Algal toxins in the Baltic blue mussel (Baltic *Mytilus trossulus edulis*)

– spatiotemporal variations in the Baltic Sea

Algtoxiner i Östersjöblåmussla (Baltic Mytilus trossulus edulis) – spatiotemporala variationer i Östersjön

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Swedish University of Agricultural Sciences, SLU
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Abstract

Algal toxins have been found to bioaccumulate and have a seasonal variation over the summer months in marine biota. This can impact the food web through trophic transfer and the potential of using blue mussels for aquaculture. In this study, Baltic blue mussels from the Hanö Bight and Nämdö Island were collected during consecutive weeks in July 2020 and analyzed for algal toxins, more specifically, brominated compounds. The results showed 20-40 times higher concentrations of 6-OH-BDE47 and ∑OH-PBDEs at Nämdö Island compared to the Hanö Bight. The 2,4,6-TBP results showed similar concentrations at both locations, between 160-270 pg g^{-1} wet weight. The highest concentration of 6-OH-BDE47 measured approximately 6 000 pg g^{-1} wet weight and above 41 000 pg g^{-1} wet weight of ∑OH-PBDEs during the 3rd week at Nämdö Island. These concentrations are in line with previous studies of algal toxins in blue mussels within the Baltic Sea, while the concentrations at the Hanö Bight were surprisingly low. The difference between the locations, as well as between the measured weeks, supports a spatiotemporal variation on a weekly basis within the Baltic Sea.

Keywords: algal toxins*,* Baltic blue mussel (Baltic *Mytilus trossulus edulis*), brominated compounds, 6-OH-BDE47, ∑OH-PBDEs, 2,4,6-TBP, Nämdö Island, Hanö Bight (Hanöbukten)

Table of contents

List of tables

List of figures

1. Introduction

The Baltic Sea is a brackish inland sea surrounded by nine countries in the Northern Hemisphere. Increased human activities have influenced the sea. Its maximum depth is 459 meters, and it has a relatively limited water exchange with the more saline North Sea by Kattegat and Skagerrak (Harvey *et al.* 2019). Due to the shallowness of the basins (mean depth 52 meter) (Wasmund 2002) and the slow water turnover, the nutrients and contaminants take a long time to degrade. The high levels of nutrients and contaminants cause changes in the ecosystem, creating favorable conditions for opportunistic species such as fast-growing cyanobacteria and filamentous algae (Wasmund 2002; Malmvärn *et al.* 2008). The increased concentrations of nutrients in an ecosystem is referred to as eutrophication (Nixon 1995). Depending on the concentrations of nutrients in the water, the algal blooms can have a more or less prominent peak.

Filamentous algae and cyanobacteria are known to produce substances with harmful consequences on their surroundings. Some of these substances can be very toxic and affect species in distinct ways (Wasmund 2002). Examples of toxins produced by primary producers and macro-algae are ichthyotoxin, hepatotoxin, diarrhetic shellfish poisoning, and paralytic shellfish poisoning (Wasmund 2002), as well as halogenated organic compounds (Dahlgren & Ek 2020). In this study, the focus has been on halogenated organic compounds, specifically on 2,4,6-tribromophenol (2,4,6-TBP) and hydroxylated polybrominated diphenyl ethers (OH-PBDEs). The 2,4,6-TBP has been found naturally in marine organisms such as algae, fish, and marine worms (Norman Haldén *et al.* 2010). Naturally produced OH-PBDEs have been identified in several marine species such as cyanobacteria (Malmvärn *et al.* 2008), algae (Malmvärn *et al.* 2005), mussels (Malmvärn *et al.* 2005), fish, marine sponges, and seals (Löfstrand 2011). According to Löfstrand *et al.* (2011), filamentous macro-algae and (possibly) cyanobacteria are important sources of OH-PDBEs for blue mussels in the Baltic Sea.

High concentrations of OH-PBDEs have been shown to have acute toxic effects; however, even exposure to low concentrations over a long time period has been shown to cause less efficient energy metabolism and severe body weight loss (Legradi *et al.* 2014; Dahlgren & Ek 2020). The compounds could also have hormonal disturbances and cytotoxic and neurotoxic effects (Lindqvist 2016; Dahlgren & Ek 2020). The 6-OH-BDE47 congener has also shown delayed development, induced mortality, and fin malformations in zebrafish embryos (Usenko *et al.* 2012). The 2,4,6-TBP has also been shown to cause interference with reproduction in zebrafish (Norman Haldén *et al.* 2010).

In a study by Malmvärn *et al.* (2008), it was suggested that cyanobacteria and filamentous algae are responsible for the considerable amounts of brominated compounds in the Baltic Sea due to the large production by these species. Previous research has shown variations of brominated phenolic substances with seasonal changes between May and August in the filamentous red macroalgae (e.g., *Ceramium tenuicorne)* (Dahlgren *et al.* 2015) and between May and October in blue mussel (Löfstrand *et al.* 2011). According to Löfstrand *et al.* (2011), a probable cause for the observed seasonal variations found in the blue mussels could be accumulation via the filamentous red macroalgae.

Increased nutrients and algal blooms are preferred conditions for filter-feeding species, such as the blue mussel (Tedengren 2008), while nutrients can cause primary producers to be stressed, leading to induced production of toxic compounds (Dahlgren *et al.* 2015). Changes in environmental variables known to induce the production of algal toxins, or act as proxies, are changes in temperature, salinity, visibility (in essence water clarity), or, as previously mentioned, increased concentrations of nutrients (Abrahamsson *et al.* 2003).

Although algal toxins have been studied in many species within the Baltic Sea, the geographical differences are rather unknown. This project was performed as a pilot study investigating the variation in algal toxins found in consecutive weeks in blue mussels at two locations. One of these locations with troubling changes within the aquatic ecosystem is the Hanö Bight, in the southern part of Sweden (Svedäng *et al.* 2018). The bight has experienced changes over the last decades, with foul-smelling water, injured fish, reproductive changes in birds, changes in the algal compositions, and declined water quality (Havs- och vattenmyndigheten 2018; Ljunghager 2018; Svedäng *et al.* 2018). Due to this, the bight is an interesting location to evaluate, and therefore it was chosen for this pilot study. The other location chosen was Nämdö Island, located within the Stockholm archipelago, where previous research has been carried out with a focus on brominated compounds. The species observed and investigated in this study were Baltic blue mussels (Baltic *Mytilus trossulus edulis)* (Väinölä & Strelkov 2011). The blue mussels are filter feeders and hence suitable to use as indicators of environmental toxins in the water phase (Tedengren 2008). Studies have demonstrated filamentous macroalgae (*Ceramium tenuicorne)* as a source for OH-PBDEs accumulated by blue mussels living close to the algae (Malmvärn *et al.* 2005). The mussels have been shown to bioaccumulate these brominated algal toxins, impacting the food web (Dahlgren *et al.* 2016). However, knowledge regarding the peak concentration to be expected in blue mussels (or other Baltic biota) in different locations within the Baltic Sea is unknown.

This thesis investigates the presence of algal toxins in Baltic blue mussel (Baltic *Mytilus trossulus edulis)* in the Hanö Bight and the Nämdö Island within the Baltic Sea during four consecutive weeks to explore the spatiotemporal variation of algal toxins in blue mussels. The research question is whether there was a concentration difference of algal toxins in blue mussels between the two locations. In addition to study investigates algal toxin concentrations, size variation of the blue mussels and environmental data with potential to impact the concentrations of algal toxins were also investigated.

2. Materials and methods

2.1. Study sites and species

2.1.1. Study sites

Hanö Bight

The Hanö Bight is a large bight located in the southern part of Sweden. The Bight stretches from the west-east, from the province of Scania to Blekinge, and thus has a relatively large catchment area (Svedäng *et al.* 2018). During the early years of the 2010s, the public noticed differences in the ecosystem functions, with injured fish, foul-smelling water, deteriorated water quality, and more floating algae (Havs- och vattenmyndigheten 2018; Svedäng *et al.* 2018). The changes in the bight caused the County Administrative Board in Scania (Länsstyrelsen Skåne) to perform studies in the area. Further on, the government commissioned the Swedish Agency of Marine and Water Management (Havs-och vattenmyndigheten) to investigate the status of the Bight through an environmental control plan (Havs- och vattenmyndigheten 2018).

Nämdö Island

Nämdö Island is one of the largest islands within the Stockholm archipelago. It is located far out in the archipelago and hence considered to be part of the Baltic Proper. The island is approximately 7 km long and 2 km wide (Isaksson-Lutteman 2020). In 2002 the island's northern part became a nature reserve to preserve biodiversity and outdoor life (Länsstyrelsen Stockholms Län, 8513-2000-48319 0120-02-048)(2002). The Svealand coastal water management association has been collecting environmental data annually since 2002 in the archipelago to evaluate the status of the aquatic ecosystem, and studies have been conducted on the island to investigate brominated compounds in algae and fish (Dahlgren *et al.* 2015; Dahlgren *et al.* 2016).

2.1.2. Baltic blue mussel

Blue mussels (Baltic *Mytilus trossulus edulis*) (Väinölä & Strelkov 2011) are among the most common species within the Baltic Sea and make up 80% of the invertebrates' biomass (Kautsky 1982; Tedengren 2008). The blue mussels are suspension-feeding bivalve mollusks that live in marine environments but have adapted to the lower salinity in the Baltic Sea (Löfstrand 2011). The species is robust and can tolerate variations in salinity and temperature (Löfstrand 2011). The adaptation to the brackish water causes the mussels to grow slower, and they become smaller compared to their equivalents in marine waters (Tedengren 2008; Lindqvist 2016). A full-grown blue mussel in the Baltic Sea measures three cm compared to 10-15 cm in marine water (Tedengren 2008).

