Oceanological and Hydrobiological Studies
International Journal of Oceanography and Hydrobiology
Vol. XXXVI, No.4

Institute of Oceanography (65-78) University of Gdańsk
ISSN 1730-413X 2007 eISSN 1897-3191

DOI 10.2478/v10009-007-0026-1
Original research paper

Received: *March 28, 2007*
Accepted: *November 23, 2007*

Submerged objects – a nice place to live and develop. Succession of fouling communities in the Gulf of Gdańsk, Southern Baltic

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Key words: marine fouling communities, succession, settlement substrates, Gulf of Gdańsk

Abstract

The process of ecological succession in marine fouling communities was investigated at two study sites in the Gulf of Gdańsk, Gdynia and Gdańsk. Settlement panels were used as substrata for sessile organisms, and the study lasted 150 days between May and October 2005. Communities were dominated by two species, *Balanus improvisus* and *Mytilus trossulus*. The process of succession differed at these two study sites, particularly in the final part of the experiment. Four stages of succession were distinguished at both study sites; at Gdańsk: (1) Biofilm – phase, (2) Green algae – phase, (3) Balanus – phase, (4) Ectocarpaceae – phase; at Gdynia: (1) Biofilm – phase, (2) Balanus – phase, (3) Green algae – phase, (4) Mytilus – phase.

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INTRODUCTION

Ecological succession is a process that occurs when new structures are established within a community (Stugren 1976). Several stages of succession can be distinguished. The community composition changes in time and space until a climax state is reached (Clements 1928). Following this classical definition of succession, the marine fouling community is a dynamic assemblage that changes in time and space. However, observed changes in marine communities can deviate from this simple model as several studies have shown that later successional stages can be either independent of or constrained by events occurring in early stages (Qvarford 2006). Patterns of colonization in macrobenthic communities within temperate regions are highly affected by seasonality, which is reflected in the species composition and abundance of communities (Hart 2005). Sessile organisms typically do not feed on each other and energy in the system is coming mainly from the water column. Colonization occurs two ways, through larval supply and lateral ingrowth. Prior studies on the development of fouling communities in the Gulf of Gdańsk, Southern Baltic have included a variety of substrata: stones, wood, fishing nets, metal and glass (Mańkowski 1975, Ciszewska and Ciszewski 1994). Submerged objects, for example concrete modules, plastic pipes, and tires, have also been used as artificial reefs in the Southern Baltic. The primary purpose of these constructions was to use fouling communities as biofiltraters to regenerate degraded components of the coastal ecosystem (Chojnacki 1993, Chojnacki and Ceronik 1996). Man – made constructions are also often used to study the development of fouling communities. Qvarford et al. (2006) conducted such a study on the pillars of the bridge that connects the Swedish mainland to the Island of Öland (56°N, 16°E). During this experiment 31 taxa were observed, of which 18 were sessile. Researches on the development of marine fouling communities on artificial and natural substrata improve our knowledge of naturally occurring processes and interactions in macrobenthic communities. During recent decades, biofouling has become a serious problem that affects many hydro – technical constructions. The most significant problems are related to the colonization and overgrowth of water pipelines (Shevtsova 1994).

The aim of this study was to follow the natural succession of fouling communities in the Gulf of Gdańsk, and distinguish particular stages of community development.

MATERIALS AND METHODS

The experiment took place in the Gulf of Gdańsk, at two study sites: Gdańsk and Gdynia, where two set – ups were deployed (Fig. 1). The study

