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Spatial variation in the abundance and growth of blue mussels along different gradients of wave exposure, depth and salinity

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Summary

Wave exposure, depth and salinity are the crucial factors in the abundance and growth of blue mussels *Mytilus edulis* in the Baltic Sea. The spatial variations in the mussel density, length and shell free biomass were studied in the West Hanko. The experiment aims to find out at which exposure and depth mussel density, length and biomass are maximized. The experiment assessed 3 levels of wave exposure and 3 depths among 9 sites. The results showed that the mussel densities and sizes were generally maximized from medium exposed to sheltered sites. At the same time, it was found that mussel density, length and biomass were maximized at 2 m and 4 m of depth. Physical stress from wave action and food concentration (microalgae) are the possible explanations for these findings. Salinity did not have any significant contribution to the variation in the mussel parameters studied, probably due to low range variation within the experimental locations of this study. It is concluded that sheltered sites at shallow depth own the most favourable condition for blue mussels. The results are useful for stakeholders interested in starting mussel farming aquaculture in the West Hanko coastal region.

Language: English Key words: wave exposure; depth; West Hanko; food concentration; favourable

1 Introduction

In the Baltic Sea proper and Gulf of Finland there are only a few marine species due to the low salinity (5-6 psu). The species *Mytilus edulis* inhabits the Baltic Sea at the edge of its range of distribution. The blue mussel *Mytilus edulis* inhabits at a depth range of 0-30 m (Westerbom & Jattu 2006). Blue mussels are globally known to function as ecosystem engineers, which are organisms able to provide physical shelter for recruitment and food for other invertebrates. It is essential to maintain biodiversity in the Baltic ecosystem. *Mytilus edulis*, as a suspension feeder, has the ability to filter water and feed on the microalgae that is its primary food resource. An increase in the availability of phytoplankton will be beneficial for blue mussels (Fréchette et al. 1989), according to Westerbom (2006). Blue mussel, in turn, is the food for seabirds, starfish, crabs and gastropod molluscs (Seed 1969).

Blue mussels live in a complex environment comprising of the interaction of several gradients, which influence their abundance and growth. For example, there are several abiotic gradients, such as salinity, wave exposure, temperature, desiccation and depth, and biotic gradients, such as competition with other species for space and food, predation and nutrient concentrations (Westerbom 2006). These gradients interact with each other, affecting the distribution and abundance of blue mussels in the Baltic Sea. However, the abundance of blue mussels in some specific sites still can not be explained by these gradients (Westerbom & Jattu 2006). In this study, the most important gradients assessed are wave exposure, depth and salinity, which have effects on the abundance and growth of blue mussels in the West Hanko region; in particular, mussel density, length and shell free biomass.

1.1 Wave exposure gradient

Wave exposure, a physical process positively related to wave energy, is dependent on prevailing wind direction, from South to East, and the distance over which the winds travel, coupled with coastline topography (Denny &Wethey 2001, Westerbom et al. 2002). Wave exposure, can be subjectively classified into several categories according to the level of wave force, such as high, medium and low (Denny 1995, Hammond & Griffiths 2004), which creates various mechanical stress for the community. The abundance of species and their interactions can be strikingly determined by wave action (McQuaid & Branch 1985), which can also indirectly determine the spatial distribution of rocky shore species. In the Gulf of Finland, wave exposure fluctuates seasonally and annually. It is not only extremely important in the abundance of blue mussels, but it also significantly affects the growth of blue mussels (Westerbom 2006). Wave exposure and its attendant effects (e.g. food availability, predation effects and sedimentation) can provide favourable conditions for blue mussels, for example, alleviating negative influence on blue mussel recruitment processes from the transport mechanisms and sedimentation effect (Kautsky 1982a), enhancing food availability and reducing the effect of predator-prey interactions and species' competition (Westerbom 2006). In synthesis, different locations with different wave exposure level might provide variability in the abundance of blue mussels in space and time. Thus, it must be essential to determine at which level of wave exposure the abundance and growth of blue mussels are maximized.

1.2 Depth gradient

In addition to the gradient of wave exposure, depth gradient also plays an important role for the abundance and growth of marine species on rocky shore. Vertically, there are a lot of variations in abiotic and biotic gradients, which can ultimately affect rocky shore organisation (Westerbom 2006). These gradients usually vary as depth becomes greater (Kautsky 1982a), for example, the spatial availability of waterborne resources (Kautsky 1982a, b). In the Gulf of Finland, variations in the distribution and abundance of blue mussels from surface to bottom are observed (Westerbom & Jattu 2006). One of the gradients can be mechanical ice abrasion, which disturbs blue mussels along depth gradient during winter time (Kiirikki & Ruuskanen 1996). Additionally, the variation along depth gradient is connected with wave exposure. Wave action decreases along depth gradient, which can lead to a change in the living conditions for blue mussels, such as predation pressure, viewed as the essential limitation on the vertical distribution of blue mussels (Westerbom 2006). Also, there is severe competition between blue mussel and algae in the shallows, whereas the severe living environment restricts invertebrates and reduces predation on blue mussels (Witman & Dayton 2001). It has been shown that the abundance of blue mussels at the depth between 5 m and 8 m is higher than at shallow depth and decreases as the depth increases until 30 m (Westerbom 2006). In brief, depth is a critical abiotic factor affecting the abundance and growth of blue mussels. Thus, there is a necessity to find out at which depth the abundance and growth of blue mussels are maximized.