Blue mussels reach reproductive age after one year, and reproduction occurs during the summer months (Löfstrand 2011). The larvae are pelagic before attaching themselves to a hard substrate, such as rocks, cliffs, and piers, from the surface down to 30 meters in depth (Tedengren 2008; Löfstrand 2011).

Although the seabird species, eider, is the blue mussels primary threat, they have few other predators in the Baltic Sea controlling the populations (Kautsky 1982; Tedengren 2008). Mussels are effective filter feeders, and one mussel can filter several liters per hour, which estimates that all blue mussels combined can filter the corresponding volume of the Baltic Sea at least once a year (Tedengren 2008). Smaller mussels have a higher size-specific filtration rate than larger mussels (Kautsky 1982; Riisgård 1998). In addition, the mussels can tolerate weight loss and poor food conditions, making them insensitive to seasonal variation in food abundance (Kautsky 1982).

In this study, the blue mussels were collected at two different locations within the Baltic Proper. The location in the Hanö Bight is referred to as "*Äspet*" (SWEREF 99 13 30, N: 6199470 E: 201254) (Figure 1), and the location in the archipelago of Stockholm, Nämdö Island, is referred to as "*Västanvik*" (SWEREF 99 18 00, N: 6563803 E: 190446) (Figure 2).

The mussels were collected from the exact location (same large cliff/rock) within the two sites during the four (and on Nämdö Island in five) consecutive weeks. The depth of the rock was estimated to 1-1.2 meters. The specific locations were chosen since the mussels were relatively protected and at no risk of drying out. The dates and number of mussels collected per date are shown below (Table 1). An important note is that the blue mussels were collected a fifth week at the Nämdö Island, resulting in more mussels at that site.

Table 1. Number of blue mussels collected per location and date in Äspet, Hanö Bight, and in Västanvik, Nämdö Island, in July of 2020.

Äspet, Hanö Bight		*Västanvik*, Nämdö Island	
Date	**Number of blue mussels collected**	**Date**	**Number of blue mussels collected**
2020-07-05	50	2020-07-04	50
2020-07-12	37	2020-07-12	50
2020-07-19	45	2020-07-18	40
2020-07-26	40	2020-07-25	30
		2020-08-01	50
Total number	172		220

2.1.3. Laboratory analysis

The blue mussels were collected by hand and kept in a freezer at -20˚C prior to the chemical analysis. During transport from the Hanö Bight to Stockholm, the samples were kept cool.

Before the chemical analysis was executed, the mussel shells were measured to the closest mm, and the soft tissue was weighed to the closest gram. Then, the mussels were pooled together, depending on the week and the location, for the chemical analysis. The chemical analysis was performed according to Lindqvist (2016) by Dennis Lindqvist at the Department of Environmental Science, Stockholm University.

2.2. Environmental data

The environmental components were collected from separate sources to gather such an accurate view of the locations as possible. In the following chapters, a detailed description of the data is provided.

Environmental variables were chosen to investigate the two locations' characteristics. These variables were chosen because they can cause environmental stress for primary producers, induce the production of algal toxins and hence affect hazardous algal blooming (Dahlgren & Ek 2020). The variables that were selected were: visibility, temperature, salinity, and concentrations of chlorophyll-a (Chl-a), oxygen (O_2), total nitrogen (Tot-N), total phosphorus (Tot-P), phosphate phosphorus (PO_4-P), and silicate (SiO_4). Only using environmental data from 2020 would not give an overall view of the conditions within each location, and therefore, data from a longer time period was considered. Due to this, the time period used for the environmental variables was July between 2006 and 2020. All measurements used for the analysis were taken at the surface (0-0.5 m).

2.2.1. Hanö Bight

The environmental data for Hanö Bight was derived from the Society for water conservation for the Western Hanö Bight (Vattenvårdsförbundet för Västra Hanöbukten 2020). The Society for water conservation performs yearly environmental controls to monitor the Bight's biological and chemical status. The control involves 15 stations measured monthly. The station of VH1 (SWEREF 99 13 30, N: 6207140 E: 213268) was chosen since it is located closest to Äspet, where the blue mussels were collected (Figure 1).

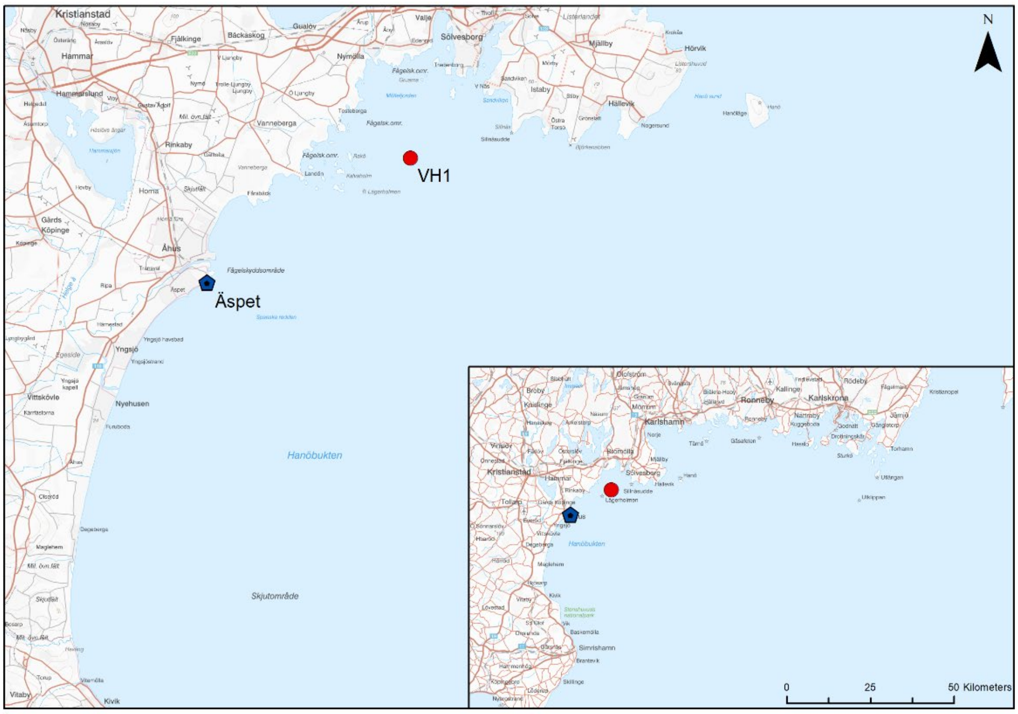

Figure 1. Location of the station, VH1, and the location where the blue mussels were collected, "Äspet" in the Hanö Bight.

The data from the Hanö Bight was positioned with a global positioning system (GPS) and a sonar (Tobiasson *et al.* 2020). The water samples were collected with a 3-liter Ruttner water sampler at each depth and further collected in rinsed polyethylene bottles and calibrated Winkler bottles. The salinity and temperature were measured at each depth using a CTD (Conductivity, Temperature & Density) (SAIV SD 204). The visibility was measured with a Secchi disc, and the oxygen was measured according to the Winkler method. Chlorophyll-a was analyzed according to the HELCOM Combine Manual (Annex C-4 2014) (Tobiasson *et al.*

2020). The samples were extracted for 20 hours, centrifuged, and then analyzed at a wavelength (monochromatic) in a spectrophotometer (Tobiasson *et al.* 2020). The water samples that were analyzed chemically were stored in cold and dark before delivered to the laboratory within 24 hours after sampling. The chemical analysis was performed by the "Vattenlaboratoriet, VaSyd" in Malmö (Tobiasson *et al.* 2020).

2.2.2. Nämdö Island

The environmental data from Nämdö Island was received upon request from Svealand's coastal water management association (Svealandskustvattenvårdsförbund 2020). The association collects annual data during July and August along the coast of Svealand.

For this thesis, there were three stations close to *Västanvik,* and hence these three stations were chosen. The stations were: S90 (*Norrfjärden*), S97 (*Södra Nämdöfjärden*), and S114 (*Jungfrufjärden)* (Figure 2). The data for the three stations at the Nämdö Island were combined in the statistical evaluation.

