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NORDIC ANTIFOULING PROJECT A follow-up of the MAMPEC workshop from 2017

Adjustment of the environment input parameters
for more realistic values

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Part IA: Determination of the value of key parameters for the Baltic sea scenario

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Preface

MAMPEC (Marine Antifoulant Model to Predict Environmental Concentrations) is a commonly used model in EU antifouling (biocidal product type 21) exposure assessment. Several scenarios, e.g. EU regional marina scenarios (Excel Tool scenarios) and the EU fishnet scenario, have been developed in MAMPEC in order to harmonize the environmental risk assessment of antifouling products in the EU. The representativeness of these scenarios is crucial in order to achieve a reliable result from risk assessment.

In the MAMPEC workshop in Helsinki in 2017 there was some discussion about Baltic regional scenarios, i.e. Excel Tool Baltic and Excel Tool Baltic Transition scenarios and certain MAMPEC input parameters, but no final conclusions were made between the participating Baltic Sea member states. There has been concern that not all input values used in the scenarios are sufficiently representative for the Baltic sea area. It was concluded that more information is needed about certain physical-chemical parameters in order to be more certain about the representativeness of the scenarios for the Baltic conditions. Thus, the Nordic biocide project was started and completed. The aim of the project was to determine representative values for certain input parameters in the Excel Tool Baltic and the Excel Tool Baltic transition scenarios. In addition, it was decided to evaluate the suitability of the EU fish net scenario for risk assessment in the Baltic Sea area. The project was conducted in cooperation between Nordic biocide authorities from Finland, Denmark Sweden and Norway.

Part I: Determination of the value of environmental key parameters for Baltic Sea and Baltic transition scenarios

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Introduction

Regional environmental exposure scenarios based on MAMPEC have been developed for the Baltic Sea region, e.g. the Excel Tool Baltic and Excel Tool Baltic Transition scenarios. Suitability and reliability of these scenarios for the Baltic Sea and Baltic Sea transition area are of primary importance for the environmental risk assessment.

In the MAMPEC workshop in Helsinki 2017 there was some discussion about certain input parameters to be used in the Baltic Excel tool scenario, but no conclusion was made between participating Baltic Sea member states. At present, the parameter values used in Excel Tool scenarios are from different sources. Environmental parameter values come from the Newcastle report (Thomason & Prowse 2013), MAMPEC default scenarios and the Finnish and Swedish national scenarios (Koivisto 2003, Ambrosson 2008), as agreed in the MAMPEC workshop. These scenarios are later referred to as the Finnish and Swedish national scenarios. During the 2017 Helsinki workshop, discussions were initiated about how the scenarios could be improved by finding relevant data for key parameters. The discussions continued via email between the Nordic member states and led to this project. The purpose of the project is to increase the reliability of the MAMPEC scenarios for the Baltic Sea and Baltic Transition area.

Parameters which have a significant effect on PEC values are considered as most important in this project. These key parameters were identified in the studies conducted in Denmark (Ma 2017) and in Finnish national scenario updating work (Hanninen 2017). An aim of this project is to generate more knowledge about physical and chemical conditions in the Baltic Sea and to determine more realistic values of key parameters for exposure scenarios. Information gathered in this report could be used to develop more realistic exposure scenarios and to increase the reliability of the environmental risk assessment in the Baltic Sea area. This report is based on available environmental monitoring and modelled data from Finland, Sweden and Denmark.

This document consists of two parts. In part 1A only the values of key parameters for the Excel Tool Baltic scenario are considered, whereas in part 1B the values of key parameters for the Excel Tool Baltic Transition scenario are examined.

Part IA: Determination of the values of key parameters for the Baltic sea scenario

1. Material and methods

Data is mainly collected from open databases. The Swedish Meteorological and Hydrological Institute (SMHI) and the Finnish Meteorological Institute (FMI) provide physical measurement data about water level, flow velocity, sea water temperature and wind speed. Data can be downloaded from the websites of the two institutes.

The Swedish Ocean Archive database (SHARK) and the Finnish environmental database (HERTTA) also provide physical and chemical environmental monitoring data from Sweden and Finland. The data were collected by several institutes and non-governmental organisations. The database HERTTA is maintained by the Finnish Environment Institute (SYKE) and the database SHARK by SMHI. Data is available for downloading from the websites of the institutes.

The databases contain a large amount of data, but only a part of it can be considered as representative. Marinas in the Excel Tool Baltic are situated in shallow coastal areas, where e.g. the impact of resuspension and primary production might be different from that in open sea areas. Therefore, only data collected from shallow coastal areas was used. More specific criteria are mentioned in the parameter discussion paragraphs.

Temporal variation is assumed for all key parameters discussed in this document. It was assumed that the length of the boating season in the Baltic Sea is about 6 months, from May 1 to October 31. In order to obtain more realistic values for exposure scenarios, all parameters were determined to correspond to situations between May to October, when the boats are in marinas. Data later than October or earlier than May was not taken into account.