1.3 Salinity gradient

In the Baltic Sea, the salinity intrusion from the Danish straits combines with a freshwater flow from northern and eastern parts of the Baltic Sea, affecting the salinity (Bergström & Carlsson 1994; Perttilä and Savchuk 1996) according to Westerbom et al. (2002). In the Gulf of Finland, freshwater run-off from eastern ground and saltwater intrusion form the Baltic Sea proper lead to western to eastern dilution of sea water. Salinity variation occurs seasonally. For instance, during the spring and early summer, large amounts of fresh water from land flows into seawater and it causes the dilution of salinity. Previous studies have showed that salinity in the Baltic Sea affects the blue mussel population, which is a key among abiotic mechanisms influencing the structure of the blue mussel population (Westerbom & Jattu 2006). In an environment with low saline (<10 psu), the blue mussel community suffers from more physiologic stress than in a high saline environment (35 psu). Living in a low saline condition, the blue mussels are suffering from continuous energy loss in order to survive. In contrast, in a high saline environment such as oceanic conditions (35psu), the blue mussels are larger and experience a high growth rate (Tedengren & Kautsky 1986). In the Gulf of Finland, the blue mussels are living at the edge of their salinity tolerance limits (<6.5psu). The occurrence of blue mussels in the central Gulf of Finland might be explained by a low salinity level that can negatively affect theirs growth, life span and reproduction (Kautsky 1982a). Nevertheless, the constant reduction in the water salinity will cause profound effects in the whole ecosystem. For deeper understanding of the growth of blue mussel, it is crucial to assess how salinity can influence the variability in the abundance of blue mussels.

Furthermore, it is hard to isolate the separate effects of wave exposure, depth and salinity since they interact with each other in a complex way, but it must be possible to find out a locality with favourable conditions for blue mussels and mussel farming.

This study is part of the main activities of the EU Interregional project Baltic EcoMussel. This project aims to achieve commercial mussel farming in an efficient and sustainable way in the Baltic Sea Region. Mussel farming is not only beneficial in a social perspective, but also in an ecological perspective. By cultivating mussels, nitrogen and phosphorus can be removed from sea water and returned to land, lessening the pressure from eutrophication in the sea.

1.4 Objectives

This study aims to assess the variability in the abundance and growth of mussels according to wave exposure, depth and salinity gradients and find out the potential location for mussel farming in the West Hanko. The objectives are listed as following: 1. to determine at which level of wave exposure the abundance and growth of blue mussels are maximized; 2. to determine at which of three depths assessed, 2 m, 4 m and 6 m, the abundance and growth of blue mussels are maximized; 3. to determine if the salinity can influence the variability in the abundance and growth of blue mussels.

2 Method

To assess the variability in the abundance of blue mussels with regard to wave exposure and depth, an experiment was set up 13th of June 2012. The experiment comprises 27 experimental units (Fig. 2) which were located on different islands (n=9) within a wave exposure gradient in the West Hanko (Fig. 1).

2.1 Assessment of wave exposure

Wave exposure is an essential factor. Different locations have their own different situations, and some of them could be completely different. In this study, the selection of locations is based on the level of wave exposure; high, medium or low exposure based on the Baardseth index (Baardseth 1970) (Fig. 1), according to Westerbom & Jattu (2006). The Baardseth index was determined by a GIS analysis. Firstly, the studied site on the sea chart with scale (1:50000) was divided into 40 parts. Secondly, the parts that did not include mainland, island, islets, skerries or rocks within a 7.5 km-long radium, so-called free parts, can be counted. Lastly, the Baardseth index was estimated by accounting the amount of free parts. Thus, a higher Baardseth index means a higher level of wave exposure.

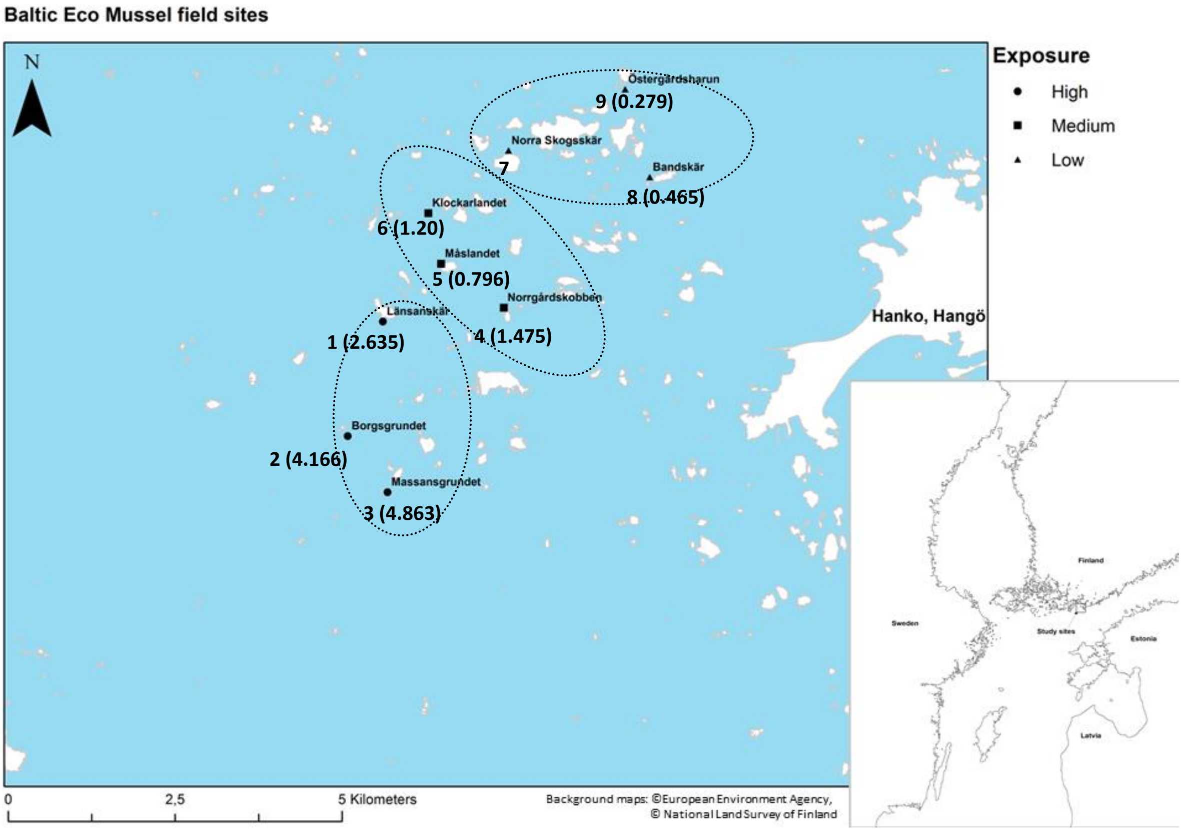

Fig. 1. *Map of the West Hanko, showing the different sites used for sampling the abundance of mussels: Länsanskär (1), Borgsgrundet (2) and Massansgrundet (3) are the sites with high wave exposure. Norrgårdskobben (4), Måslandet (5) and Klockarlandet (6) are the sites with medium wave exposure. Norra Skogsskär (7), Bandskär (8) and Östergårdsharun (9) are the sites with low wave exposure. The Baardseth indexes are given within the brackets.*