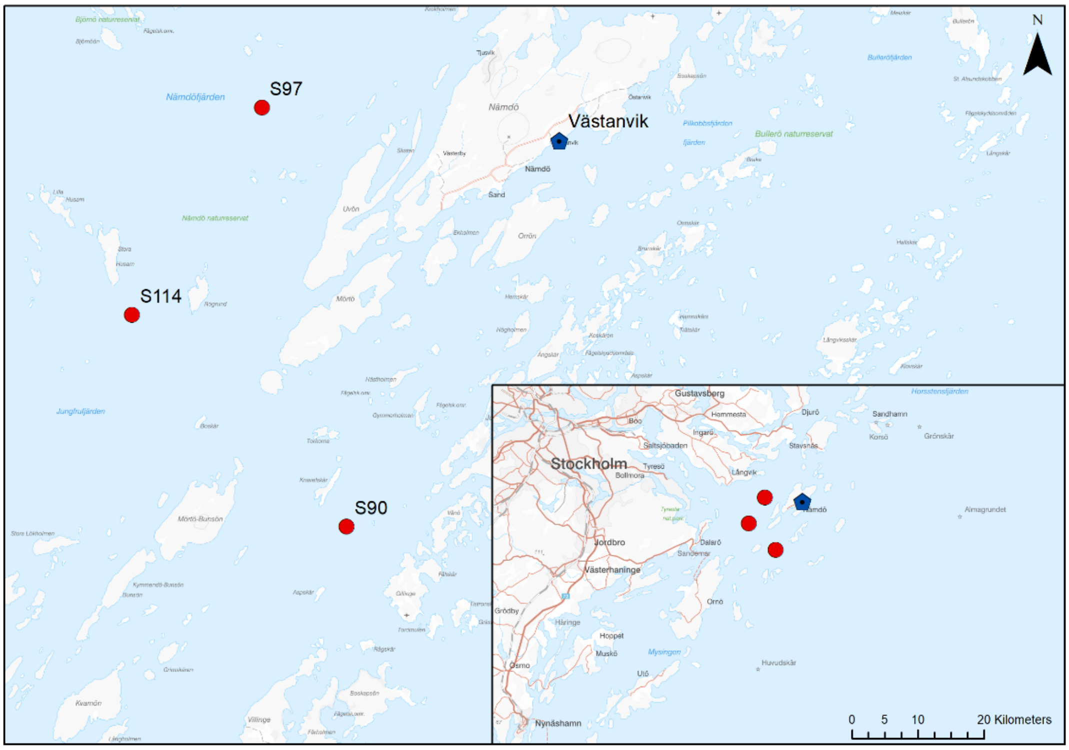

Figure 2. Stations at the Nämdö Island; S90 "Norrfjärden", S97 "Södra Nämdöfjärden", and "114 "Jungfrufjärden", from Svealand's coastal water management association and the location where the blue mussels at Nämdö Island were collected (Västanvik).

The data for the three stations at Nämdö Island have been collected using the following methods. The salinity and temperature were measured using CTD (Walve

2021). The visibility was measured using a Secchi disc and water telescope, and the oxygen was measured using an optical oxygen sensor. Water samples were taken for chlorophyll-a according to HELCOM, guidelines for monitoring of chlorophyll-a. The chlorophyll-a was analyzed using a spectrophotometer after extraction with ethanol. All samples were collected following the HELCOM Manual for Marine Monitoring in the COMBINE Programme of HELCOM. The Marine Ecological Laboratory analyzed the water samples at DEEP, Stockholm University (Walve 2021).

2.3. Statistical analyses

In order to evaluate environmental differences between the two locations, the blue mussels and the algal toxins within the mussels, statistical analyses were conducted. All statistical analyses were performed using R's statistical software program (R Core Team 2021).

The blue mussels were studied regarding their weight and length to determine differences between the two locations and between weeks. Since the size can indicate how much water can be filtered, i.e., the exposure to algal toxins, knowledge of size differences between the blue mussel groups is crucial for the interpretation of their respective levels of algal toxins.

The Shapiro-Wilks normality test and the assumption of homoscedasticity graphs showed that the dataset indicated a non-normal distribution. Since the dataset showed a non-normal distribution, the non-parametric test Mann-Whitney U-test and the Kruskal-Wallis test were chosen. The Mann-Whitney U-test was used to evaluate the relationship of the sampled blue mussels between the two locations, while the Kruskal-Wallis test was used to evaluate the relationships among the weeks at each location. To further investigate the differences in length between the weeks, a pairwise comparison using the Wilcoxon rank-sum test with continuity was performed. The significance level was set to 5%.

The algal toxins were plotted in a graph to visualize the differences between the weeks and the locations. Since the individual blue mussels were pooled together to one sample per week, it resulted in too few sample points to perform any statistical test. The option to pool the weeks together for analysis of differences between locations was ignored. The reason was that it would have contradicted the hypothesis that there is a temporal difference in concentrations.

In order to evaluate the environmental differences at the two locations, the descriptive data (maximum, minimum, mean, standard error, median, and standard deviation values) of each variable were compiled using measurements from July each year through the years 2006-2020. As mentioned earlier, the stations at Nämdö Island ($n = 3$) were added together for each year, and the mean value was used for the statistics. To analyze potential differences in environmental variables between locations, generalized linear models (GLMs) were done according to:

$$\text{independent variable} \sim \text{year} + \text{location}$$

GLMs using environmental data and the algal toxins were not performed since the data available was only one measurement from one occasion in July of each year and for each location. Therefore, comparing environmental variables based on one measurement was not suitable.

3. Results

The following section presents the results found within this study. The first section *3.1. Blue mussels* present the results regarding the size of the mussels between the locations as well as between the weeks at each location. The second section *3.2. Algal toxins* show the concentrations of brominated compounds found within the blue mussels. The last section, *3.3. Environmental variables* present the environmental data and the variations among the two locations.

3.1. Blue mussels

The mussels at the Nämdö Island were longer (19.00- 36.00 mm) compared to the Hanö Bight (13.00-25.00 mm) (Figure 3A). The blue mussels at the Nämdö Island also weighed more (0.57- 3.32 g) compared to the ones from the Hanö Bight (0.17-1.34 g) (Figure 3B).

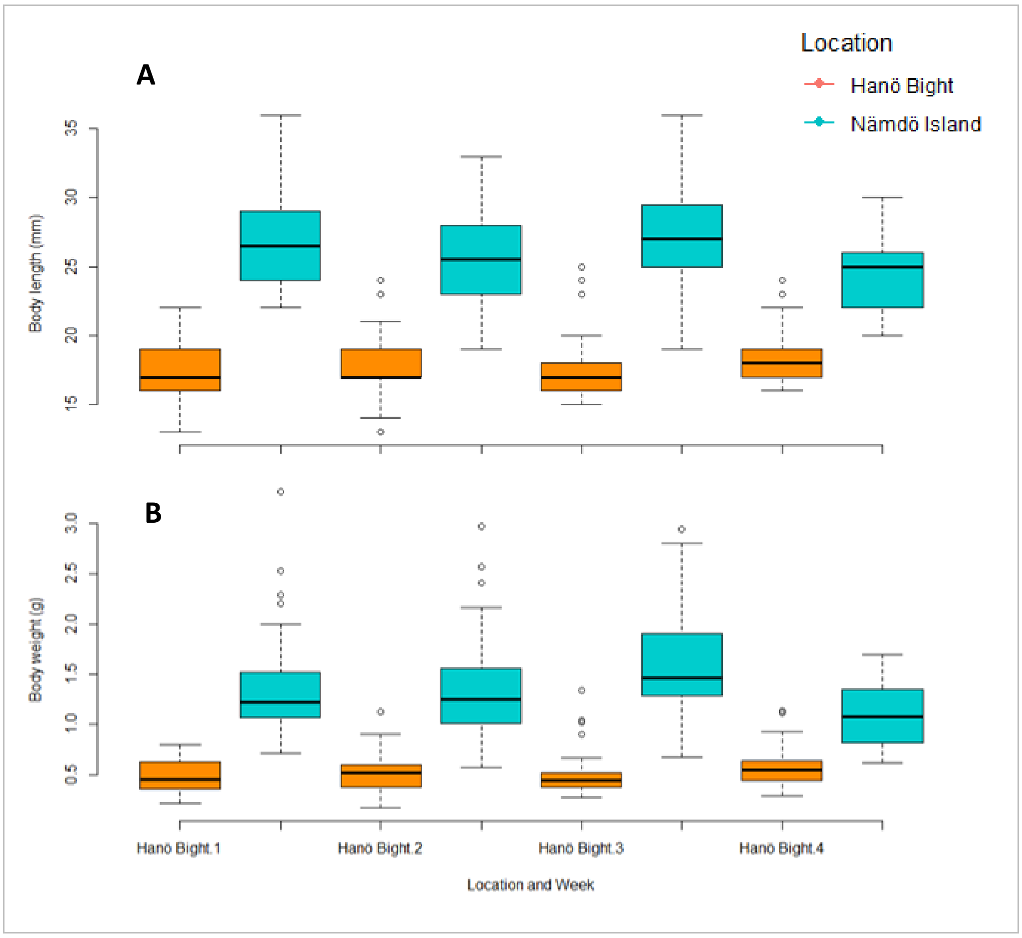

Figure 3. Boxplots showing the lengths (mm) (A) and weights (g) (B) of the blue mussels collected during four consecutive weeks in July 2020 at Hanö Bight and Nämdö Island. The boxplot shows the minimum, first quartile, median (thick line), third quartile, and maximum. The circles outside the maximum are outliers.

The Mann-Whitney U-test (Wilcoxon rank test in R) showed a statistically significant difference ($W=594$, $p < 2.2e-16$) in the lengths between the two locations, with larger blue mussels from Nämdö Island.

The Kruskal-Wallis rank-sum based on the length of the blue mussels showed a significant difference (Chi-square = 7.8782, $p = 0.0486$, $df = 3$) among the four weeks from the Hanö Bight. In addition, the pairwise Wilcoxon rank-sum test showed a statistical significance between weeks 3 and 4 at the Hanö Bight (Table 2).

At the Nämdö Island, the Kruskal-Wallis showed a significant difference (Chi-square = 11.936, $p = 0.007607$, $df = 3$) among the four weeks. The pairwise Wilcoxon rank-sum test showed a statistical significance between weeks 1 and 4 and between weeks 3 and 4 (Table 2).

