BIOFOULING ON AN OFFSHORE RIG IN THE BALTIC SEA

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ABSTRACT

Biofouling is called “lessons from nature”. Currently, governments and industry spend more than 5.7 billion USD annually to control unwanted marine biofouling, aquatic flora and fauna on submerged construction leading to various technical, economical, and ecological problems. In turn, the Baltic Sea is defined as a “time machine” for the future coastal ocean, as processes occurring in the Baltic Sea are related to future changes. Our study describes the biofouling community at 12 sites located at different depths on the legs of the “Baltic Beta” oil platform that resulted in finding a maximum of 1,300 individuals on 400 cm^2. We analyzed: spatial distribution of dominant marine organisms living on a steel platform surface, their abundance and mass. Our work showed no significant difference in the benthic samples mass among different depths or cardinal directions of the rig columns. Our research can help to predict offshore biofouling on other devices in the Baltic Sea, to control invasive species and to estimate environmental load.
Keywords: marine growth, biomass, hydrodynamic efficiency, alien species, epifauna.

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INTRODUCTION

Marine growth known as "biofouling" refers to the undesirable accumulation of biological material on artificial structures [1]. The Offshore Renewables Joint Industry Programme for Ocean Energy describes biofouling as a "reef" and "introduction of non-native invasive species", which is an issue for ocean energy projects [2]. Artificial hard substrate provides an ideal basis for sedentary and sessile marine organisms to settle and grow, but assemblage structures of biofouling communities on artificial substrates do not resemble those on natural reefs [3,4,5,6]. They are an important consideration for structure developers, they affect hydrodynamic efficiency and are not yet considered by regulatory bodies as a key strategic issue regarding consent to the renewable marine energy industry [1].

Little is known about the ecological effects of fouling on offshore devices, although some studies have been carried out on offshore structures such as wind power piles and offshore oil rigs [7,8]. In aquatic environments, biofilms increase corrosion of metal structures [9]. That information could help to manage maintenance work or coating specification, as well as protect devices effectively and thus reduce management costs [10]. Det Norske Veritas [11] has published offshore standards, according to which submerged construction hydrodynamics and marine growth should be taken into account by increasing the outer diameter of a structural element in the calculations of hydrodynamic wave and current loads. The thickness of marine growth depends on the depth and orientation of the structural component. Cathodic protection and coatings are used to control corrosion of submerged components, but it has been studied that under certain conditions it could enhance marine growth [12,13].

In the Baltic Sea, offshore oil and gas exploration has not been massively developed. However, the scale of this industry can increase in near future, as there are plans to exploit a number of oil fields in Polish and Russian waters. Biological data describing offshore platform biofouling communities are scarce, and mostly involve oil and gas platforms and wind energy installations [14,15,16].

Most benthic invertebrates produce free-swimming larvae that spend time in the water column. Pelagic development and passive dispersal result in higher connectivity and low genetic differentiation among benthic species populations over long distances [17]. Until now, 4000 species from offshore structures have been reported [18]; however, this is a very small proportion of known marine species [19]. Moreover, biofouling communities on artificial structures can promote growth of non-native species [1]. Interestingly, North Sea studies have been largely confined to fouling predictions and have tended to focus on the organisms important with regard to hydrodynamic loading and corrosion [20,21,22,23].

Biodiversity and succession of epifauna on artificial devices of Southern Baltic Sea were investigated by Bałazy et al [24] and [25,26,27]. The adaptation of species to brackish conditions in the Baltic Sea caused both morphological and genetic differences compared to their salt/fresh water analogues [17]. Submerged objects generally support two to three invertebrates species and about 25 times higher number of individuals (but not diversity) than the soft bottom in the vicinity [24].

The Baltic Sea can serve as a "time machine" for studying the consequences and contemporary ecological perturbations worldwide [28]. Many species in the Baltic Sea constitute unique evolutionary lineages with lower genetic diversity compared to the North Sea [29,30,31]. According to Coolen et al. [32] epifaunal organisms use artificial structures as stepping stones to spread to areas that are too distant to reach within a single generation.

