the study indicated that communities from all depths in Puck Bay became uniform after a colonisation period of two months. The analysis of variance revealed that species diversity and evenness were dependent on depth. This relationship was statistically significant (Table 2).

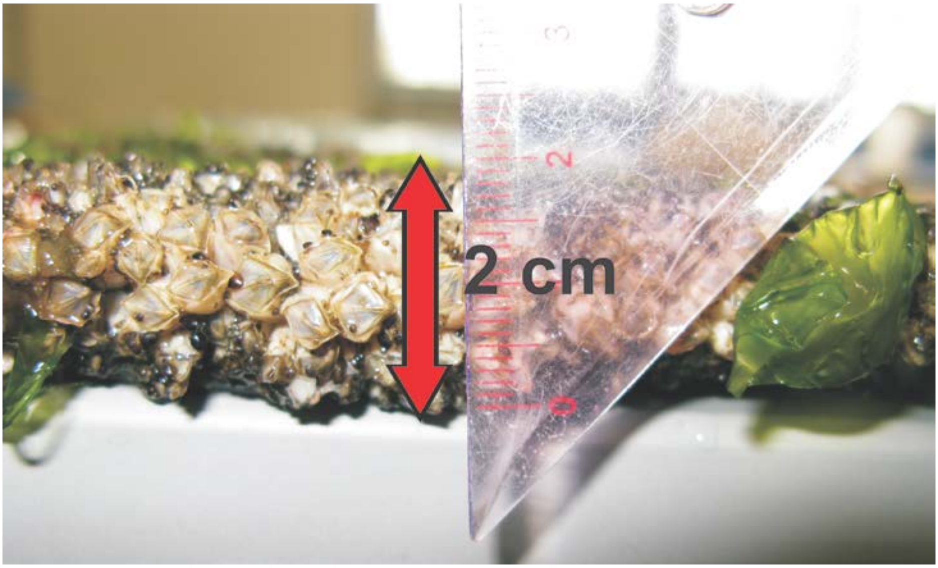

Fig. 6. PVC panel after two months' exposure to succession.

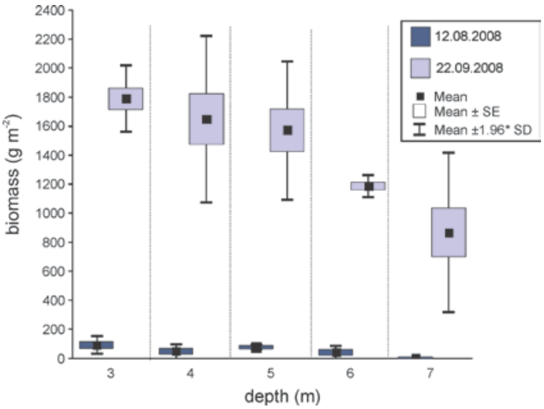

Fig. 7. Changes in community biomass at different depths at the first sampling day and the last one.

DISCUSSION

The seasonal dynamics of marine benthic ecosystems are strongly dependent on the annual changes of environmental parameters. The main factors are temperature, food availability and light. This pattern is characterised

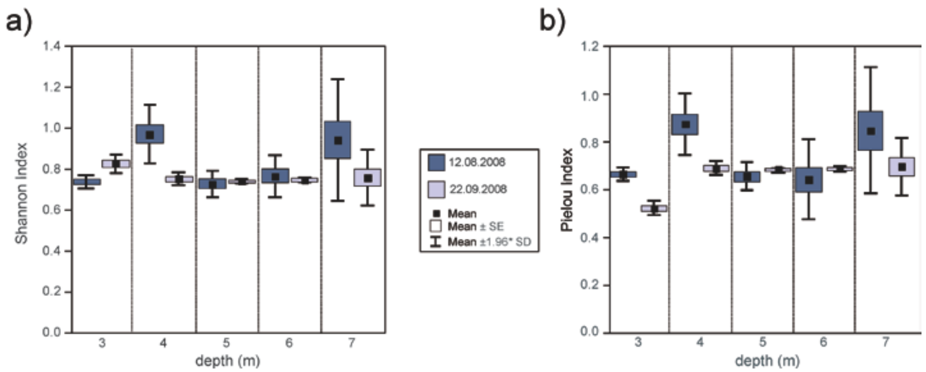

Fig. 8. Changes in (a) community biodiversity (Shannon Index) and (b) community evenness (Pielou Index) at different depths at the first sampling day and the last one.

by an increase in the activity and secondary production of most taxa during spring and summer, and a decrease in autumn until minimum activity is reached in winter. Activity-dormancy cycles are common among benthic invertebrates (Coma et al. 2000). The season during which the study was conducted, as well as our own observations, indicated that this was a period of intense activity: growth, increase in abundance, feeding activity and sexual activity.