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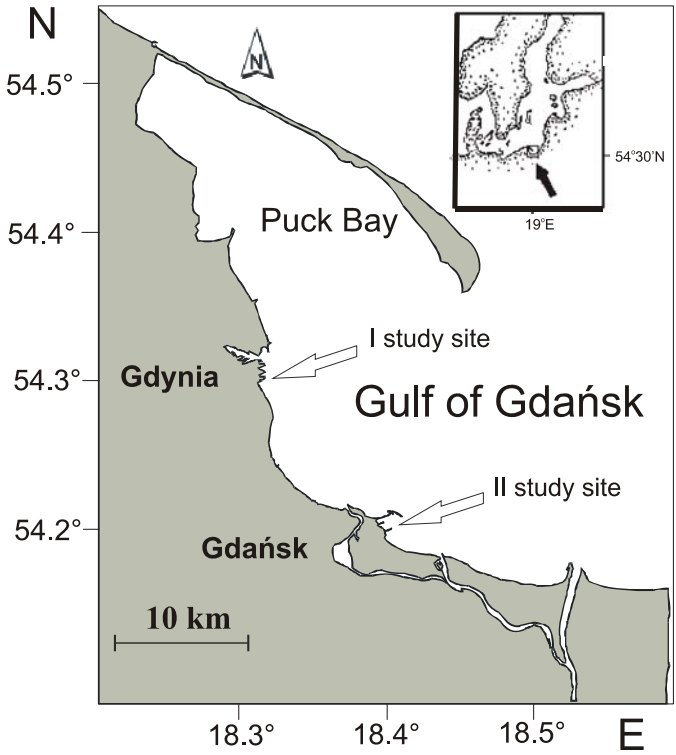


Fig. 1. Location of study sites.

lasted 150 days, between 14 May 2005 and 12 October 2005. The set – ups were deployed on 22 April 2005 in Gdańsk and on 4 May in Gdynia, to allow fouling communities to establish before our first measurements.

Investigations were restricted to sessile organisms that established on artificial substrates, i.e. PVC panels. One set – up consisted of five PVC rings, each of them carried ten settlement panels (15 × 15 cm, 0.3 cm thick) that were roughened with sand paper. The panels were fixed vertically to the inside of the PVC rings, with a diameter of 80 cm and a height of 20 cm. Each ring was suspended from a buoy, so that the top of the ring was in a water depth of approximately 0.5 m. The distance between rings was at least 1.5 times their diameter. The rings were fixed to ground weights (100 kg per ring) which anchored them to the bottom (Fig. 2). This design allowed the rings to move with changes in the water level and respond to moderate water currents.

Temperature (with 0.1°C accuracy) and salinity (with 0.1 PSU accuracy) were measured every fifth day. Two panels from each ring also were checked

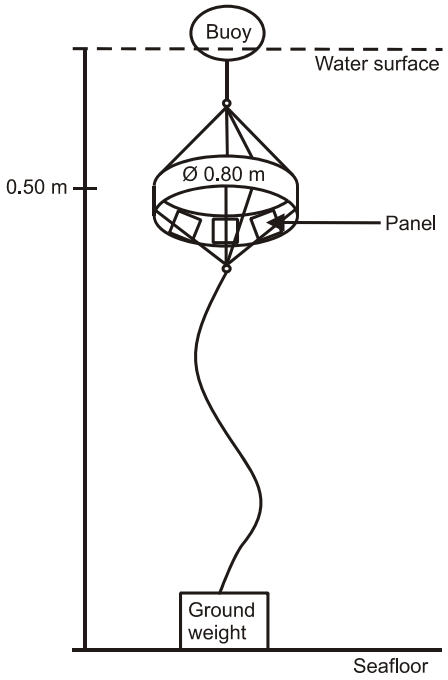


Fig. 2. Construction of the set – ups.

every fifth day. The sampling procedure was non – destructive, while each panel was examined carefully with the naked eye and a stereoscopic microscope. The number of sessile organisms >1 mm present on the panels was recorded and organisms were identified to the lowest possible taxonomic level. A margin of 1 cm around the panel was ignored to avoid the sampling of edge effects. The PVC frame was used to mark the respective area. Abundance of the communities was measured as percent cover of each species. To standardize the procedure, the panels were put in a vertical position to let the adherent water run off for one minute. Visual estimation of percent cover of sessile organisms was standardized by placing a grid on the panel, which divided each panel into four sub – quadrats (6.5 × 6.5 cm), and using a 5% interval – step scale. Exceptions were made for single individuals of some species, which 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 that created layers and grew on top of one another (multi – strata growth), such as *Balanus improvisus* and *Mytilus trossulus*, the percent cover reached much higher than 100%. The average time necessary for visual estimation of one panel was 3 minutes. After each sampling, all panels were reattached to the rings from which they were taken. The position of the panels in the rings was altered, with the new position chosen randomly, to reduce any tendency for community growth under certain conditions as much as possible.