We expect decreasing depth-related gradient in epifauna abundance and diversity along the platform legs. On the other hand, the average annual directions of winds and sea currents at depths 5 m and 40 m is significantly different, therefore it may have an impact on the species composition and their quantitative accumulation depending on cardinal directions. So that this study investigated the main macrobenthic species forming the biofouling community on the "Baltic Beta" platform in the Baltic Proper. Two main research hypothesis were tested, i.e., i) the mass of biofouling macrobenthos decreases with depth, ii) macrobenthic communities species composition and frequency of individuals depend on cardinal directions or water depth.

MATERIALS AND METHODS

The Baltic Sea (Fig. 1) is an evolutionarily young marine ecosystem [29]. Salinity gradient present in the Baltic Sea area spans from 25 to 2 in the Bothnian Bay. Along this gradient, marine species are disappearing according to their tolerance to low salinity to be gradually replaced by freshwater species [33]. At present, many stressors (e.g., eutrophication, warming, oxygen, and acidification status) occurring in the Baltic Sea [28]. Currently, 132 non-indigenous species (NIS) have been recorded in the Baltic Sea [34]. Alien species account for about 30% of the total number of macrofauna taxa in brackish coastal waters of the Gulf of Gdańsk [35], and their number is constantly increasing. The Baltic Sea also demonstrates how rapidly progressing global pressures, particularly the warming of Baltic waters and the surrounding catchment area, can diminish the efficacy of current management approaches; it is also one of the most intensely studied coastal areas with high data density and many long-term data series [28]. Oxygen-free "dead zones" are increasing worldwide, but a particularly drastic 10-fold increase, occurring mainly at greater depths, has been observed during the past 115 years in the Baltic Sea [36].

The production facility, the "Baltic Beta" platform (Fig. 2), is located on the oil field "B-3" about 80 km north of the Rozewie city (Fig. 1). The platform was installed in 1993. "Baltic Beta" has 3 pairs of legs and each leg has 3 columns connected by a complex arrangement of diagonal and horizontal members. The metal structure was covered with anti-fouling paint. Platform legs are set at the bottom of the sea at a depth of 80 m (Fig. 2). Sampling sites are characterized by large annual variations in seawater temperature at surface (surface water temperatures range from below the freezing point during winter to above 20°C in summer); at greater depths, the temperature is constant (at approximately 3-4°C).

The sampling area (Fig. 2) was located at GPS geographical coordinates of 55°28'50.67″N and 18°10'54.03″E on one platform leg (leg 2 and 12 sampling sites on columns 1, 2 and 3). The survey was carried out on August 1, 2018. All sampling work was conducted by a commercial diver in accordance with Polish regulations. A square frame with a diameter of 20×20 cm was used to mark the sampling area, and all the material was scraped off by a diver and placed in a container. The thickness of the bioformation was measured using a calibrated ruler at the sampling site. The material was preserved in 70% ethanol. In addition, visual ROV (Remotely Operated Vehicle Saab Seaeye Falcon) inspections were performed to determine the maximum depth of biofouling on the legs of the "Baltic Beta" platform and the neighboring "PG-1" platform (built in the late 1990s).

In the laboratory, organisms in samples were identified and counted. The sampling method did not prevent the escape of the majority of motile species (crustaceans could escape, which probably accounts for the relatively low numbers of motile species recorded).

Mass and abundance were expressed in units per 400 cm2 (including shells). The weight was net material content in a volume of 1000 ml; mass determined weight of the collected material and the maintenance ethanol in a volume of 1000 ml. The mean mass and standard error (95% interval) were calculated for 4 depths: 5 m, 10 m, 20 m and 36 m (from different geographical directions). For data, Pearson's correlation coefficient R2 (the coefficient of determination) was calculated for regression, for the number of macrobenthic individuals and mass of samples for each depth and cardinal directions.

The similarity index was used to quantify differences in species composition and abundance between different sampling sites. The Bray-Curtis algorithm based on the paired group was used for hierarchical UPGMA clustering in the PAST 4.1 software.