Table 2. Pairwise comparison of the lengths (mm) of the blue mussels between the weeks in July 2020, at the Hanö Bight and Nämdö Island. Bold numbers show a significant difference (p<0.5)

	Hanö Bight			Nämdö Island		
Week	1	2	3	1	2	3
2	0.794	-	-	0.2511	-	-
3	0.251	0.250	-	0.4483	0.0814	-
4	0.401	0.541	**0.021**	**0.0281**	0.2511	**0.0072**

For bodyweight, the Mann-Whitney U-test showed a statistically significant difference (W=782, $p < 2.2e-16$) between the two locations. The heavier blue mussels were from Nämdö Island.

The Kruskal-Wallis rank test showed a significant difference (Chi-square = 19.874, p = 0.0001802, df = 3) was found among the four weeks at the Nämdö Island. A pairwise comparison using Wilcoxon rank-sum test with continuity showed a statistical difference between week 1 and 3, week 2 and 3, week 1 and 4, week 2 and 4, and week 3 and 4 at Nämdö Island (Table 3).

The Kruskal-Wallis rank test did not show a significant difference (Chi-square = 7.7201, p = 0.05216, df = 3), however, the comparison Wilcoxon rank-sum test showed a statistical significance between weeks 3 and 4 (Table 3).

Table 3. Pairwise comparison of the weights (g) of the blue mussels between the weeks in July 2020 at the Hanö Bight and the Nämdö Island. Bold numbers show a significant difference (p<0.5).

	Hanö Bight			Nämdö Island		
Week	1	2	3	1	2	3
2	0.546	-	-	0.91216	-	-
3	0.89	0.546	-	**0.02004**	**0.02141**	-
4	0.084	0.366	**0.034**	**0.02141**	**0.02669**	**0.00015**

3.2. Algal toxins

The blue mussels were analyzed for algal toxins. The analysis showed that the Nämdö Island had higher concentrations of the analyzed substances (Table 4).

Table 4. Concentrations of 2,4,6-TBP, 6-OH-BDE47, and ΣOH-PBDEs in pg g^{-1} w.w. in blue mussels collected in July 2020 in Hanö Bight and the Nämdö Island.

Location	Week	Weight (g w.w.)	2,4,6-TBP (pg g-1 w.w.)	6-OH-BDE47 (pg g-1 w.w.)	ΣOH-PBDEs (pg g-1 w.w.)
Hanö Bight					
	1	1,00	170	202	903
	2	1,00	170	152	771
	3	1,01	162	210	896
	4	1,01	164	258	1 661
	Mean	1,00	166	206	1 058
	Stdev.	0,01	4	38	352
Nämdö Island					
	1	1,01	187	3 956	34 546
	2	1,05	271	4 348	38 439
	3	1,00	157	5 948	41 343
	4	1,01	195	4 051	29 567
	5	1,04	168	2 770	17 997
	Mean w 1-4	1,02	202	4 576	35 974
	Mean w 1-5	1,02	196	4 215	32 378
	Stdev.	0,02	40	1 020	8 204

The 2, 4,6-TBP exhibited an inversed relationship to the other substances. This was particularly clear at Nämdö Island, where the concentration was highest in week two and lowest in week three Table 4, Figure 4A).

The concentrations of the 6-OH-BDE47 were measured to approximately 200 pg g^{-1} wet weight (w.w.) throughout the weeks at the Hanö Bight. The concentrations were roughly 20 times lower than at Nämdö Island. At Nämdö Island, this congener showed a distinct increase during week three, with a peak of almost 6 000 pg g^{-1} w.w., which was almost 30 times higher than the concentrations found at Hanö Bight during the same week (Table 4, Figure 4B).

The ΣOH-PBDEs increased between the first and the last week at the Hanö Bight, whereas the concentrations at the Nämdö Island followed the same trend as the congener 6-OH-BDE47 (Table 4, Figure 4C). The Nämdö Island also exhibited approximately 30 times higher concentrations of the summed OH-PBDEs than the Hanö Bight.

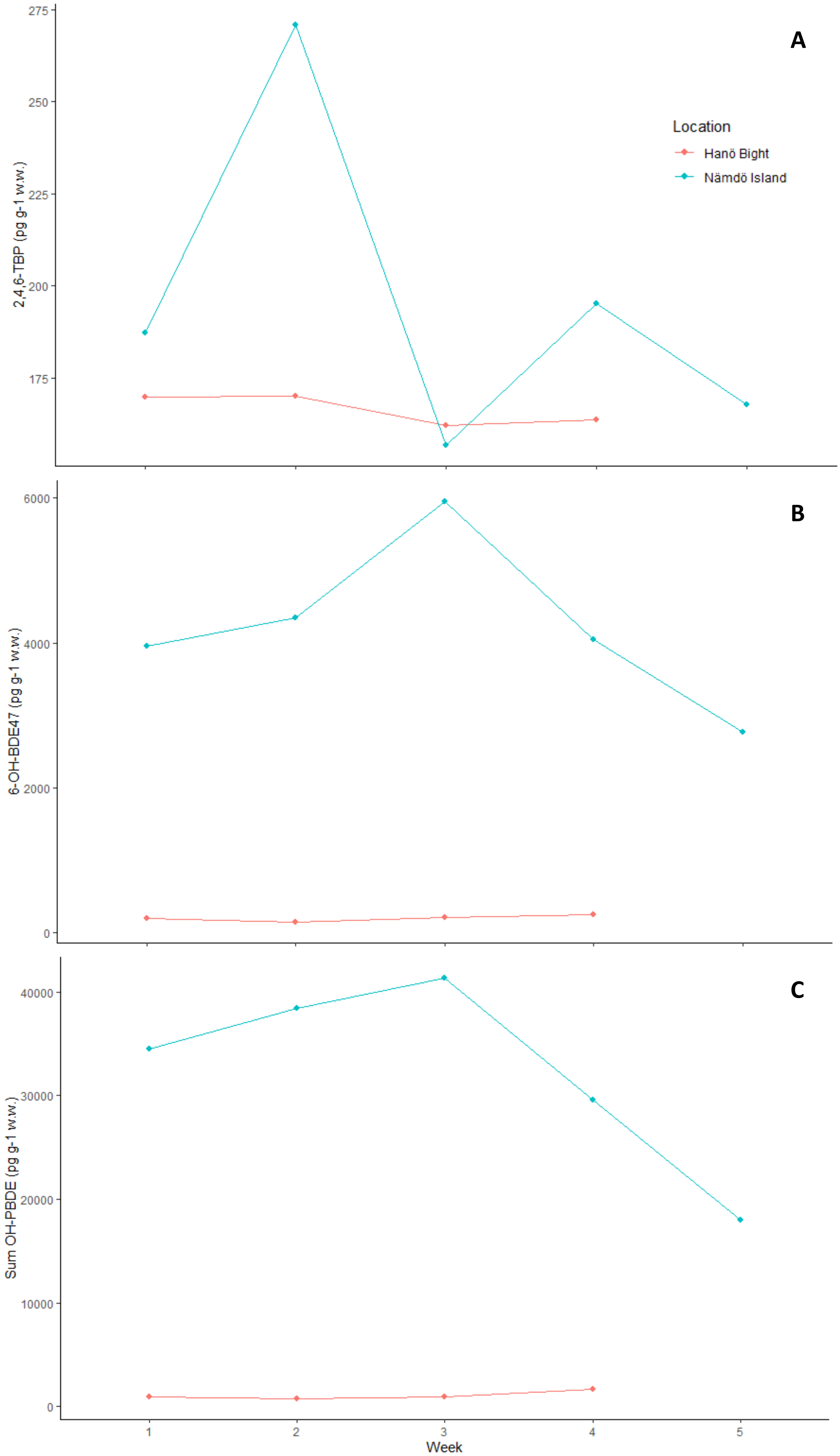

Figure 4. Concentrations of 2, 4, 6-TBP (A), 6-OH-BDE47 (B), and ΣOH-PBDEs (C) found in blue mussels collected during four consecutive weeks in July 2020 at Hanö Bight and Nämdö Island. Concentrations are shown in pg g-1w.w.

3.3. Environmental variables

The environmental trend data showed a higher variability for visibility at the Hanö Bight (Table 5), with increased visibility during the measured years, whereas Nämdö Island shows a negative trend in visibility (Appendix Figure 1). The generalized linear model (GLM) shows significantly higher values ($p< 0.001$), with better visibility at the Hanö Bight (Appendix Figure 1). The measured temperature did not show as great of a difference between the two locations ($p= 0.07$) (Table 5, Table 6), with the highest temperatures measured during the same years (Appendix Figure 1). The salinity at the two locations has a statistical difference ($p< 0.001$) but seems to follow the same trends in changes over the years (Table 6, Appendix Figure 1).

The total nitrogen concentrations showed higher values at the Nämdö Island ($p< 0.001$) (Table 6) and over the years (Table 6) ($p< 0.01$). The measurements only follow the same pattern during 2014 and after 2017- the Hanö Bight measure higher concentrations during 2018 and 2020. However, the residuals of the total nitrogen do not follow a normal distribution ($p< 0.004$), and therefore the results do not have as vital statistical significance as if the residuals were to be normally distributed. The total phosphorus concentrations showed higher values at the Hanö Bight ($p< 0.001$) and for the years ($p< 0.01$) (Table 6, Appendix Figure 2). The phosphate concentration showed significance between the locations ($p< 0.001$) but not between years. The measured data showed a pending trend at the Hanö Bight, while the measurements at Nämdö Island show a steady trend with peaks in 2008 and 2020 (Appendix Figure 2). The silicate data showed higher values at Nämdö Island ($p< 0.01$) and for the years ($p< 0.001$) (Table 6).