2.2 Effect of depth

The experimental units aim at assessing the effects of depth in the abundance and growth of mussels. The experimental units comprise a principal line from where 9 ropes of 15 cm hang at 2 m, 4 m and 6 m (3 ropes at each depth). The purpose of the rope is to provide independent samples in time for the abundance of *Mytilus edulis*. Samples for this study were taken on the 4th and 5th of September 2013.

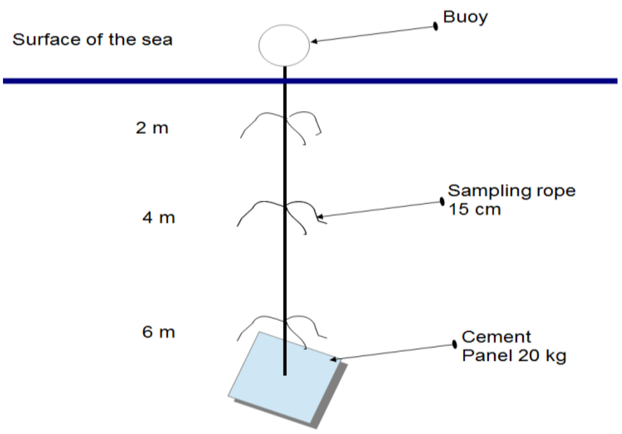

Fig. 2. *Scheme of the experimental unit used. A buoy is tied with a long principal rope. The buoy is floating above the surface of the sea, which can ensure that the long rope is straight. The buoy can also work as an outstanding sign for identification of the location. There is a 20 kg heavy cement panels, tied to the tail of the rope. Based on the background date of the Gulf of Finland, three depths are studied in this study, 2 m, 4 m and 6 m, respectively. Three 15cm long sampling ropes are tied at every depth.*

2.3 Assessment of salinity

In order to measure salinity, a digital refractometer was used. The salinity at the depth of 2 m and 6 m was estimated by collecting water samples with Limnos bottle (Kuparinen 2009). The duration of the assessment was from June 2012 to October 2013.

2.4 Sampling

The sampling method was designed and conducted by a SCUBA diver. At each site, one sampling rope at each depth was extracted from each experimental unit and put in a bag underwater. The samples were immediately frozen and analysed in the laboratory. The mussels from each rope were removed and counted, additionally the lengths of 15 random mussels were estimated with a vernier calliper (0.5 mm accuracy) and the shell free dry weights were estimated with a scale (0.0001 g accuracy). The rope length was measured to estimate the acreage of the rope surface. Although we aimed at sampling 9 sites, 2 were lost due to extremely strong wave exposure; while 2 ropes were missed by possible human intervention within each experimental unit at site 9. Thus, there were only 6 sites with available data in this study.

2.5 Analysis

2.5.1 Mussel density

To simultaneously compare the effects of wave exposure and depths on the mussel density, a two-way ANOVA test was run. We used parametric tests whenever it was possible. Homogeneity and normality were checked before the test was run. The test was carried out in the program SPSS 19.0.

2.5.2 Mussel length

To compare simultaneously the effects of wave exposure and depths on the mussel length, a two-way ANOVA test was run. We used parametric tests whenever it was possible. Homogeneity and normality were checked before the test was run. The test was carried out in the program SPSS 19.0.

2.5.3 Shell free biomass

To compare simultaneously the interaction between the effects of wave exposure and depths on the shell free biomasses of blue mussels, a two-way ANOVA test was run. We used parametric tests whenever it was possible. Homogeneity and normality were checked before the test was run. The test was carried out in the program SPSS 19.0.

2.5.4 Salinity

To estimate the possible relationship between salinity and the mussel density, length and shell free biomass, a Pearson correlation test was run. We used parametric tests whenever it was possible. Homogeneity and normality were checked before the test was run. The test was carried out in the program SPSS 19.0.

3 Results

Results showed that wave exposure, depth and salinity have effects on the abundance and growth of blue mussels in the West Hanko region, particularly, mussel density, length and shell free biomass.

3.1 Mussel density

3.1.1 Wave exposure

The factor "wave exposure" had an influence on the mussel density (Table 1, $p < 0.05$). The maximum mussel density was found at site 7 (8.48 ± 2.59 individuals per cm^{-2}), and the minimum was found at site 3 (5.06 ± 1.00 individuals per cm^{-2}) (Fig. 3 A). The sites can be divided into two groups. One was site 6 and 7, another was site 3, 4, 5 and 8. Within each group mussel densities were similar (Fig. 3 A) (Post Hoc: Tukey test, $p < 0.05$). The densities at site 6 and 7 were larger than at site 3, 4, 5 and 8. Mussel densities at site 6 and 7 were both more than 8 individuals per cm^{-2} (Fig. 3 A). Thus, a majority of blue mussels were found at sheltered sites.

3.1.2 Depth

The factor "depth" was found to largely affect the mussel density (Table I, $p < 0.05$). The maximum mussel density was found at 4 m (8.26 ± 2.50 individuals per cm^{-2}), and the minimum was found at 6 m (4.77 ± 1.67 individuals per cm^{-2}) (Fig. 3 B). The results indicated that mussel density at one depth differs from each other (Fig. 3 B) (Post Hoc: Tukey test, $p < 0.05$), mussel density at 4 m was larger than at 2 m, both of them were larger than at 6 m (Fig. 3 B).