RESULTS

A total of 7,445 macrobenthic organisms were found in samples. There was a noticeable decrease in the weight of the samples with depth (Fig. 3). A lower mass on column 2 was also observed compared to other columns (Fig 4). Pearson's correlation coefficient (Fig. 3), including the correlation value R^2, and the sample size is listed in Table 1. Biofouling mass and geographical directions were not correlated ($p>0.05$, Table 1.). It should be noted that in one case (36 m), p-value reached the level of 0.13 (increasing numerical trend). There was a trend of sample mass increase from south to north. However, we did not gather supporting evidence to prove the thesis that there were differences in sample masses and geographical directions. We obtained similar results when analyzing regression of mass to depth (Fig. 3); the p-value reached an apparent trend of 0.27 and $R^2 = 0.19$ (Table 1), and we could conclude that the depth was not related to the mass of the samples. However, some trends were visible, and obviously our analyses were difficult due to the small number of samples. On the other hand, the results did not differ significantly, which indicated a constant mass and thickness of biofouling.

In total, 7 main groups of macrobenthic organisms were observed (Fig. 3). The number of individuals in each group tended to decrease along with increasing depth (Fig. 4). Some of them were found only at 5 m. Relationship between abundance and depth was analyzed for 4 the most numerous groups (Fig. 4), correlation was significant only for amphipods ($R^2 = 0.59$, $p = 0.021$, Table 1). Some results close to the threshold of significance were obtained for *Mytilus* sp., p-value = 0.22, however, unfortunately there was a poor correlation of R^2 = 25 (Table 1). As with barnacles, amphipods were found on the surface of the shells and their number decreased with depth. The largest number of amphipods were found at shallow stations (at 10 or 5 m, depending on the column). Larval stages of organisms residing in fouling communities were also found. Turbellaria and *Enteromorpha* occurred in minimal numbers, and research on these organisms may require a different sampling methodology.

Biofouling assemblages reached a thickness of about 50 mm of epifauna at each sampling site as a result of the stratified fouling process. Inner layer was formed by *Mytilus* sp. (100% surface coverage at each station). The largest observed shell length reached up to 40 mm. Visual inspection showed that the thickness of this inner layer could reach up to 100 mm (in the corners of structure pipes). Bay barnacle *Amphibalanus improvisus* grew on mussel shells, forming another layer called an overgrowth, thereby creating multi-layered stratum. Overgrowth layer contained different numbers of organisms at different depths (maximum at 20 m, Fig. 3).

Biofouling containing bivalves and crustaceans ended at a depth of 50 m on each leg and also at the same depth on the accompanying PG1 platform (ROV inspection). The shallowest sampling depth was 5m, shallower than that the construction was overgrown with algae. In "Baltic Beta", we observed large accumulations of these organisms from splash zone up to 1 m. However, at a depth of 5 m, they occurred only at one site.

Hierarchical clustering of the Bray-Curtis similarity index (Fig. 6) showed three main clusters of samples; then these 3 groups separated into 4. The main result is that communities can be divided into 2 main groups: shallow and deep. The samples analyzed at 5 and 10 m clearly differed from the groups at 20 and 36 m.

DISCUSSION

To our knowledge this is the first report on the occurrence of epifauna on the 'Baltic Beta' oil rig. The formation of fouling communities depends on many biotic and abiotic factors, such as predation, competition, geographic location, light, depth, temperature, salinity and local hydrodynamic regime, ice, bottom topography and substrate morphology [1,11]. From the beginning of the foundation, the epifauna has never been removed from the platform legs. Neither were any actions taken to limit it, or there was no massive contamination causing lethal actions. Det Norske Veritas [11] published data indicating that marine growth: at depth 2 m to 40 m could reach 100 mm, below 40 m - 40 mm in the central and northern North Sea. For comparison, in the Norwegian Sea fouling organisms could reach 60 mm (2 to 40 m) and 30 mm (below 40 m). Marine growth thickness reaching 200 mm is common offshore Africa and central and southern California. Fouling in the Baltic Sea (50-100 mm) seems to develop smaller sizes than in the North and Norwegian seas, mainly caused by a difference in the species composition of habitats [1,11].