Chlorophyll-a measurements showed significantly higher values at Nämdö Island ($p< 0.001$) and increased over the measured years ($p< 0.01$) (Table 6). The years followed the same trends except for 2010 when the chlorophyll concentration decreased at the Nämdö Island, and for 2018, which is the only year that the Hanö Bight measured higher chlorophyll concentrations than the Nämdö Island (Appendix Figure 3).

The measured oxygen showed no statistical difference between the locations (Table 6), but the data set missed many measurements to retain relevant results (Appendix Figure 3). Nevertheless, the data shows an oxygen-rich environment in both locations during the last two measured years.

Table 5. Environmental parameters for the Hanö Bight (station VH1) and the Nämdö Island (stations S90, S97, and S114). All measurements were taken in July 2006-2020. The table shows the lowest (min) and highest (max) measured values, the mean and the standard of error (SEM), as well as the median and standard variation and the number of observations (n) in each calculation.

Location	Visibility (m)	Temperature (°C)	Salinity (PSU)	Chl-a (µg L^{-1})	O2 (mg L^{-1})	Tot-N (µg L^{-1})	Tot-P (µg L^{-1})	PO4P (µg L^{-1})
Hanö Bight								
Min-Max	4.10-14.20	12.26-20.71	6.7-7.98	0.3-10.91	9.01-10.42	210.0-430.0	14.71-34.00	2.02-15.00
Mean ± SEM	9.03 ± 0.70	15.99 ± 0.61	7.38 ± 0.10	1.72 ± 0.65	9.89 ± 0.13	273.79 ± 18.16	23.75 ± 1.29	8.82 ± 1.14
Median	8.50	16.00	7.50	0.92	9.93	246.00	23.56	9.46
Stdev.	2.82	2.45	0.39	2.62	0.40	70.52	4.99	4.43
n	15	15	15	15	8	14	14	14
Nämdö Island								
Min-Max	3.5-8.0	14.46-22.72	5.06-5.79	1.36-6.81	8.40-11.61	274.96-444.43	9.94-22.64	0.22-3.81
Mean ± SEM	5.78 ± 0.17	17.09 ± 0.26	5.53 ± 0.03	3.68 ± 0.19	10.06 ± 0.14	319.37 ± 5.16	16.39 ± 0.38	0.91 ± 0.10
Median	5.70	17.01	5.54	3.44	9.88	313.59	16.44	0.72
Stdev.	1.16	1.79	0.18	1.32	0.78	35.75	2.62	0.69
n	47	48	48	48	32	47	47	48

*Table 6. Generalized linear model (GLM) of the environmental variables; visibility, temperature, salinity, chlorophyll-a, O_2, Tot-N, Tot-P, POP_4, and SiO4. ('***'p<0.001, '**'p<0.01, '*'p<0.05, '.'p<0.1).*

Variable	Coefficients:	Estimate	Std. Error	t-value	p-value	
Visibility						
	(Intercept)	53.38	100.47	0.53	0.60	
	Year	-0.02	0.05	-0.44	0.66	
	Location	-3.25	0.51	-6.41	0.001	***
Temperature						
	(Intercept)	104.57	114.41	0.91	0.36	
	Year	-0.04	0.06	-0.77	0.44	
	Location	1.08	0.58	1.86	0.07	.
Salinity						
	(Intercept)	-10.27	14.14	-0.73	0.47	
	Year	0.01	0.01	1.25	0.22	
	Location	-1.85	0.07	-25.63	0.001	***
Chlorophyll-a						
	(Intercept)	-260.02	94.11	-2.76	0.01	**
	Year	0.13	0.05	2.78	0.01	**
	Location	2.01	0.48	4.18	0.001	***
O2						
	(Intercept)	46.85	62.87	0.75	0.46	
	Year	-0.02	0.03	-0.59	0.56	
	Location	0.23	0.31	0.75	0.46	
Tot-N						
	(Intercept)	-7683.47	2527.35	-3.04	0.01	**
	Year	3.95	1.26	3.15	0.01	**
	Location	47.92	13.00	3.69	0.001	***
Tot-P						
	(Intercept)	-504.98	184.05	-2.74	0.01	**
	Year	0.26	0.09	2.87	0.01	**
	Location	-7.20	0.95	-7.61	0.001	***

POP4						
	(Intercept)	-44.79	127.19	-0.35	0.73	
	Year	0.03	0.06	0.42	0.68	
	Location	-7.89	0.66	-11.97	0.001	***
SiO3,4Si						
	(Intercept)	-15228.23	3189.64	-4.77	0.001	***
	Year	7.67	1.58	4.84	0.001	***
	Location	46.00	16.54	2.78	0.01	**

4. Discussion

The following sections will go deeper into the results found in this pilot study regarding the spatiotemporal variations of algal toxins found in the Baltic blue mussel at the Hanö Bight and Nämdö Island. The concentrations from the locations will be compared with results from previous research and highlight the importance of potential consequences for the food web and of using blue mussels in aquaculture.

4.1. Spatiotemporal variations

The blue mussels at Nämdö Island showed higher mean concentrations of 2,4,6-TBP, 6-OH-BDE47, and the ∑OH-PBDEs compared to Hanö Bight. The 2,4,6-TBP concentrations were slightly higher at the Nämdö Island compared to the Hanö Bight, however, this difference was not as distinct as the two other compounds. The concentrations of 6-OH-BDE47 with 16 to 30 times higher concentrations each week at Nämdö Island compared to Hanö Bight. The ∑OH-PBDEs also showed concentrations of 18 to 50 times higher concentrations at Nämdö Island than at Hanö Bight. However, since the blue mussels were pooled together to one sample per week, no statistical test was performed on the algal toxins. Moreover, there were not any replicate blue mussel samples, also restricting any statistical analysis.

Compared to previous research studying OH-PBDEs in blue mussels from the Baltic Sea, the results from Nämdö Island (mean concentrations of 2,4,6-TBP= 202 pg g^{-1} w.w.; 6-OH-BDE47= 4 576 pg g^{-1} w.w.; ∑OH-PBDEs= 35 974 pg g^{-1} w.w) were in line with results from Löfstrand *et al.* (2011) (mean concentrations: 6-OH-BDE47= 8 580 pg g^{-1} w.w.; ∑OH-PBDEs= 50 050 pg g^{-1} w.w). In contrast, the concentrations of OH-PBDEs in blue mussels from the Hanö Bight were very low (mean concentrations: 2,4,6-TBP= 166 pg g^{-1} w.w.; 6-OH-BDE47= 206 pg g^{-1} w.w.; ∑OH-PBDEs= 1 058 pg g^{-1} w.w.).

The results from this study also showed a temporal variation between the different weeks. The highest concentrations were measured during week three at Nämdö Island (6-OH-BDE47= 5 948 pg g^{-1} w.w.; ∑OH-PBDEs= 41 343 pg g^{-1} w.w.) while the highest measurements at the Hanö Bight were during week 4 (6-OH-BDE47= 258 pg g^{-1} w.w.; ∑OH-PBDEs= 1 661 pg g^{-1} w.w.). Although the concentrations found in the blue mussels at the Hanö Bight were low, these levels of toxins have previously been found in the filamentous red macroalgae *Ceramium tenuicorne* during June and August (Dahlgren *et al.* 2015).

The concentrations of 6-OH-BDE47 found in this study showed different results during July. The mean concentrations of 6-OH-BDE47 found in this study were proximately 4 000 pg g^{-1} w.w. at Nämdö Island, aligning with previous recorded concentrations in blue mussels concentrations during the summer months within the Stockholms archipelago (Löfstrand 2011). The results in the blue mussel study by Löfstrand (2011) showed a concentration peak of 6-OH-BDE47 during the summer months in June. The mean concentration in June was 8 580 pg g^{-1} w.w. of 6-OH-BDE47, compared to 422 pg g^{-1} w.w. in May, 1 790 pg g^{-1} w.w. in August, and 853 pg g^{-1} w.w. in October. Even though the mean concentration at Nämdö Island was considerably higher than at the Hanö Bight, it is also important to recognize the peak concentration found within the month. At Nämdö Island, week three measured the highest 6-OH-BDE47 concentration found in this study with a concentration of almost 6 000 pg g^{-1} w.w.

A variation of ∑OH-PBDEs concentrations was found in the blue mussels. The results from this study showed mean concentrations of approximately 35 000 pg g^{-1} w.w. of ∑OH-PBDEs at Nämdö Island and roughly 1 000 pg g^{-1} w.w. at the Hanö Bight. The highest concentration of ∑OH-PBDEs was once again found during week three at Nämdö Island, with a concentration of approximately 41 000 pg g^{-1} w.w. The concentrations from Nämdö Island were comparatively higher than the Hanö Bight, but lower compared to the results found by Löfstrand *et al.* (2011). The study by Löfstrand *et al.* (2011) showed that mean concentrations of ∑OH-PBDEs found in blue mussels were 50 050 pg g^{-1} w.w. in June, compared to 1 984 pg g^{-1} w.w. in May, 5 907 pg g^{-1} w.w. in August, and 2 790 pg g^{-1} w.w. in October. Thus, even though the results in this study had a lower mean concentration than previous findings, the concentrations still showed a prominent trend over the weeks. The concentrations in Löfstrand *et al.* (2011) were presented in ng g^{-1} lipid weight in the original report but have been converted to compare similar units.