3.1.3 Wave exposure and depth

There was a significant interaction between the effects of wave exposure and depth on variability in the mussel density (Fig. 3 C) (Table 1, $p < 0.05$). The mussel density was maximized at site 7 at 4 m (Fig. 3 C). Every site had a different pattern in the density along depth gradient. There was a similar variation pattern at site 4, 7 and 8, at which the mussel densities at different depths differed remarkably (Pairwise Comparisons, $p < 0.05$). Other sites had their own variation patterns (Fig. 3 C). At site 6, a majority of mussels could be found at 2 m and 4 m. Conversely, at site 4, 5, 7 and 8, a majority of mussels could be found at 2 m or 4 m. There was a striking variation in mussel density between 4 m and 6 m depth at these sites except site 3. At site 4, 5, 7 and 8, there was obvious variation between 2 m and 4 m depths. However, site 3, an exposed site, showed a similarity in mussel density at all depths.

Table 1. *Results showing the variability in mussel density according to factors "wave exposure" and "depth" using 2-way ANOVA*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1593.861	1	1593.861	1702.351	.000
Wave exposure	65.972	5	13.194	14.093	.000
Depth	74.651	2	37.326	39.866	.000
Wave exposure * depth	82.270	10	8.227	8.787	.000
Error	16.853	18	.936		

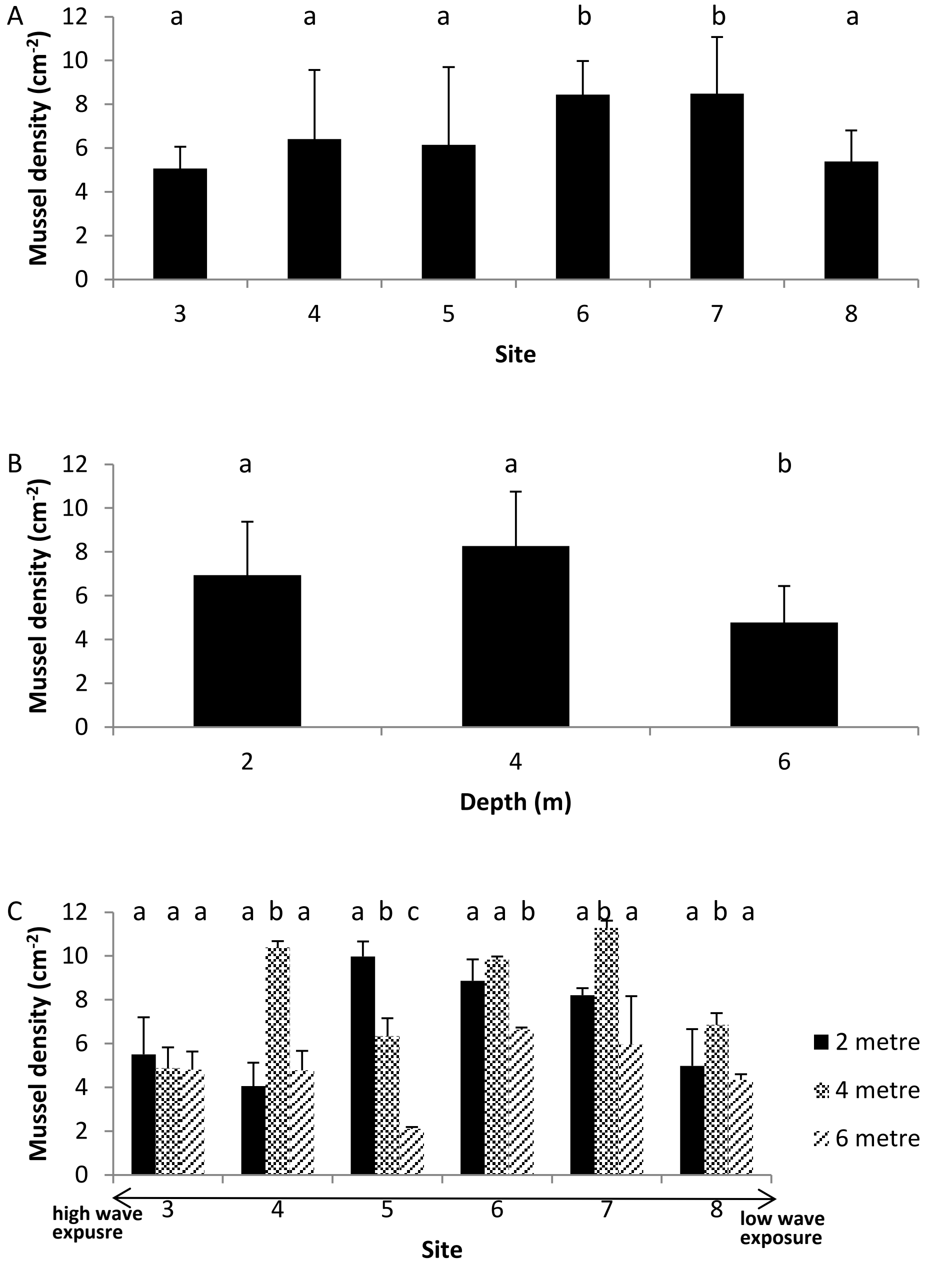

Fig. 3. *The relationship between mussel density and the factors wave exposure and depth. A: variation in mussel density at different sites; B: variation in mussel density at different depths; C: variation in mussel density with the interaction of wave exposure and depth. For clarity, only mean values and standard deviation at these sites are showed. Significant results along different depths also are given for mussel density at each site. No significant difference ($p > 0.05$) is marked with the same letter, whereas significant difference ($p < 0.05$) is marked with a different single letter. It would be marked with "ab" if data at this depth had no significant difference with the other two depths. The tests were performed with a Tukey test on untransformed data.*

3.2 Mussel length

3.2.1 Wave exposure

Factor “wave exposure” had an influence on the mussel length (Table 2, $p < 0.05$). Mussel lengths of all these sites were over 0.9 cm (Fig. 4 A). The maximum mussel length was found at site 6 (1.18 ± 0.33 cm), and the minimum mussel length was found at site 4 (0.93 ± 0.28 cm) (Fig. 4 A). The sites were divided into two groups, within which the mussel lengths were similar (Fig. 4 A) (Post Hoc: Tukey test, $p < 0.05$). Site 3, 4 and 5 belonged to the same group and site 6, 7 and 8 belonged to another group (Fig. 4 A). Mussels at site 6, 7 and 8 had over 1.1 cm lengths, which were longer than site 3, 4 and 5 (Fig. 4 A). The mussel lengths at sheltered sites were longer than at exposed sites.