In case of no raw data about parameters, or if data was limited, scientific publications and expert's personal comments were used. All statistical analyses were made using Excel (Microsoft Excel 2016).

Environmental conditions vary considerably between marinas, and it is not possible to determine one key parameter value which would be representative for all marinas. It would be ideal to use marina-specific values. However, it is difficult to determine specific values for each marina, because monitoring data from marinas is not available and regional coverage of available data is usually poor. It was assumed that the most important factors affecting environmental parameters are how open the location of the marina is and whether the marina is located in an estuary or non-estuary area. Location of all [marinas](#) in the Excel Tool Baltic were checked from aerial photographs, and marinas were divided into sheltered or non-sheltered and estuary or non-estuary marinas. Sheltered marinas were surrounded by islands, or they were situated in sheltered bays. Non-sheltered marinas were situated along the seashore where there were no islands (Figure 1). Non-estuary marinas were situated in areas where a significant impact of rivers is not assumed. Most of the marinas in the Excel Tool Baltic scenario are situated in sheltered and non-estuary areas (Table 1). In order to take into account the differences between marinas, the aim was to determine the values of parameters for each type of marinas. General values were used if no marina-type specific values could be determined.

Table 1. Type of location of marinas from the Baltic scenario.

Marina	Location		Marina	Location	
DK 12	Non-Sheltered	Non-Estuary	FI 4	Sheltered	Estuary
DK 13	Non-Sheltered	Non-Estuary	FI 5	Sheltered	Estuary
DK 14	Non-Sheltered	Non-Estuary	FI 6	Sheltered	Non-Estuary
DK 15	Non-Sheltered	Non-Estuary	FI 7	Sheltered	Non-Estuary
DK 16	Non-Sheltered	Non-Estuary	FI 8	Sheltered	Estuary
DK 8	Non-Sheltered	Non-Estuary	FI 9	Sheltered	Non-Estuary
EE 1	Sheltered	Non-Estuary	LT 1	Non-Sheltered	Non-Estuary
EE 10	Non-Sheltered	Estuary	LV 2	Non-Sheltered	Non-Estuary
EE 2	Non-Sheltered	Non-Estuary	PL 2	Non-Sheltered	Non-Estuary
EE 3	Non-Sheltered	Non-Estuary	PL 3	Non-Sheltered	Non-Estuary
EE 4	Sheltered	Non-Estuary	PL 5	Non-Sheltered	Non-Estuary
EE 5	Non-Sheltered	Non-Estuary	PL 7	Non-Sheltered	Non-Estuary
EE 7	Sheltered	Non-Estuary	SE 10	Sheltered	Non-Estuary
EE 8	Non-Sheltered	Estuary	SE 11	Sheltered	Non-Estuary
EE 9	Sheltered	Non-Estuary	SE 12	Sheltered	Non-Estuary
FI 1	Sheltered	Non-Estuary	SE 13	Sheltered	Non-Estuary
FI 10	Sheltered	Estuary	SE 14	Sheltered	Non-Estuary
FI 2	Sheltered	Estuary	SE 7	Sheltered	Non-Estuary
FI 3	Sheltered	Estuary	SE 9	Sheltered	Non-Estuary

Figure 1. Examples of different types of marinas. A: Estuary marina (FI 5), B: Sheltered marina (FI 7) and C: non-sheltered marina (DK 5)

1.1. Non-tidal daily water level change (Daily water level change)

Daily water level change was determined by using water level data provided by SMHI and FMI. Data was used from 14 tide gauges, located in different parts of the coast of Finland and Sweden (Figure 2). In Sweden the data used was from the years 2000-2017 and in Finland from the years 2007-2016. Water levels were measured once per hour, so the regional and temporal coverage of data was quite good. The daily water level change was determined by calculating the difference between the daily maximum and minimum values. The median and average values of daily water level changes were measured for each station.

In MAMPEC there are two different water level-related parameters: non-tidal daily water level change and tidal difference. Non-tidal daily water level change in MAMPEC is for use in areas where there is no or very small tidal motion and it is determined by calculating the average non-tidal daily water level change (van Hattum et al. 2016). In MAMPEC there is no parameter of daily water level change, which actually consists of both the impact of tides and non-tidal water level change. However, tides in the Baltic sea are only few centimeters, and the impact of non-tidal water level change is dominant. For simplicity, the daily water level change was used to represent non-tidal daily water level change and it was assumed that the tidal difference is 0 m.

Figure 2. The location of tide gauges.

1.2. Wind speed

Wind speed was determined based on data provided by SMHI and FMI. Data from 27 weather stations located in different parts of the coast of Finland and Sweden was used (Figure 3). All data was collected between the years 2010 and 2017. Measurements have been continuous and wind speeds are reported as average speeds over periods of one to three hours.