The peaks of algal toxins concentrations that were found in this report have been shown in previous research. For instance, the research on the red macroalgae *Ceramium tenuicorne* at Nämdö Island, from June to September 2011, also showed a seasonal variation with 1 068 pg g-1 w.w. of 6-OH-BDE47 in the middle of July, showing a prominent peak during that month (Dahlgren *et al.* 2015). The concentrations of 6-OH-BDE47 were comparatively low in June (23 pg g^{-1} w.w. on the 13th and 115 pg g^{-1} w.w. on the 27$^{th)}$. They were also comparatively low at the beginning of July (224 pg g^{-1} w.w. on the 3rd and 566 pg g^{-1} w.w. on the 12th) until the measured concentration mentioned earlier of 1 068 pg g^{-1} w.w. on the 19th of July. Concentrations were measured once in August (145 pg g^{-1} w.w. on the 4th) and once in September (50 pg g^{-1} w.w. on the 18th). Even though these results have been found in *Ceramium tenuicorne,* the concentrations of these compounds show a seasonal variation that should be recognized.

In the Hanö Bight, the situation was different. All concentrations of 6-OH-BDE47 and ∑OH-PBDEs were low at the Hanö Bight (Table 4). They were unexpectedly low since the bight has shown troubling changes within the ecosystem, foul-smelling water, brownification, fish injuries, and seabirds and fish deaths (Havs- och vattenmyndigheten 2018; Svedäng *et al.* 2018). A possible explanation for the decreased fish populations and illness shown in seabirds and fish could be the consequences of high levels of algal toxins. However, since the Bight showed low levels of the compounds, this could either be a year with low algal toxins in the bight or other environmental toxins impacting the ecosystem.

The concentrations of 6-OH-BDE47 that were seen at Nämdö Island were three to six times higher than in *Ceramium tenuicorne* in previous studies, which also were carried out at Nämdö Island in July (Dahlgren *et al.* 2015). The concentrations were considerably higher at Nämdö Island than Hanö Bight; however, previous research has found concentrations this high, and even slightly higher, in blue mussels during the middle of June (Löfstrand *et al.* 2011). This would indicate that the 6-OH-BDE47 concentration levels found at Nämdö Island are reasonable to expect in similar environments during June and July in the Baltic Proper.

The concentrations of 2,4,6-TBP found in the blue mussels at Hanö Bight and Nämdö Island were assessed to the approximately same concentrations. Additionally, the concentrations of 2,4,6-TBP decreased the same week as when peak concentrations of 6-OH-BDE47 and ∑OH-PBDEs could be seen. This is interesting since the 2,4,6-TBP and the OH-PBDEs compete in regard to formation. The concentrations of 2,4,6-TBP can hence impact the concentrations of other substances, e.g., OH-PBDEs. For the Hanö Bight, the highest concentrations were measured during week four and at Nämdö Island during week three. The concentration of 2,4,6-TBP decreased during these weeks, indicating that the 2,4,6-TBP relationship between these two compounds exists. The decrease of 2,4,6-TBP, and the simultaneous increase of 6-OH-BDE47, have also been shown in *Ceramium tenuicorne.* This occurred when the highest concentration of 6-OH-BDE47 was found on the 19th of July (1 068 pg g^{-1} w.w.). The 2,4,6-TBP decreased from 1 216 pg g^{-1} w.w. on the 12th of July to 751 pg g^{-1} w.w. on the 19th of July (Dahlgren *et al.* 2015). The relationship between these two compounds is important to recognize since low concentrations of 2,4,6-TBP can still imply high levels of the toxic 6-OH-BDE47.

4.2. Size difference among the blue mussels

Mussels from Nämdö Island were both longer (19.00- 36.00 mm) and heavier (0.57-3.32 g) compared to the blue mussels at Hanö Bight (13.00-25.00 mm and 0.17-1.34 g) (Figure 3). The size difference is relevant in the context of algal toxins since smaller mussels have a higher size-specific respiration rate (Riisgård 1998) and, therefore, can filter more water than larger mussels. Since the blue mussels were smaller at the Hanö Bight, they should contain higher concentrations of algal toxins if the same amounts of concentrations were found in the water. The algal toxins showed the highest amounts of 6-OH-BDE47 and ∑OB-PBDEs at Nämdö Island during the third week, which is the week with the heaviest and longer mussels (Figure 3, Table 2, Table 3). Therefore, the size difference does not have an impact on the overall result of this study.

The blue mussels in the Baltic Sea have adapted to the brackish water (Kautsky 1982; Löfstrand 2011; Lindqvist 2016); however, the blue mussels were expected to grow more prominent at the Hanö Bight due to the fact of higher salinity at this location (Kautsky 1982). One reason for the unexpected results could be that there were no larger mussels at the Hanö Bight. At both locations, the mussels were collected on the premises that they would be big enough for analysis, and they were collected by different people, implying that the entire population might not be represented in the sampled pool.

Assuming there were no larger mussels at the bight, this could be explained by the amount of available food for the blue mussels. Another possible explanation could be the deteriorated water quality, which could impact the mussels to decrease the amount of water they filter. This would decrease both food uptake and the concentration of algal toxins found within the mussels.

4.3. Spatial differences influencing exposure to algal toxins

The fact that there are concentration differences between the locations could be due to the differences in habitat. Previous research has shown that certain algae species, such as *Ceramium tenuicorne*, can produce brominated aromatic compounds under induced stress by external factors (Dahlgren *et al.* 2015). Blue mussels living close to *Ceramium tenuicorne* have been shown to accumulate these compounds (Malmvärn *et al.* 2005). If there were more *Ceramium tenuicorne* at one location compared to the other, this could explain the concentration differences between the Hanö Bight and the Nämdö Island. Therefore, the blue mussels' external environment could be one part of the explanation. The *Ceramium tenuicorne* can grow on both hard substrate and as loose drifting algal mats (Bergström *et al.* 2003;

Lindqvist 2016). Although *Ceramium tenuicorne* is commonly distributed in the Baltic Sea (Lindqvist 2016), it is prone to have regional differences. These regional differences also include different tolerant ranges to changes in salinity (Bergström & Kautsky 2006). The acclimatization possibility for the algae and the unknown distribution in the two locations creates uncertainty in whether the species would be affected (stressed) by the changes in salinity or not. The algae can drift with the currents; hence its distribution can change over the day, depending on the currents.

The Hanö Bight mainly consists of a sandy bottom and has shown a decrease in both seaweed and eelgrass (*Zostera marina*), which could be influenced by the changes in filamentous algae (Svedäng *et al.* 2018). The area has reported thick filamentous algae mats of *Ceramium tenuicorne* on the sea bottom at depths of 4 meters during an inventory in 2014 (Svedäng *et al.* 2018), however, as the algae can drift with the currents (Svedäng *et al.* 2018), the algae could have been within the location where the mussels were collected, even though they were collected at a shallower depth (0-0.5 meter). This could explain the concentration differences between the two locations; however, no species inventory was performed at either location during the collection of the blue mussels to confirm this.

Monitoring algae blooms is an essential aspect of observing and understanding the eutrophication effects of the Baltic Sea (Kratzer 2005). The algae blooms have been reported since the 1800s and are recurring more frequently (Kratzer 2005). The monitoring and measuring of chlorophyll-a is a common technique to assess eutrophication (Harvey *et al.* 2019); however, it could potentially also be an essential assessment of algal toxins. Löfstrand *et al.* (2011) found that OH-PBDE (and MeO-PBDE) concentrations in blue mussels had started to decline before the algal bloom in July and August. A study by Dahlgren *et al.* (2015) showed both a peak and high concentrations of OH-PBDE (and MeO-PBDE) in the red algae *Ceramium tenuicorne* in the middle of July (2011) (collected from a depth of 0-1 meter). The concentration peak was probably due to environmental stressors, such as changes in temperature and light intensity (Dahlgren *et al.* 2015). A missing factor in the two aforementioned studies is the lack of data on when the algae blooms occurred.

Concentrations of algal toxins could be impacted by climate change. According to Walve *et al.* (2021), the deep current water from the Baltic Proper has affected the larger bays in the Stockholm archipelago due to the widespread lack of oxygen in the deeper parts of the Baltic Sea. In the last couple of years, the oxygen concentration levels have increased at Nämdö Island (Walve *et al.* 2021), but the concentration levels are still not to the same extent as the Hanö Bight. If the oxygen levels were to continue to decrease at Nämdö Island, this could cause implications for the aquatic ecosystem (Wasmund 2002).

The intensity of algal bloom varies between years. Two of the stations by Nämdö Island (Nämdöfjärden and Jungfrufjärden) were relatively spared of algal blooms during July and August of 2020 (Walve *et al.* 2021), even though the measured mean chlorophyll-a concentrations were higher than in the Hanö Bight. The nitrogen and phosphorus concentrations were measured lower at Nämdö Island during July 2020, which, combined with the lower temperature and reduced visibility, could explain the absence of an algal bloom. However, historically, chlorophyll-a data have displayed higher concentrations at the Nämdö Island (Appendix Figure 3). The higher concentrations of chlorophyll-a could indicate more phytoplankton (Kratzer 2005) and, therefore, more nutrition for blue mussels (Tedengren 2008) and algal toxins accumulated in the mussels.