After the final sampling, organisms were scraped off the panels and the community dry weight was obtained for each panel. The material was desiccated at a temperature of 60°C. The desiccation lasted seven days, to constant weight. Biomass was given in g dry weight m^{-2} (including shells).

Qualitative and quantitative changes in macrobenthic communities were assessed on the basis of the percent cover data. The appearance of single specimens of a given species was considered to be the beginning of settlement.

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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 that were defined by changes in the dominant organisms (Aleem 1957).

RESULTS

A total of 15 taxa were distinguished over the course of the experiment (Table 1). Diatoms and the green alga *Cladophora rupestris* were the only organisms that established on the settlement panels during the first two months (May, June) of exposure to natural colonization (Fig. 3a and 4a). The increase in temperature affected development of other species (Fig. 3b and 4b). There were no significant differences in salinity between the two study sites.

Table 1

Taxa identified during the experiment

Taxa	**GDAŃSK**	**GDYNIA**
CYANOPHYTA		
Spirulina sp.	+	+
CHLOROPHYTA		
Cladophora rupestris (Linnaeus) Kützing, 1843	+	+
Enteromorpha ahlneriana Bliding, 1944	+	+
PHAEOPHYTA		
Ectocarpaceae	+	-
RHODOPHYTA		
Callithamnion byssoides Arnott, 1833	-	+
Ceramium rubrum (Hudson) C. A. Agardh, 1817	-	+
HYDROZOA		
Laomedea loveni (Allmann, 1859)	+	+
Cordylophora caspia Pallas, 1771	+	+
Clava multicornis (Forskal, 1775)	+	+
BIVALVIA		
Mytilus trossulus Gould, 1850	+	+
Cerastoderma glaucum Poiret, 1789	-	+
Mya arenaria Linnaeus, 1758	-	+
CRUSTACEA		
Balanus improvisus Darwin, 1854	+	+
BRYOZOA		
Electra crustulenta Pallas, 1766	+	+
Bowerbankia gracilis Leidy, 1855	+	+
Total	11	14

(+ presence, - absence)