3.2.2 Depth

The factor “depth” was found largely affecting the mussel length (Table 2, $p < 0.05$). The maximum mussel length was found at 4 m (1.16 ± 0.31cm), and the minimum mussel length was found at 6 m (0.94 ± 0.30 cm) (Fig. 4 B). Results indicated mussel lengths at 2 m and 4 m were similar, which was larger than at 6 m (Fig. 4 B) (Post Hoc: Tukey test, $p < 0.05$).

3.2.3 Wave exposure and depth

There was a significant interaction between the effects of wave exposure and depth on variability in the mussel length (Table 2, $p < 0.05$). The mussel length was maximized in the shallows (at both 2 m and 4 m) at site 6. Every site had a different pattern in the mussel length along depth gradient. There was a similar variation pattern at site 3, 5, 6 and 7 at which mussel lengths at 2 m and 4 m were similar and both of them were longer than at 6 m (Pairwise Comparisons, $p < 0.05$), and there is a different variation pattern at site 4 and 8 (Fig. 4 C). A striking variation in value between 4 m and 6 m depths at these sites was observed. Conversely, there was no obvious variation in mussel length between 2 m and 4 m depth, except for site 4 and 8. Besides, results showed a visible variation between 2 m and 6 m at all these sites except site 4 and 8.

Table 2. *Results showing the variability in mussel length according to factors "wave exposure" and "depth" using 2-way ANOVA*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	41.167	1	41.167	14087.053	.000
Wave exposure	.315	5	.063	21.524	.000
Depth	.320	2	.160	54.759	.000
Wave exposure * Depth	.071	10	.007	2.442	.048
Error	.053	18	.003		

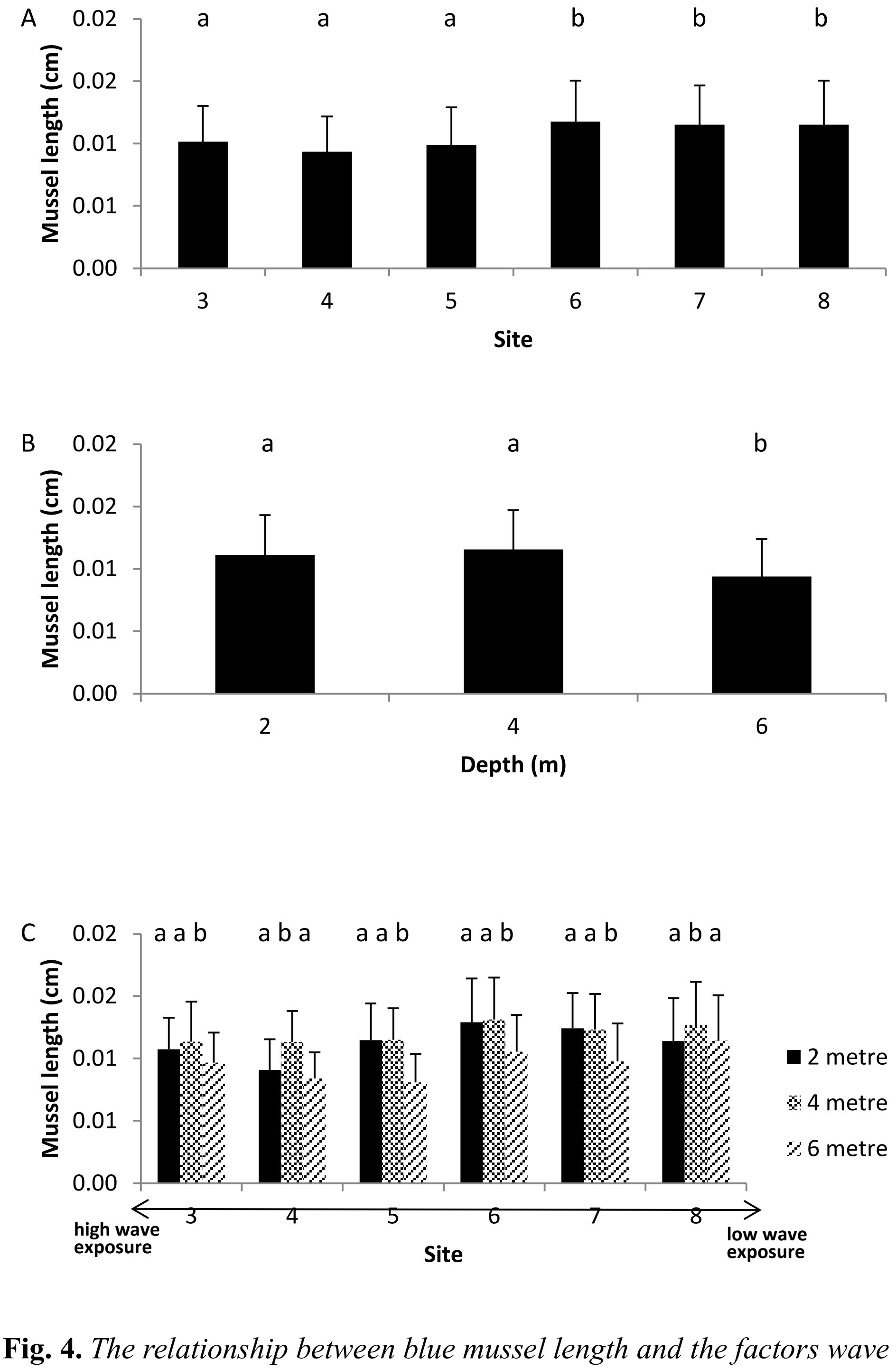

Fig. 4. *The relationship between blue mussel length and the factors wave exposure and depth. A: variation in mussel length at different sites; B: variation in mussel length at different depths; C: variation in mussel length with the interaction of wave exposure and depth. For clarity, only mean values and standard deviation at these sites are showed. Significant results along different depths are also given for mussel length at each site. No significant difference ($p > 0.05$) is marked with the same letter, whereas significant difference ($p < 0.05$) is marked with a different single letter. It would be marked with "ab" if data at this depth had no significant difference with the other two depths. The tests were performed with a Tukey test on untransformed data.*