4.4. Consequences of algal toxins in the Baltic blue mussel

A study by Dahlgren *et al.* (2016) demonstrated the bioaccumulation of naturally produced MeO/OH-PBDEs within the trophic food web. Their results show that the MeO-PBDEs biotransform to OH-PBDEs and could be detected at high concentrations in the upper end of the food web, specifically in perch (*Perca fluviatilis*) (Dahlgren *et al.* 2016). This supports the idea that the conjugates can hydrolyze in predators that feed on blue mussels (Lindqvist *et al.* 2014). The concentrations of algal toxins can hence be hazardous for organisms that feed on the blue mussels.

During the last few years, there have been pilot studies regarding blue mussels in aquaculture (Dahl *et al.* 2019). Some of these pilot studies have been carried out as the Baltic Blue Growth project by the Submariner Network (2016-2019), and another project is the Rich Waters (Sweden's first project in the EU's environmental program LIFE IP). Using blue mussel farming as mitigation for the high concentrations of phosphorus and nitrogen is one aspect of aquaculture, while the other is to use harvested mussels to feed chicken or even fish for human consumption (Gren *et al.* 2009; McLaughlan *et al.* 2014). Thus, the potential toxic aspect of algal toxins in harvested blue mussels needs to be considered in this context. It warrants further research to improve knowledge on toxic effects as well as seasonal variations in algal toxins to reduce risks by harvesting the blue mussels during low concentrations of algal toxins in the aquatic ecosystem. This thesis and previous research (Löfstrand *et al.* 2011; Dahlgren *et al.* 2015) show a temporal variation of brominated compounds over the summer months. Previous research (Löfstrand *et al.* 2011; Dahlgren *et al.* 2015) has seen the variation monthly, from May to September/October, while this pilot study confirms weekly temporal variation. The weekly temporal variation can indicate a time window within the seasonal trend when the mussels could be harvested. However, there are many uncertainties in that equation; recognizing the seasonal trend (both monthly and weekly), indicating unpredictable fluctuations, and it could be questioned if the blue mussels should be harvested at all during the summer months. No research has been conducted regarding algal toxins from the fall-spring months, which could be a more suitable time for harvesting. The lack of all-year-around data causes difficulties in evaluating if the concentrations found during a specific year are within the temporal variation or if they would be an anomaly.

The other aspect to consider regarding locations for mussel banks are the spatial differences between locations. The results at Nämdö Island were similar to what has been found in blue mussels along the coast within the Baltic Proper (Löfstrand *et al.* 2011); however, the results from the Hanö Bight were surprisingly low. According to the results found in this thesis, an option for using blue mussels in aquaculture without the risk of high concentrations of algal toxins is to choose a location with lower concentrations. Although this study had locations right along the coastline, blue mussel farming can occur further from the coast and be less affected by contaminated sediments (Sipiä *et al.* 2001). By placing the mussel banks in the pelagic zone, contaminated sediments can be excluded, but the blue mussels are still susceptible to algal toxins (Kotta *et al.* 2020) that can be produced during algae blooms.

The importance of location for the mussel banks and recognizing the seasonal trends of algal toxins could have significant consequences for aquaculture. For future studies, algal toxins in blue mussels should also be investigated during other seasons, and species inventory of algae should be performed in the locations where mussel banks are located. This information could fill in the knowledge gap regarding when it would be considered safe to harvest blue mussels for further consumption.

4.5. Further research and suggestions

This pilot study has shown variations of brominated compounds in the Baltic blue mussels collected at Nämdö Island and the Hanö Bight during July 2020. The results showed variations during the continuous weeks, which implies that there is also a weekly variation within the monthly seasonality of concentrations. To statistically evaluate this relationship, more samples were needed.

To better evaluate the environmental aspects of the blue mussel populations, the sampling points of environmental data and the blue mussels should be taken from the exact location. When sampling the blue mussels, a species inventory of algae is recommended to increase the understanding of which species are important for producing these brominated compounds/algal toxins.

Algal toxins data have previously only been measured during the summer months, giving a skewed picture of the fluctuations of algal toxins during a whole year. Future studies should measure algal toxins in blue mussels monthly throughout the year, preferably a few years in a row, to make it possible to evaluate whether or not the concentrations found are to be expected in a specific location.

Since pilot studies of blue mussel farming have started within the Baltic Sea, these mussels should be analyzed for algal toxins, in addition to metals and other environmental pollutants that they are already tested for today.

5. Conclusion

This pilot study has shown a variation of brominated compounds, 2,4,6-TBP, 6-OH-BDE47, and ∑OH-PBDE, in the Baltic blue mussel (Baltic *Mytilus trossulus edulis*) collected during continuous weeks of July 2020. The results showed 20-40 times higher concentrations of 6-OH-BDE47 and ∑OH-PBDEs at Nämdö Island than at Hanö Bight. The highest concentrations were measured during week three at Nämdö Island, to almost 6 000 pg g^{-1} w.w. of 6-OH-BDE47 and 41 000 pg g^{-1} w.w. of ∑OH-PBDEs pg g^{-1} w.w. These concentrations were slightly lower than previously found during the summer months in blue mussels from the Baltic Sea (Löfstrand *et al.* 2011). The results of the 2,4,6-TBP were approximately the same at both locations during the collected time. However, both locations showed a decline of the substance during the same weeks as the two other substances peaked. The simultaneous decline of 2,4,6-TBP, an increase of 6-OH-BDE47 and ∑OH-PBDEs, supports the concept that there is a relationship between these substances. This is important to consider since low concentrations of 2,4,6-TBP could indicate high concentrations of more toxic substances. The results from this study add to the knowledge regarding regional and temporal concentration differences of algal toxins that can be found in the Baltic blue mussel.

Popular Science Summary

The Baltic Sea is a fragile body of water with many contributing factors damaging this marine environment. Due to the shallowness of the basins and the slow water turnover, the nutrients and contaminants take a long time to degrade. In addition, variations in salinity make the Baltic Sea a challenging environment for marine species to acclimatize and thrive. One species that has adapted to this environment is the Baltic blue mussel. The blue mussels are filter feeders, making them suitable species to use as indicators of certain compounds found in the water phase. An example of such compounds is algal toxins.

Primary producers and algae produce algal toxins. Previous research has seen a monthly variation in algal toxin levels in blue mussels. The variation has been seen from May to October, with a distinct peak of concentrations during June-July. This thesis has zoomed in on that variation and can confirm a weekly temporal variation. Two locations, Nämdö Island and Hanö Bight have been used to evaluate the concentration differences within blue mussels. The blue mussels were collected during the consecutive weeks of July 2020. Comparisons in algal toxins levels were made between the two locations as well as between the collected weeks. Environmental variables that could affect the production of algal toxins were included in the comparison. The comparison showed that the blue mussels at Nämdö Island contained more algal toxins than those at the Hanö Bight. This is the first study comparing algal concentrations found in the Baltic blue mussel from different locations during the same time frame. The results from this study support that there are weekly concentration variations expected at different locations during July.