Mytilus sp., the dominant member of the studied biofouling community, is a filter feeder preying mainly on phytoplankton. Mussels are strong competitors for space due to massive recruitment and rapid growth. Similarly, to our findings Mytilus sp. was one of dominants in the depth zone of up to 30 m [1,24]. On the Baltic Beta platform, it occurred down to 50 m, but they were found at depths of more than 50 m in other locations. It is likely that their range is limited by low concentration of oxygen at greater depths (Kur unpublished).

In the colonization experiment performed in Baltic Sea coastal waters biofouling, performed by two dominant competitors, i.e. Amphibalanus improvisus and Mytilus sp., reached a thickness of 2 cm in 2 months [37]. In the experimental small-scale farming mussel shell length after 3 years reached a maximum of 40 mm in the Gulf of Gdańsk [38]. Similar maximum shell sizes (40 mm) were observed in our study, where the colonization process began about 30 years ago (since the moment of platform construction). Initially, the probability of barnacle and blue mussel settling on a new construction was approximately equal, but the coverage percentage of Amphibalanus improvisus and Mytilus sp. generally decreased with depth [37]. However, this decline may be an effect of delayed settlement of organisms at greater depths or a smaller amount of available suspended particulate matter (SPM), the main food resource of suspension feeders [34,38]. It can be argued that the members of collected species are somewhat universal in these parts of the Baltic Sea.

The diagram UPGMA clustering results (Fig. 6) epifauna communities distinguish themselves into complexes associated with the occurrence at particular depths. The most visible is difference between the community up to 20 m and the community below 20 m, and these results are comparable to other authors [24,27,37]. The general conclusion is that the shallow communities consist of a greater number of species. In the report by Witalis et al. [27] authors found six epifauna species and six taxa of associated mobile fauna recruited on artificial panels located in the three ports of southern Baltic Sea. International seaports and offshore rig are habitats strongly disturbed by anthropogenic activity. In ports the species richness was higher despite that panels were exposed to recruitment only for 12 months. In this study we found a lower number of species. First the epifauna was never removed from the legs of the Baltic beta platform. This may be due to the fact that on the legs of the platform there is a lot of competition for the space of invasive species, which limits the number of other species. A greater number of species in ports may be the result of freshwater influences, which may have resulted in an increase in biodiversity.

Competition for space and food between *Amphibalanus improvisus* and *Mytilus* sp. is a common phenomenon, usually starting at the beginning of succession, when the blue mussels form a layer on top of the barnacles. In the course of succession, the inverse stratification (barnacles on blue mussels) develops, can indicate a possible commensalism relationship between the two species [37].

Mussel has a long planktonic larval phase, lasting generally 3-4 weeks, but as long as 5-6 weeks in the Baltic Sea, which gives a potential for long distance dispersal. They have a life span of around 12 years and a generation time of 1-2 years. Bay barnacle can grow very fast; in three weeks a newly metamorphosed individual may reach a diameter of 5 mm, and the species may have three generations in one summer season. When settling on *Mytilus* sp., they prefer the posterior end of the shell, near the in- and exhalent openings of the mussel, so they can benefit from the feeding current of the mussel [39].

Occurrence of a larger number of individuals in a relatively smaller mass at a shallow depth can protect them from the exposure to wave action and it is an important factor in determining the community structure of marine organisms [40,41]. In our research, we observed a large number of individuals and a small sample mass. This could be due to smaller sizes of individuals. The total number of *Mytilus edulis* individuals found on marking buoys in Brofjorden was 3792. The mean biomass of *Mytilus edulis* on the marking buoys was 11.3 ± 3.2 kg m^{-2} and was significantly higher on exposed buoys than on sheltered ones. In our case, it was hard to compare the mass of the samples, because we had a different measurement methodology, but we can compare the number of individuals. We found about 838 individuals in the area of 400 cm^{-2}, by interpolation, it gives about 2095 individuals per 1000 cm^2, but our samples were not collected at the surface. Water turbulence is higher near the surface than at 10-15 m. McLachlan et al., [41] postulated that the sheltered shore supported more macrofauna species than exposed shores and the protected shore had lower biomass than the exposed one. In addition, field studies reported positive relationships between current velocity, size and diversity of suspension feeders [16,32]. In the present study, we did not find statistically significant relationship with the current or wave directions. On the other hand, we took into account the average annual direction of wind and current at depths, which did not exclude currents and winds from other directions.