3.3 Shell free biomass

3.3.1 Wave exposure

The factor “wave exposure” had an influence on shell free biomass of mussels (Table 3, $p < 0.05$). The maximum shell free biomass of mussels was found at site 6 (0.0735 ± 0.0545 g), and the minimum shell free biomass of mussels was found at site 4 (0.0353 ± 0.0290 g) (Fig. 5 A). The sites can be divided to two groups, within which values of the shell free biomass were similar (Fig. 5 A) (Post Hoc: Tukey test, $p < 0.05$). Site 3, 4 and 5 belonged to the same group and sites 6, 7 and 8 belonged to another group (Fig. 5 A). Shell free biomasses of mussels at site 6, 7 and 8 were apparently heavier than site 3, 4 and 5 (Fig. 5 A).

3.3.2 Depth

The factor “depth” was found largely affecting the shell free biomass of mussels (Table 3, $p < 0.05$). The maximum shell free biomass of mussels was found at 4 m (0.0638 ± 0.0450 g), and the minimum was found at 6 m (0.0387 ± 0.0386 g) (Fig. 5 B). The results indicated that shell free biomass of mussels at 2 m was similar with 4 m, which was heavier than at 6 m (Post Hoc: Tukey test, $p < 0.05$) (Fig. 5 B).

3.3.3 Wave exposure and depth

There was no significant interaction between the effects of wave exposure and depth on the variability in the shell free biomass of mussel (Table 3, $p > 0.05$). It is apparent that the shell free biomass of mussels was maximized in the shallows (at both 2 m and 4 m) at site 6, 7 and 8 (Fig.5 C).

Table 3. *Results showing the variability in shell free biomass of mussels according to factors "wave exposure" and "depth" using 2-way ANOVA*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	.101	1	.101	1372.132	.000
Wave exposure	.007	5	.001	18.665	.000
Depth	.004	2	.002	27.061	.000
Wave exposure * Depth	.002	10	.000	2.193	.071
Error	.001	18	7.350E-005		

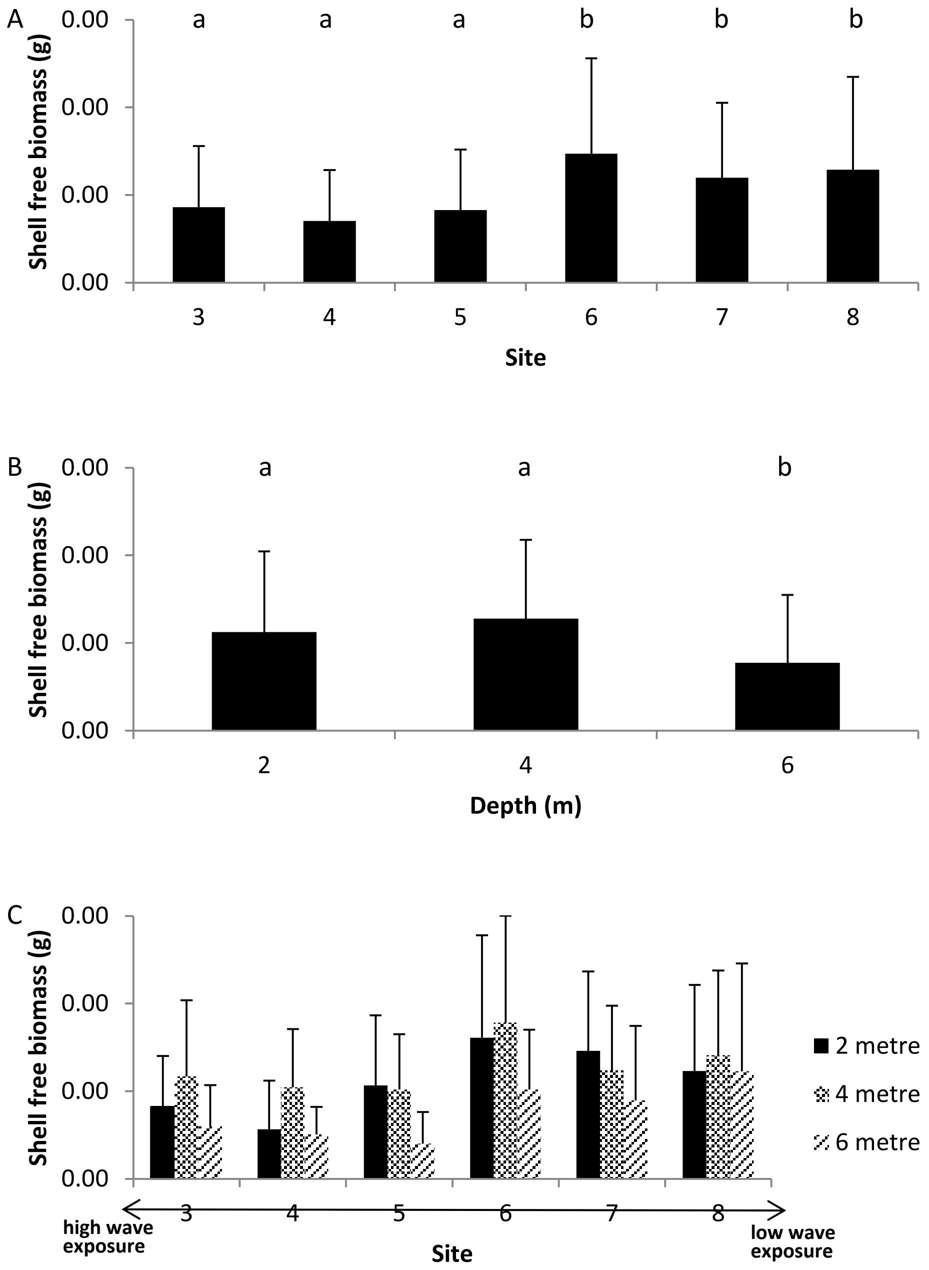

Fig. 5. *The relationship between shell free biomass of mussels and the factors wave exposure and depth. A: variation in shell free biomass at different sites; B: variation in shell free biomass at different depths; C: variation in shell free biomass with the interaction of wave exposure and depth. For clarity, only mean values and standard deviation at these sites are showed. Significant results along different depths are also given for shell free biomass of blue mussels at each site. No significant difference (p > 0.05) is marked with the same letter, whereas significant difference (p < 0.05) is marked with a different single letter. It would be marked with "ab" if data at this depth had no significant difference with the other two depths. The tests were performed with a Tukey test on untransformed data.*