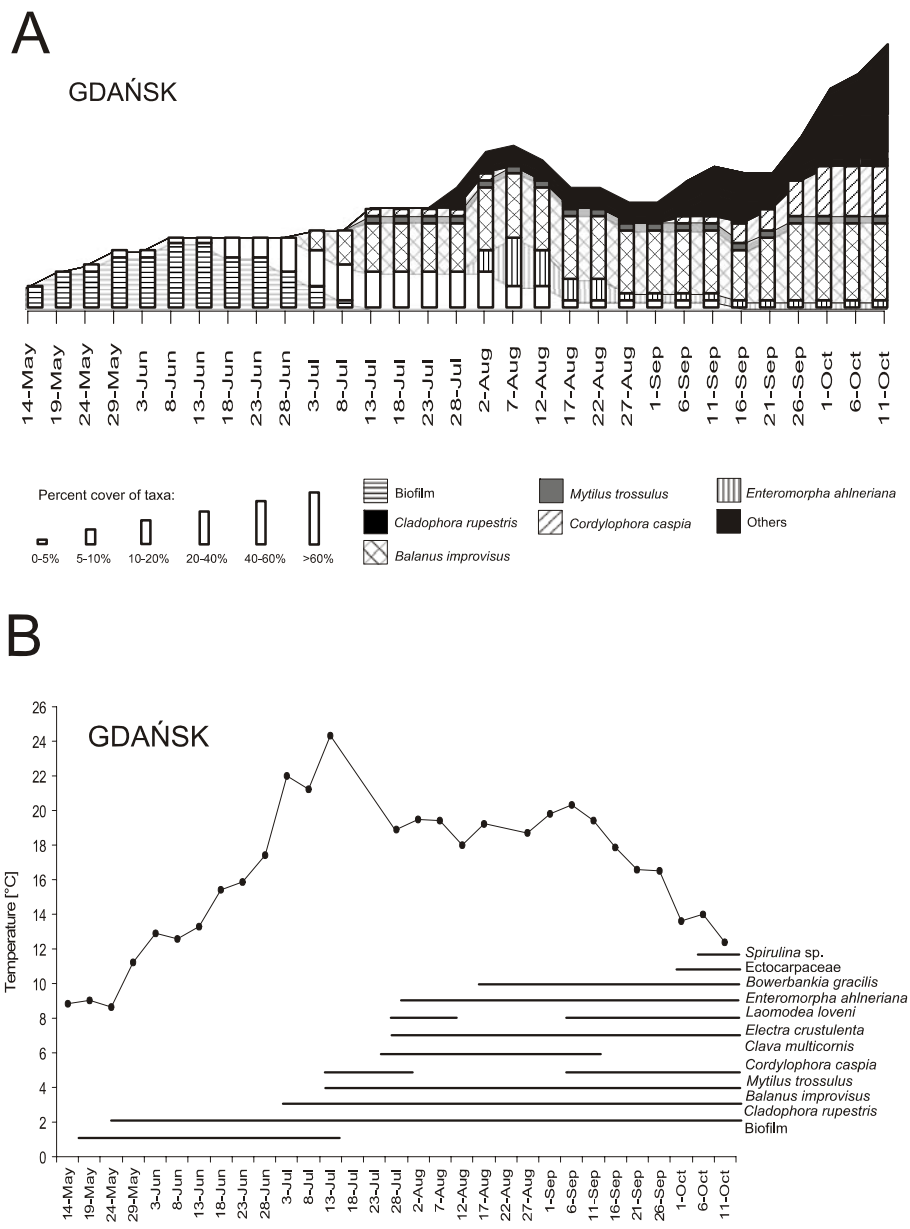


Fig. 3. A) Changes in abundance of particular taxa in the fouling communities during the experiment (Gdańsk); B) The timing of appearance of particular taxa in relationship to water temperature (Gdańsk).

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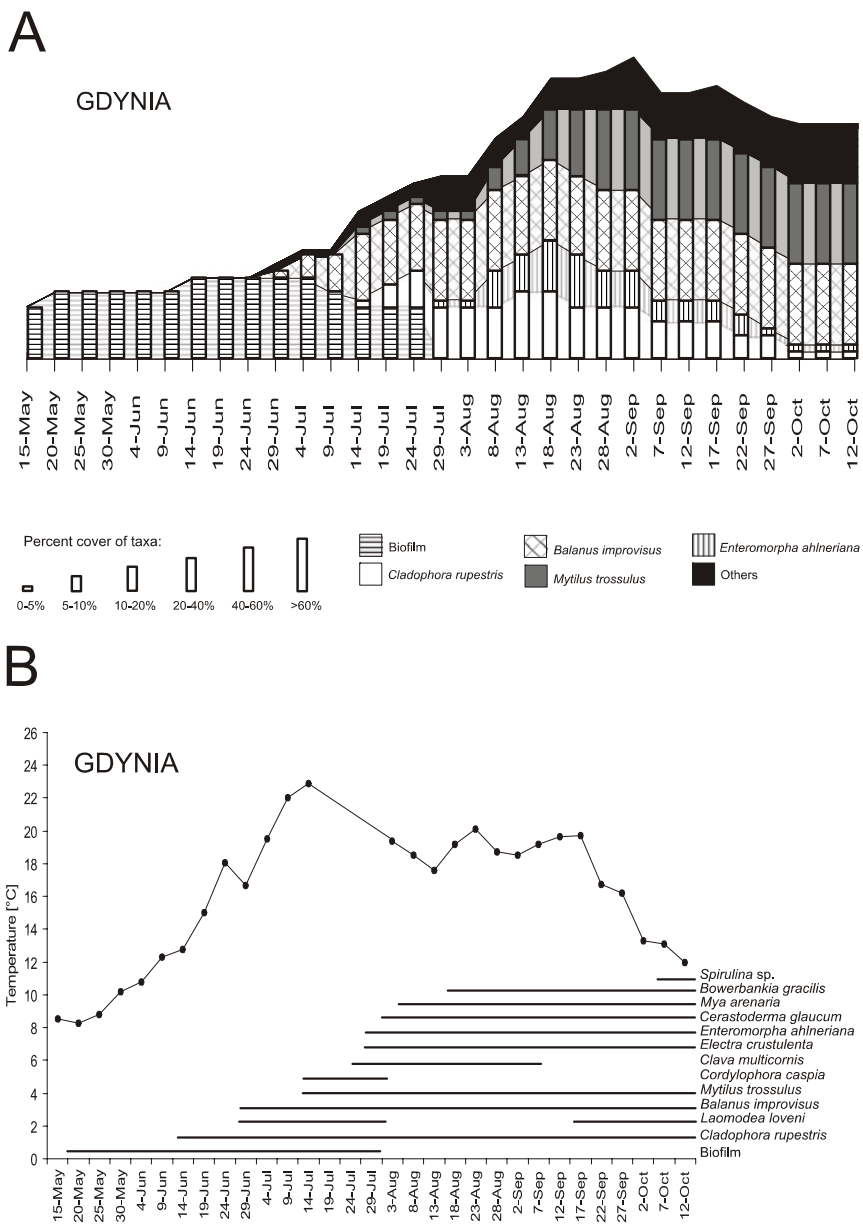