The process of succession is inseparably linked to competition within the community, and some species usually begin to prevail. Our study distinguished two dominant competitors, *Balanus improvisus* and *Mytilus trossulus*. Competition for space and food between them is a common occurrence (Dürr, Wahl 2004), usually starting at the beginning of the succession, when the blue mussels form a layer on top of the barnacles. The inverse relation (barnacles on blue mussels) once the macrobenthic succession has become well advanced is indicative rather of commensalisms between the blue mussel and its epibiont (Laihonen, Furman 1986). The most significant changes in the abundance of fouling assemblages at different depths were related to these species. The percentage cover of *B. improvisus* and *M. trossulus* generally decreased with depth. This relationship may be an effect of the delayed settlement of organisms at greater depths or the smaller amount of available suspended particulate matter (SPM), the main food resource of suspension feeders.

The decreasing abundance (percentage cover) trend was slightly interrupted at 6 m and 7 m (Fig. 5). These results can be explained by the relatively high density of acorn barnacle larvae and blue mussel larvae in the near-bottom area. The concrete ring used to anchor the whole set-up was already very heavily colonised by fouling organisms, as it had been placed in Puck Bay coastal waters during the summer of 2000 (eight years before our study started) for other purposes. The adult fouling organisms covering the ring, mainly *B. improvisus* and *M. trossulus*, were probably the main reason for the high larval density in the near-bottom area, especially as there was no firm substratum within a radius of nearly 300 m from the set-up. However, the main trend of decreasing percentage cover and biomass is evident and has been confirmed by other studies. Earlier research demonstrated that biomass, number of specimens and percentage cover of fouling communities decrease with depth in the Baltic Sea. These earlier observations usually applied to a depth range from > 20 m to 124 m; the 0–20 m range was not investigated (Olenin 1997). It seems that the same relationship between abundance and depth can be observed already at water depths ranging from the surface to 7 m.

The species richness of the shallow-water fouling assemblages in Puck Bay was enhanced during the summer by the appearance of macrophytes, which were most abundant at 3 m depth. In Puck Bay green algae are sporadically found at depths greater than 1 m, so 3 m seem to be their maximum depth of occurrence under good light conditions (Pliński, Florczyk 1993). *Enteromorpha intestinalis* was the most abundant of all macrophytes, with the longest period of occurrence on the PVC panels. It was recorded from June to October and is the most common *Enteromorpha* sp. in the Gulf of Gdańsk (Pliński, Florczyk 1993; Haroon et al. 1999). Although the cyanobacterium *Spirulina rosea* has become an important and interesting component of assemblages, it was not as abundant as the macrophytes. Pliński and Komárek (2007) regard it as a potential coloniser of the Gulf of Gdańsk. But it is a common component of fouling communities in the southern Baltic (Pankov 1971).

The structural effect of multi-strata growth is endorsed by results obtained during a field experiment conducted in the Gulf of Gdańsk in 2005 (Dziubińska, Janas 2007). This is a common situation resulting from the natural settlement adaptations and competitive relationship between barnacles and mussels. Ciszewska and Ciszewski (1994) also demonstrated that *M. trossulus* needs a more porous substratum than *B. improvisus*: barnacles can settle on a smooth substratum (e.g. PVC panels), after which mussels settle on top of the rough barnacle shells. These double-layered communities were present at all depths. Larval growth to metamorphosis in these two species takes place during spring and early summer at temperatures of c. 10°C or higher (Żmudziński 1990; Furman, Yule 1991; Seed, Suchanek 1992) and lasts for nearly the same time: 2–5 weeks in *B. improvisus* (Furman, Yule 1991) and 2–4 weeks in *M. trossulus* (Seed, Suchanek 1992). Therefore, the probabilities of barnacles and blue mussels settling on the panels were approximately equal. By the end of the study *B. improvisus* and *M. trossulus* dominated the communities at all depths.

Even though the taxa composition and percentage cover differed among the five depths, the biodiversity became very similar after the two months of the study.

CONCLUSIONS

Balanus improvisus and *Mytilus trossulus* are the first macro-colonisers of the hard bottom in the shallow waters of Puck Bay during summer. Their percentage cover decreased with depth. This was probably the effect of a slower growth rate and/or delayed colonisation at greater depths. The biodiversity of fouling assemblages from different depths became similar (uniform) after a two-month colonisation period in Puck Bay, as the communities became dominated by two species. Consequently, the general pattern of benthic zonation also appeared in shallow waters of depths < 8 m within a very short time (two months).

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