Amphibalanus improvisus may occur in densities of several thousand per m^2 ; we found a maximum of 287 individuals on 1000 cm^2. Bałazy et al. [24] found abundant (on avg. 379 ind. 144 cm^{-2}) assemblages and confirmed that differences in the assemblage structure between different objects were most likely associated with depth-related environmental variables at the shallow depths. Amphipods were not determined to the species level, however, there was a high probability that there were species considered as invasive among the relatively large group of Amphipoda. Their accumulation was relatively high compared to other studies. However, platform legs can be a resting place in the future dispersion of invasive species. Invasive species have been found on the Polish coast and the island of Bornholm, which lies within a 100 km radius of the platform [42].

Algae can be dominant near the surface on platform legs where light can penetrate, while mussels can dominate deeper in the water column [38]. Green algae are sporadically found at depths greater than 1 m on underwater objects [24].

Many studies have focused on factors controlling settlement [1,2] and antifouling agent development. We found that at depths up to 10 m, shells were attached to the substrate much stronger than at deeper levels. Our research was not able to assess the influence of epifauna on the occurrence of corrosion or possible changes in the structure of the metal. This creates an interesting topic for future research. We can also argue that removing them from underwater constructions will only result in a temporary reduction in the number of organisms. After removal of biofouling, colonization and settling of organisms on the substrate starts and restoration of the initial status occurs after several months.

CONCLUSIONS

We documented no significant differences in the biomass of biofouling macrobenthos related to depths or cardinal directions of the rig columns. Underwater vertical constructions in the Baltic Proper are fairly evenly covered by macrobenthos organisms, that make multilayered 5-10 cm thick structure. Our results could be considered universal for submerged structures built in this region and the reported characteristics of biofouling are important because of future projects and calculations of the environmental load of vertical submerged structures. In addition, we observed a low number of taxa in macrobenthic species regardless of depths. There are also two issues to note: at first structures can increase biodiversity at shallow depths. And the second, every sea structure is a transfer vector of non-native invasive species, they become "Artificial islands" or "Hitchhiker's squats" at greater depths. The lesson we can learn from our "Baltic studies" is that the level of the Baltic anaerobic zone is really a "dead zone" even for invasive ubiquitous organisms below 50 m in this region.

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Fig. 1 Petrol rig "Baltic Beta" location.