Fig. 4. A) Changes in abundance of particular taxa in the fouling communities during the experiment (Gdynia); B) The timing of appearance of particular taxa in relationship to water temperature (Gdynia).

C. rupestris firstly settled on the panels in Gdańsk and three weeks later appeared on the panels in Gdynia (Fig. 3b and 4b). The barnacle *Balanus improvisus* settled on the panels in Gdynia at the end of June, and in Gdańsk at the beginning of July, respectively. *B. improvisus* became the most abundant species and dominated communities by the end of the study (Fig. 3a and 4a). During the last phase of the experiment, the blue mussel *Mytilus trossulus* increased in abundance (from 0 – 5% to >60% of community) and strongly competed with *B. improvisus* (>60% of community) on the panels deployed in Gdynia (Fig. 4a). *M. trossulus* appeared later on the settlement substrata than *B. improvisus,* but quickly formed a compact layer covering the already – established barnacles (Fig. 4a). In contrast, brown algae of the family Ectocarpaceae and the bryozoan *Bowerbankia gracilis* were very abundant in Gdańsk, especially during the last phase of succession.

After 75 days of exposure to colonization (beginning of August), a decrease in the colonization intensity by young barnacles was observed at both study sites. During the last month of the study, only adult barnacles and no newly – settled recruits of *B. improvisus* were present in the communities. At the same time, blue mussel larvae settled heavily in Gdynia, so that at the end of the experiment, high numbers of young *M. trossulus* were found there. Their percent cover was always over 60%, very often reaching up to 100% (Fig. 4a). Therefore, the mean value of total abundance and biomass of communities was much higher in Gdynia (202.1%, 3159.7 gm^{-2}) than in Gdańsk (134.7%, 2076.9 gm^{-2}; Fig. 5 and 6). In addition to these abundant organisms, a few rare species were observed on the settlement panels: the cockle *Cerastoderma glaucum* (only in Gdynia), the bryozoan *Electra crustulenta* and the hydrozoan *Laomedea loveni* (Fig. 3b and 4b).

DISCUSSION AND CONCLUSIONS

This study revealed that ecological succession in marine fouling communities takes place in a particular order in the Gulf of Gdańsk. Prior authors have distinguished several stages that give the community a characteristic pattern (Aleem 1957, Wahl 1989, Khalaman 2001). These stages are called ‘phases’ and are defined by the dominant organisms. Aleem (1957) researched the succession of macrobenthic communities on plexiglass panels immersed in coastal waters at La Jolla, California (14 m below mean water level). He identified five phases: (1) Bacterial – phase, (2) Diatom – phase, (3) Hydroid – phase, (4) Ectocarpales – phase and (5) Balanus – phase. The first two phases appeared in our study: however, Bacteria and Diatoms were defined as the biofilm layer. With regard to the phases mentioned above, there was a difference in the order of appearance of the two last phases in the Gulf of