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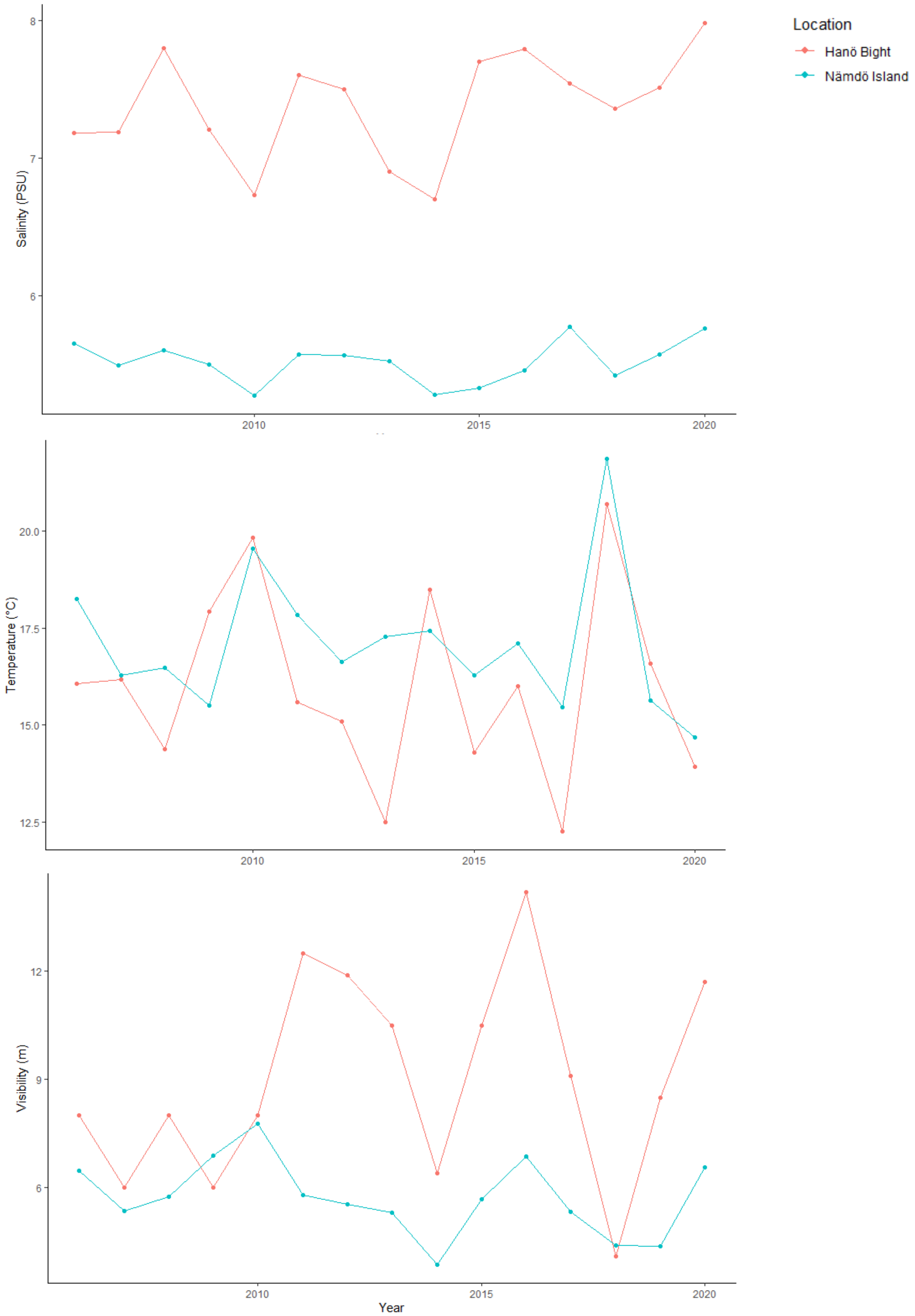
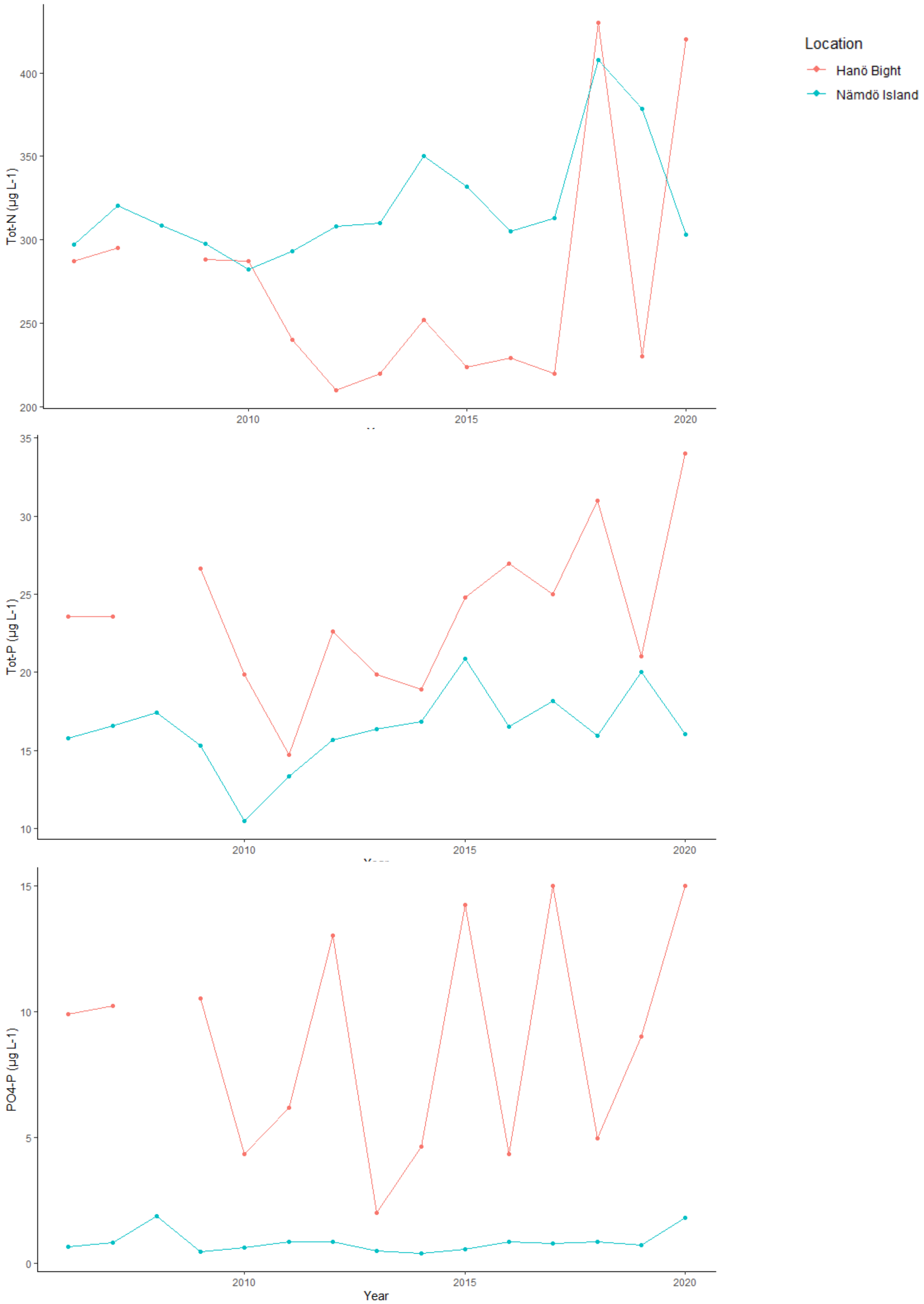
Appendix 1

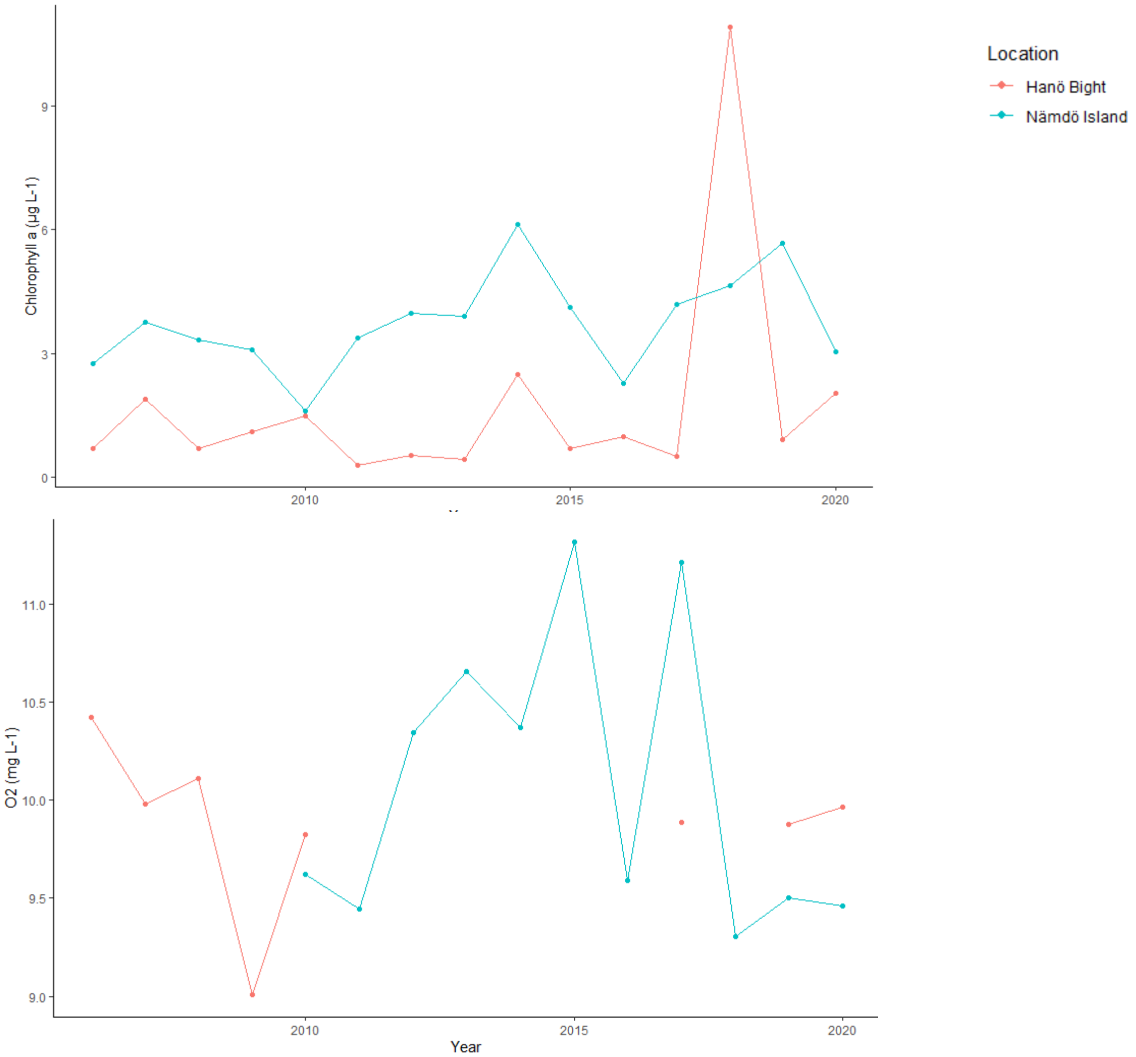
In the following appendix, nine graphs with different environmental variables from the years 2006-2020, from the Nämdö Island and the Hanö Bight, are shown.



Appendix Figure 1. Measured values in July 2006-2020 for salinity (PSU), temperature (˚C), and visibility (m) at the Hanö Bight and Nämdö Island.



Appendix Figure 2. Measured values in July 2006-2020 for total nitrogen (µg L-1), total phosphorus (µg L-1), and phosphate phosphorus (µg L-1) at the Hanö Bight and Nämdö Island.



Appendix Figure 3. Measured values in July 2006-2020 for chlorophyll-a (mg L^{-1}), and oxygen (mg L^{-1}) at the Hanö Bight and Nämdö Island.