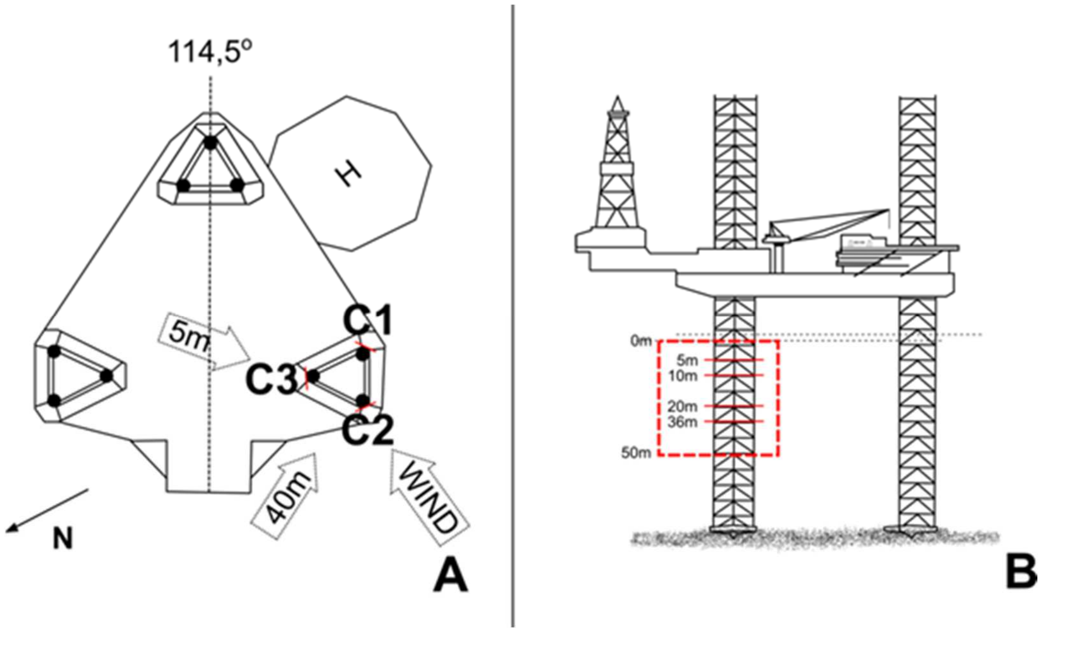

Fig. 2 The object "Baltic Beta" on the surface and underwater with marked study sites. A: plan view with geographical direction, C1-C3 – rig columns. Estimation of the average annual directions: winds and sea currents at depths 5 m and 40 m read from figures by Jędrasik and Kowalewski [43]. B: section view with marked depths of sampling stations.

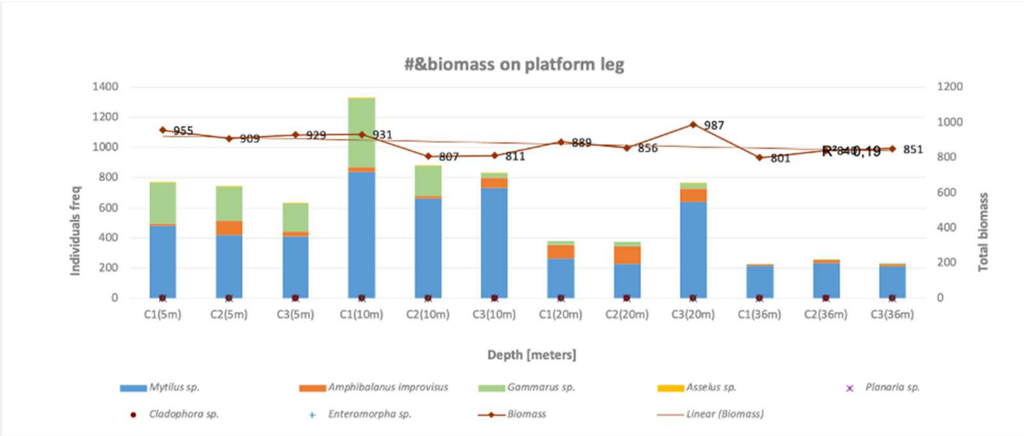

Fig. 3 Abundance (bars) and biomass (points) of biofouling community at sites: (C1, C2, C3) and depths (5,10,20, 36 m) on "Baltic Bet a' construction. In addition, the right axis contains the value of the R2 correlation coefficient.