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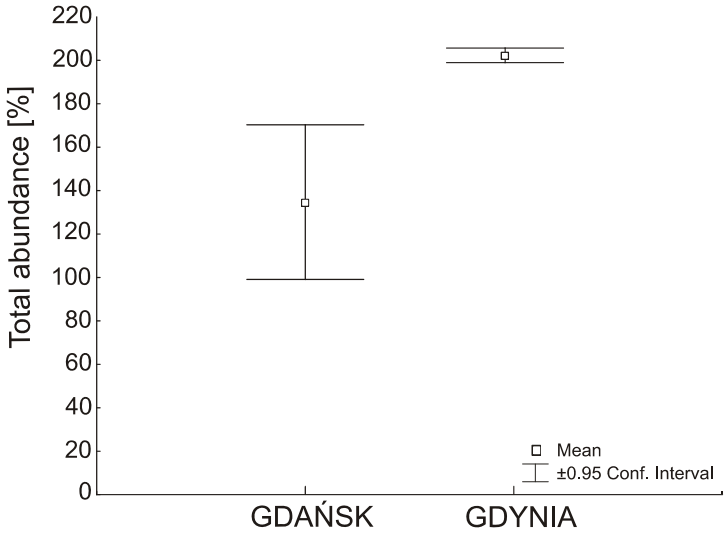


Fig. 5. Total abundance of communities in Gdańsk and Gdynia.

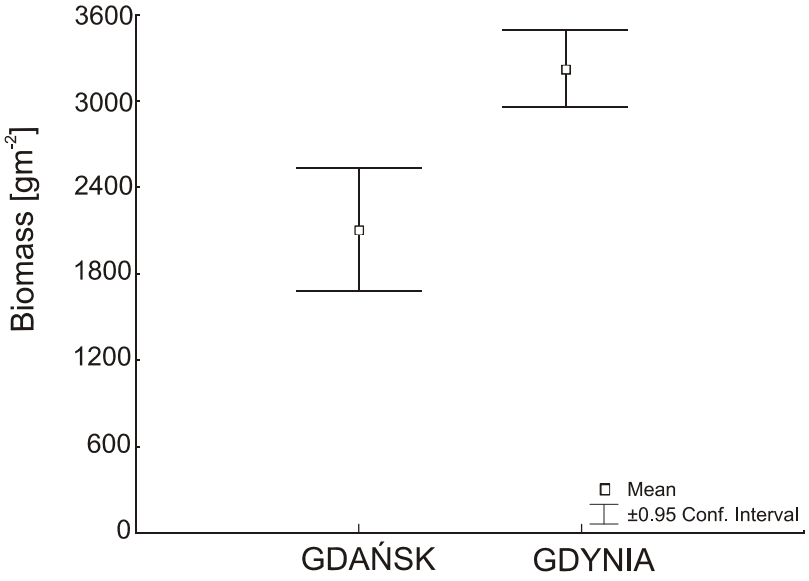


Fig. 6. Biomass of communities in Gdańsk and Gdynia.

Gdańsk: *Balanus improvisus* settled earlier than Ectocarpaceae. In Gdynia, the last stage should be called the Mytilus – phase. It is also notable that the Hydroid phase did not develop as strongly in the Gulf of Gdańsk as the green algae phase. Following Aleem's scheme, four stages can be distinguished at the study site in Gdańsk: (1) Biofilm – phase, (2) Green algae – phase, (3) Balanus – phase, (4) Ectocarpaceae – phase, and four stages for the study site in Gdynia: (1) Biofilm – phase, (2) Balanus – phase, (3) Green algae – phase, (4) Mytilus – phase (Fig. 3a and 4a).

Over thirty years ago, Mańkowski (1975) made observations on the succession of fouling communities on submerged objects in the Gulf of Gdańsk. This study as well as many others, conducted in the Baltic and other Seas, revealed that *Balanus* sp. and *Mytilus* sp. are among the most important components of macrobenthic assemblages (Berntsson and Jonsson 2003, Dürr and Wahl 2004, Qvarford et al. 2006). Differences in colonization and ingrowth abilities of these two species were observed. The most abundant crustacean, *B. improvisus* was colonizing free substrate patches very quickly during summer. Prior experiments (Ciszewska and Ciszewski 1994) have shown that barnacles can settle on all kinds of substrata (fishing nets, rocks, metal, glass). Blue mussels, on the contrary, need a slightly rougher surface. In consequence, panels were initially occupied by *B. improvisus*. Larval growth to metamorphosis of these two organisms takes place during spring and early summer, at around 10°C or more (Żmudziński 1990, Furman and Yule 1991, Seed and Suchanek 1992), and lasts nearly the same length of time: for *B. improvisus* 2 – 5 weeks (Furman and Yule 1991), for *Mytilus trossulus* 2 – 4 weeks (Seed and Suchanek 1992). Therefore, barnacles and blue mussels had approximately equivalent probabilities of settling on the panels. Intense recruitment of *M. trossulus* in Gdynia enabled blue mussels to create a very compact layer on previously settled barnacles, which was reflected in the high total abundance of communities. There was also a shift in the intense recruitment period of these organisms (*B. improvisus* – June, *M. trossulus* – July), which meant that young mussels were competing with adult barnacles. All these observations led us to conclude that different conditions (e.g. wave action, type of background, total depth) in the two study sites could have affected changes in the structure of communities.