3.4 Salinity effects

Corresponding data had normality as assessed by Shapiro-wilk test. The result indicated a weak predictability between salinity and the mussel density, length and shell free biomass according to the results of the Pearson correlation tests between salinity and mussel density, mussel length and shell free biomass, respectively (Fig. 7) ($p > 0.05$).

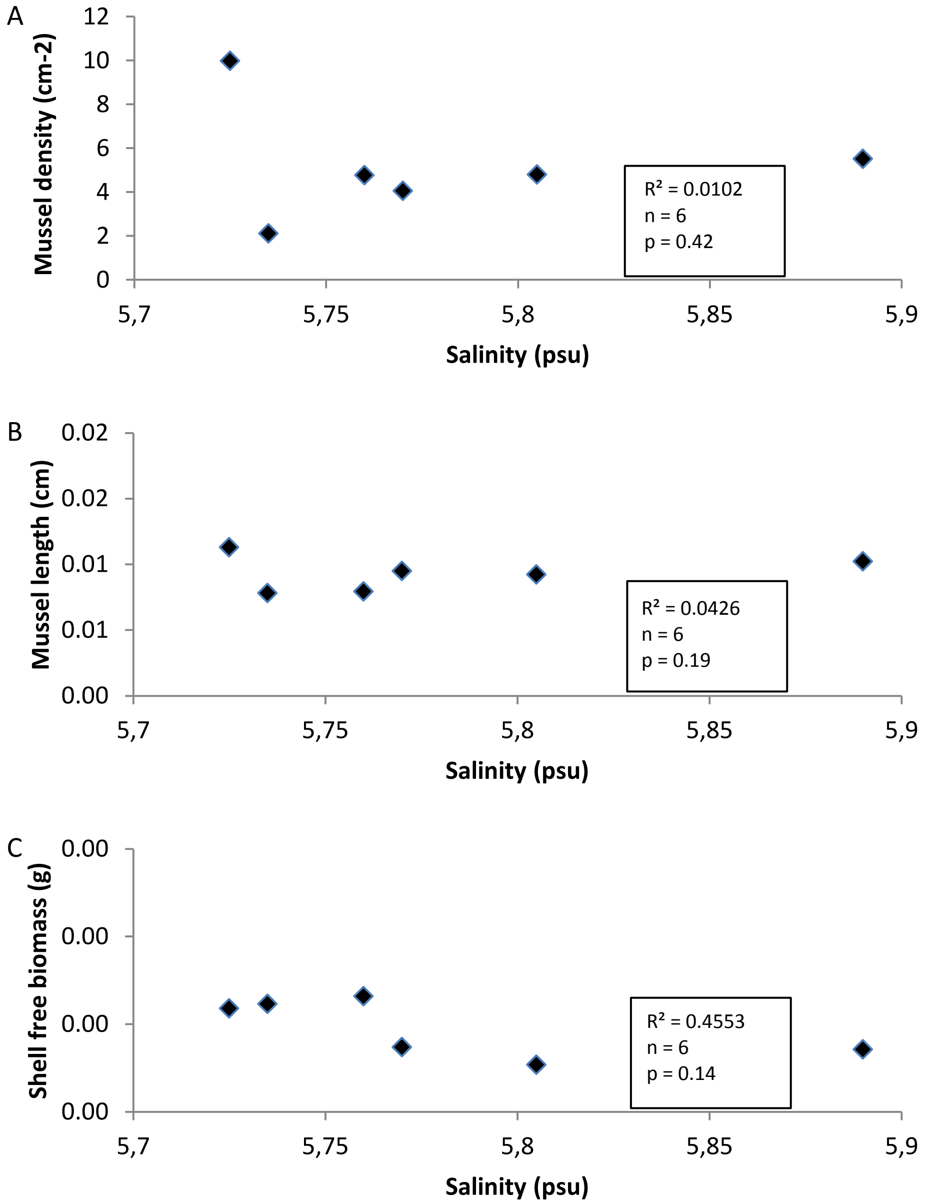

Fig. 7. *Mytilus edulis. Relationship between salinity and mussel density (A), length (B) and shell free biomass (C). For clarity, only mean values at these sites are showed.*

4. Discussion

The relationships between wave exposure and mussel density, length and shell free biomass were variable at these sites studied. The peak values were generally found at sheltered sites whereas the minimum values were found at high or medium exposed sites.

An early finding made by Westerbom & Jattu (2006) predicted that mussel density increases with increasing wave exposure, which was not supported by our results. In this study, the mussel densities were generally maximized at more sheltered sites except site 8. Our study demonstrates that larger mussels were generally found at sheltered sites at shallow depths while the opposite finding was made by Westerbom & Jattu (2006). The differences between the studies can be related to different factors, but are mainly due to differences in experimental designs. Westerbom & Jattu (2006) studied the population of mussel attached to rock substratum at a depth below 6 meters where the effect of wave exposure is minimized. On an exposed rock island, the oxygenation rate and delivery of phytoplankton are generally higher than at sheltered sites, additionally mussels below 6 m are found in dense patches which provide extra mechanical support and attachment to the substratum. High wave exposure induces lower predation pressure (Menge & Branch 2001), lower sedimentation (Westerbom & Jattu 2006) and extra food delivery for mussels (McQuaid & Lindsay 2000), affecting their density. In the present study based on the use of ropes as artificial substratum, a low mussel density was found at higher wave exposure, since the lack of extra mechanical support from natural populations, when suffering from strong wave action (Menge 1978, Alvarado & Castilla 1996, McQuaid & Lindsay 2000).