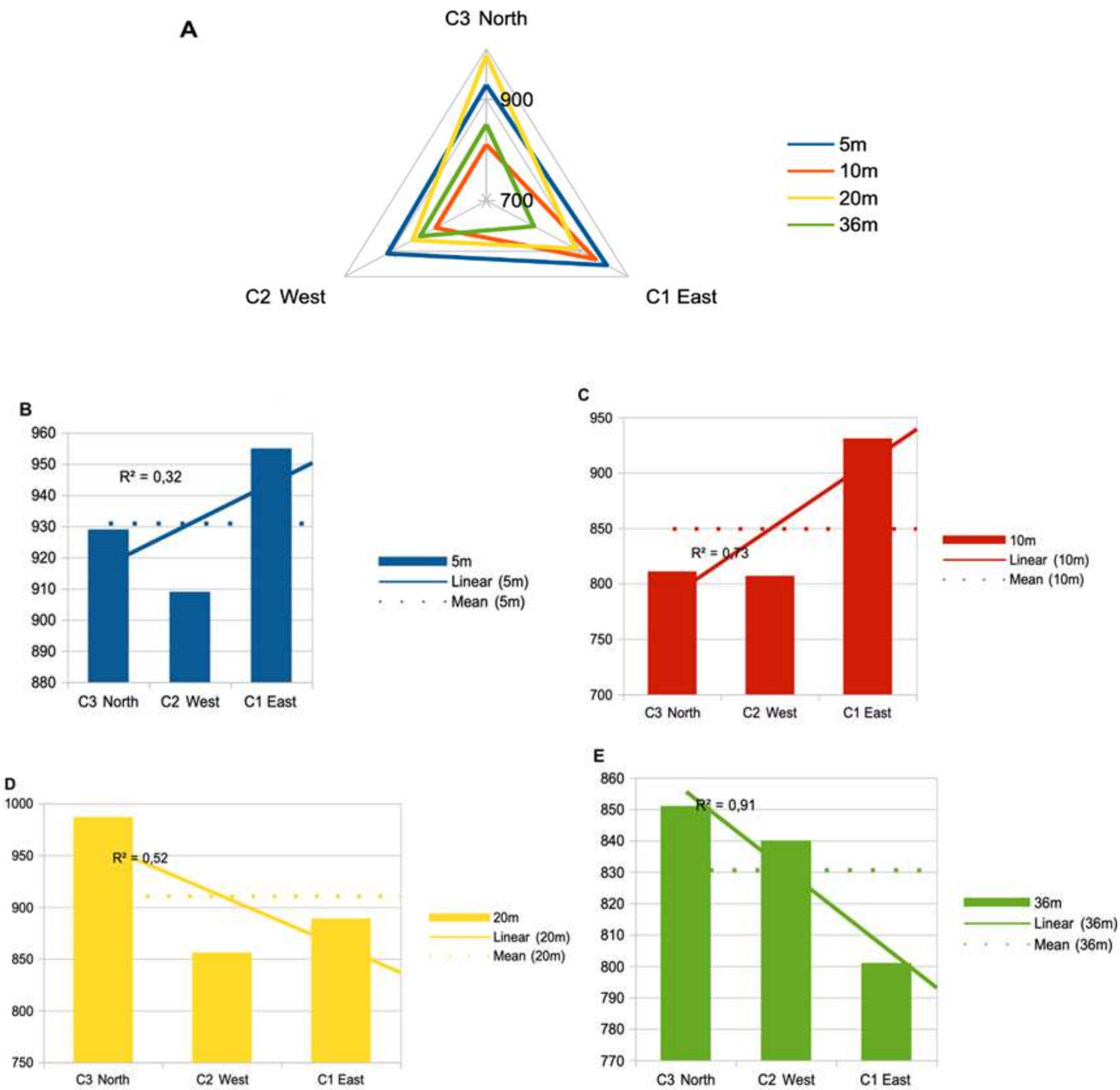

Fig. 4 A: sample biomass at geographically different sampling sites (C1, C2, C3). B: R2 for a depth of 5m. C: R2 for a depth of 10m. D: R2 for a depth of 20m. E: R2 for a depth of 36m. The depths are color coded; blue is 5m, red is 10m, 20m yellow and 36m green.