Why did blue mussels influence communities so strongly in Gdynia?

Temperature, salinity, food availability, parasitism and also interspecific competition for space and food are factors that may affect growth rates of *M. trossulus*. Several factors may interact, depending on location and environmental conditions (Seed and Suchanek 1992). As there were no

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significant changes in salinity or temperature at the two study sites, we suspect that competition for space and food may have been the factors that favoured *M. trossulus* in Gdynia. A second possibility is that *M. trossulus* did not find relevant substrates to settle on (in Gdańsk), as they usually do not settle on an algae and prefer firm surfaces (Newell 1989). *Cladophora rupestris* appeared much earlier in Gdańsk, and overlapped in time with the arrival of mussel larvae, perhaps making settlement impossible. However, the most plausible explanation came with visual inspection of panels in early successional stages, when we noticed that more young mussels were attached to the panels in Gdynia than in Gdańsk. This observation means that the experiment in Gdynia was close to a spawning site for *M. trossulus*. Studies and monitoring of the blue mussel distribution in the Gulf of Gdańsk confirm our observations (Warzocha, unpublished data). *M. trossulus* appears at numerous sites in Gdynia, while it is in low abundance in Gdańsk, most probably due to the local hydrography and a reduction in the number of larvae transported to Gdańsk. Newell (1989) distinguished several environmental factors that may limit the area of blue mussel appearance, for example the type of substrate, high velocity water currents and high energy waves. However, it is important to note that blue mussels have evolved a suit of sophisticated adaptations that enable survival in a rigorous environment.

Focusing on the relationship between barnacles and blue mussels, three successional stages can be distinguished in the experiment in Gdynia. Competition for space appeared first. The substratum was initially occupied by *B. improvisus,* and this created a favorable background for *M. trossulus* settlement. After two months, the density of blue mussels had increased substantially. During this period, *M. trossulus* and *B. improvisus* coexisted. Coexistence of these two species is commonly observed, as in the subtidal Kiel Fjord, Western Baltic, where Dürr and Wahl (2004) investigated recruitment, population dynamics and community structure on hard substrata as influenced by these competitors. In the final part of this experiment, blue mussels dominated communities, with barnacles the only other species able to coexist with mussels. However, we suspect that *M. trossulus* hindered effective feeding by barnacles, as blue mussels covered them completely.

In conclusion, a distinct ecological succession was observed in the marine fouling communities in the Gulf of Gdańsk. This process differed in Gdańsk and Gdynia, particularly in the final part of the study (Fig. 7), which was primarily due to the difference in total abundance of *M. trossulus.* This mussel was very abundant in Gdynia and sparse in Gdańsk. Several stages of the succession can be distinguished, in which biofilm was the first stage and Ectocarpaceae (in Gdańsk) or *M. trossulus* (in Gdynia) was the last one. This study has shown that slight differences in patterns of recruitment and growth