The lack of mussels at shelter substratum found by Westerbom & Jattu (2006) can be explained by accumulation of sediments. Sedimentation is an important factor explaining the variation in mussel density and size from sheltered to exposed sites (Westerbom & Jattu 2006). Low wave flow leads to accumulation of sediments on the rocky bottoms (Kiirikki 1996, Westerbom 2006), which can disturb the normal filtration behavior of blue mussel and restrict its abundance and growth. In contrast to Westerbom & Jattu (2006), the samples in this study were taken from artificial experimental units (ropes) instead of rocky natural substratum. Therefore sedimentation was minimized since ropes do not accumulate sediment and make predation more difficult.

The main advantage of using ropes as artificial substratum in sheltered areas is that the mussels are able to absorb more microalgae in their diets, which is accumulated in sheltered sites in the Gulf of Finland (Kiirikki 1996). This could be beneficial for the abundance and growth of blue mussels (Kautsky 1982a). Therefore, the high concentration of phytoplankton can explain that the larger densities and larger mussels were found in this study.

Variations in the mussel density, length and shell free biomass were modulated by differences in depth. The mussel density, length and shell free biomass were maximized at 2 m and 4 m. It is possible that mechanical stress from the wave action influence the mussel density at shallow depths by reducing them. Dislodgement by wave action results in fewer mussels at shallow depths on natural rock substratum (Westerbom & Jattu 2006). Physical stress from wave action in the shallows was also observed in this study, e.g. at site 3, the most exposed site, there was no variation in the mussel density within three depths. Nevertheless, this effect can be less significant in the sheltered sites where mussels suffered less wave force, increasing the density towards the more shallow samples, which can also take advantage of the extra phytoplankton supply. Another physical stress related to the depth is the ice formation, which could also contribute to reducing the abundance of blue mussels in the shallow in natural populations. Nevertheless, in this study, the experimental units were submerged below 2 m, which can keep them away from freezing mussels.

Other biotic factors related to wave exposure and depth may play a role in the abundance and growth of blue mussels. As the stress from wave action decreases deeper down, competition increases (Menge & Olson 1990, Bertness 2002, Westerbom et al. 2006). Blue mussels compete with filamentous algae, Fucus and barnacle for space in the shallow, but not below 6 m, where they start to compete with other mussels for food and space (Westerbom et al. 2008). The effects of intraspecific competition among mussels may induce low growth rates due to food competition (Kautsky 1982a). In this study, mussels on ropes at 6 m might compete with mussels from natural substratum for space, explaining partly the low abundance, smaller size and low shell free biomass of blue mussels, but also taking into consideration that at 6 m the supply of phytoplankton was lower than at 2 m and 4 m. The results of this study were supported by a previous study conducted by

Kautsky (1982a), where it was proven that the growth of juvenile mussels after settlement showed a high growth rate in the shallows and this decreases deeper down.

There was no apparent correlation between salinity and the mussel density; length and shell free biomass, although previous studies showed a strong positive relationship between the abundance and growth of blue mussels and salinity (Tedengren & Kautsky 1986, Westerbom et al. 2002). The contrasting results can be associated to the range of salinity used in different studies. In this study, salinity was at the range from 5.7 psu to 5.9 psu, the variation among sites was not larger than 0.2 psu. This slight value could be considered a non-significant difference and not relevant at a larger scale. Thus, the results in this study did not contradict earlier studies. Salinity is an extremely important factor for the abundance and growth of blue mussels at larger scales (100 km) in the Baltic Sea, but it did not play a significant role on the scale studied in this study (5 km).

From spatial and temporal perspectives, patterns that are distinct to any range of scales have their own distinct causes and biological influences (Levin 1992). Therefore, how pattern and variability interact with the scale is required when analysing the results of a study. From what it is discussed above, some variations between the early study conducted by Westerbom & Jattu (2006) and this study are clearly acknowledged and mainly related to natural substratum and experimental units, but there is also a difference in the spatial scale studied. Compared to the study conducted by Westerbom & Jattu (2006), the present study appears to be done at a finer-scale. The study area comprised only the West Hanko instead of the Gulf of Finland. In this study, three levels of wave exposure were defined at 9 sites where the samples were collected. Site 1, 2 and 3 (Baardseth index between 2.5 and 5) belong to a high exposed category, site 4, 5 and 6 (Baardseth index between 0.7 and 1.4) belong to a medium exposed category, and site 7, 8 and 9 (Baardseth index between 0.2 and 0.5) belong to a sheltered category. Westerbom & Jattu (2006) worked within a larger span of Baardseth indexes as they were studying more islands. Interestingly, Westerbom & Jattu (2006) worked only at the protected side of each island, while in this study the experimental units were always facing the predominant winds. This could generate certain differences in the variability of abundances of blue mussels and I suggest this should be further examined as a next step from this study. Finally, due to the fact of working in extreme wave exposures, 2 experimental units were missed. This was probably caused by strong storms in the most exposed sites, therefore the data from high exposed site is less representative, but this phenomenon still suggests high stress from wave action on blue mussels at the exposed site and shallow depths, as it was suggested by Westerbom & Jattu (2006).

Furthermore, the analysis in this study only focuses on the spatial perspective, making it difficult to fully understand the whole natural variability. One of the prior purposes in this study as part of EU project Baltic EcoMussel is to determine the favourable condition for cultivation of blue mussels in the West Hanko. This study suggests that sheltered sites at shallow depths are the most favourable locations for mussel farming in the West Hanko. These results can be utilized by stakeholders interested in finding optimal places for mussel farming in the Gulf of Finland. It is worth noticing that these findings would not be possible to be extrapolated from studies of mussels inhabiting natural substratum, instead, it is necessary to work with similar substratum to those facilities used in the mussel farms.

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