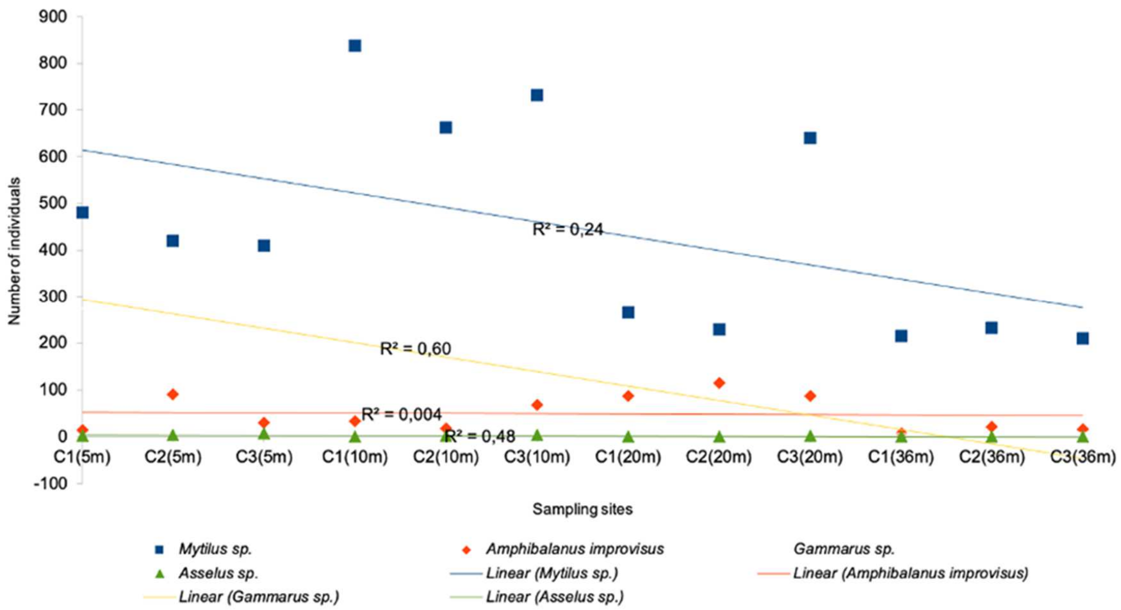

Fig. 5 The number of individuals occurring at different locations and at various depths, and the calculated correlation coefficient R2 for the number of individuals in particular groups of organisms and the depth.

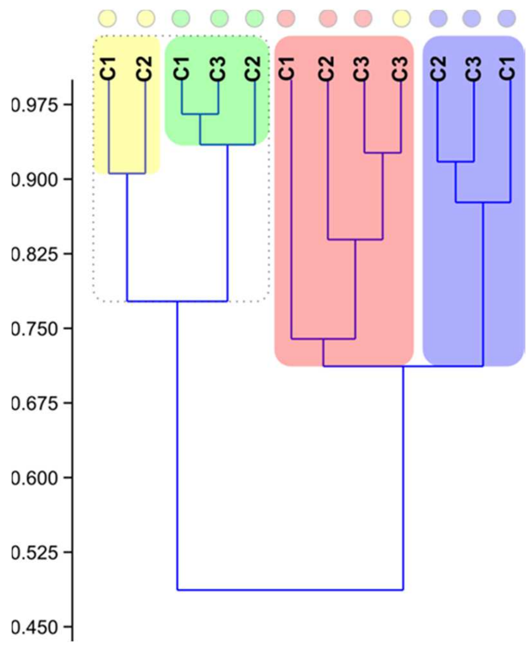

Fig. 6 Hierarchical clustering of Bray-Curtis similarity among samples. The algorithm based on paired group (UPGMA). C1, C2, C3 – names of columns, the depths are color-coded (blue is 5 m, red is 10 m, 20 m is yellow and 36 m green).

Tab. 1

The table is divided into 3 subtables (significant / close to statistical significance results in bold): A - results of R2 , N - number of samples in the test, and P-value of significance of regression in mass of samples, at a depth of 5 m, the larger mass decreases R2 = 0,32 from south to north, at 10 m it decreases south to north R2 = 0,73 , at a depth of 20 m it increases from south to north R2 = 0,52, at 36 m it increases from south to north R2 = 0,32. B – sample weight regression related to depth (column description as above). C - decrease in the number of individuals of systematic groups related to depth (column description as above).

A Test R^2	R^2	N	p-value
5m	0,32	3	0,39
10m	0,73	3	0,23
20m	0,52	3	0,32
36m	0,91	3	**0,13**
B Mass/depth	R^2	N	p-value
	0,19	12	0,27
C Individ./depth	R^2	N	p-value
M. trossulus	0,24	12	**0,22**
A. improvisus	0,004	12	0,49
Amphipods	0,59	12	**0,02**
Isopods	0,48	12	0,57
Turbellaria	n/a		
Enteromorpha	n/a		
Cladophora	n/a		

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