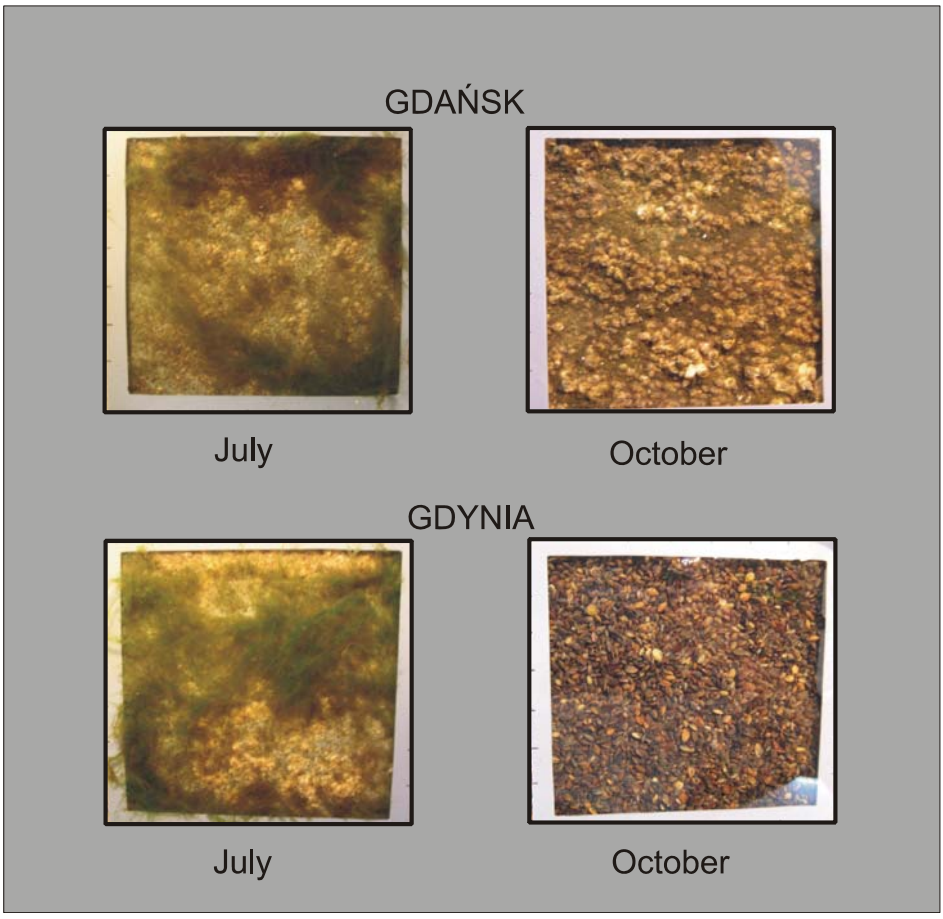


Fig. 7. Seasonal changes of communities in Gdańsk and Gdynia:
July: **Gdańsk** – 35% *B. improvisus*, 25% *C. rupestris*, 1% *C. multicornis*, 1% *L. loveni*; **Gdynia** – 100% *B. improvisus*, 35% *C. rupestris*, 1% *L. loveni*, 1% *M. trossulus*
October: **Gdańsk** – 100% *B. improvisus*, 20% *B. gracilis*, 5% Ectocarpaceae, 5% *C. caspia*, 5% *M. trossulus*, 1% *C. rupestris*, 1% *Spirulina* sp., 1% *E. crustulenta*; **Gdynia** – 100% *M. trossulus*, 95% *B. improvisus*, 1% *E. ahlneriana*

can change the successional process of fouling communities. If possible, future experiments should include more environmental measurements, for example the content of inorganic and organic matter in the water column, type of natural substratum and wave action, which may help explain factors determining community composition and change in marine fouling communities.

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ACKNOWLEDGMENTS

We thank Prof. Anna Szaniawska for supervision of the study, and staff members from the Department of Experimental Ecology of Marine Organisms, University of Gdańsk, in particular Dr. Monika Normant, M.Sc. Monika Michałowska and M.Sc. Marcin Dziekoński. We are grateful to M.Sc. Filip Pniewski (University of Gdańsk) for algal identifications. Special thanks go to M.Sc. Sigrun Schröder whose energy and hard work helped greatly in completing the experiment. We thank the crew of R/V Oceanograf 2 for invaluable help in reaching the study site in Gdynia and for assistance with fieldwork. The set – ups were deployed by courtesy of the Port of Gdańsk Authority SA and the Port of Gdynia Authority SA. This research was conducted as part of the GAME programme, IFM – GEOMAR, Leibniz – Institute of Marine Sciences at Kiel University, Germany, and was financed by the Mercator Foundation.

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