The location of all the stations chosen was checked from aerial photographs, and stations were divided into open and sheltered stations based on the coverage of islands between the station and the open sea. Sheltered stations located in the inner archipelago were surrounded by islands. Open stations were in outer parts of the archipelago or on the seashore where there were no islands.

Figure 3. The location of weather stations.

1.3. Flow velocity

Flow velocity data is poorly available from the Baltic Sea region. Most of measurements have been made in the open sea area, but these cannot be used to determine representative values for marina scenarios. However, FMI provided information of flow velocities in the Archipelago Sea based on raw measurement data (Figure 4).

Most of measurements were made in four years between May and November in the 1970s. The data was presented in the flow velocity project in the 1970s (Virtaustutkimuksen neuvottelukunta 1979). In the project, only flow velocity above 1.5 m/s could be detected, which makes it difficult to determine the exact averages (Pekka Alenius, personal comm. 2018). Analyses are based on measurements made at a depth of 15 m or less.

Flow velocities were also measured in the year 2013, at one measurement station situated in the outer archipelago. The measurements were made between June and November. Data is also presented in other studies (e.g. Kanarik 2018). The measurements were made using Acoustic Doppler current profiler (ADCP).

Figure 4. The location of flow measurement stations.

1.4. Temperature

Water temperatures were determined using water temperature data provided by SMHI. Data from 3 measurement stations located in different latitudes on the coast of Sweden was used. All stations were located near the coast line in the inner archipelago. Data collected between the years 2010 and 2017 was chosen, when measurements were made every hour. Temporal coverage of the data is good. Average temperatures for each month and average temperatures for the whole boating season from 1 May to 31 October were calculated.

1.5. Suspended particulate matter (SPM)

Water quality data from the Finnish environmental database (HERTTA) was used. All available data about SPM in coastal areas during the years 2010-2017 was analysed, but only data from sampling stations situated in the shallow coastal area was taken into account (Figure 5). Only data from stations where the water depth is less than 6 m was used. In total, there was data from 76 sampling stations. SPM concentration is typically higher in the coastal area, where resuspension and primary production is usually high. It was assumed that data from shallow coastal stations correspond sufficiently well to marina conditions.

It was assumed that SPM concentration could be higher in river water than in sea water. Consequently, the location of all the coastal stations chosen was checked from aerial photographs and the stations were divided into estuary and non-estuary stations. The division was based on general understanding of the area on the basis of aerial photographs. Estuary stations were situated near rivers, where the impact of river water is obvious. Non-estuary stations were situated in areas where significant impact of rivers is not assumed. Examples of the division are shown in Appendix 1. Stations located in the same municipality were grouped together and certain statistics were calculated in order to define municipality level. Only municipalities with at least 15 samples were taken into account.

Figure 5. The location of SPM measurements

A strong negative relationship exists between Secchi depth and concentration of SPM (Håkanson 2006). In order to estimate SPM concentrations in coastal areas of Sweden, Secchi depth data from Sweden was used and compared to data from Finland. Secchi depth data from the HERTTA and SHARK databases were used. All the analysed data from Sweden was between the years 2010 and 2017 and totally 52 shallow coastal station were chosen. Data from Finland was from the same stations where concentrations of SPM were measured. In total, data from 18 Finnish stations was used. Stations located in the same municipality were grouped together and certain statistics were calculated for municipality level. Only municipalities with at least 15 samples were taken into account.

1.6. Particulate organic carbon (POC)

Quality data from SHARK and HERTTA was used. POC is not a typical monitoring parameter, and therefore the available data was very limited and could not be used to determine representative values for exposure scenarios. However, data about TOC (total organic carbon) was available and was used to estimate values of DOC and POC. TOC consists of DOC, POC and VOC (volatile organic carbon). The portion of VOC is negligible compared to DOC and POC (Orlikowska & Schulz-Bull 2009). Hence, it could be assumed that the measured value of TOC was the sum of DOC and POC.

All available data from Finland between the years 2010 and 2017 and from Sweden between the years 2000 and 2017 was analysed, but only data from sampling stations situated in shallow coastal areas was taken into account (Figure 6). Only data from stations where water depth is less than 6 m was used. In total, data was available from 85 sampling stations.

It was assumed that organic carbon concentration could be higher in river water than in sea water. The location of all the chosen stations was checked from aerial photographs, and stations were divided into estuary and non-estuary stations. The division was based on general understanding of the area on the basis of aerial photographs. Estuary stations were situated near rivers where the impact of river

water is obvious. Non-estuary stations were situated in areas where significant impact of rivers is not assumed. Examples of the division are shown in Appendix 1. Only municipalities with at least 15 samples were taken into account.

Figure 6. The locations of organic carbon measurements.

2. Results and discussion

2.1. Non-tidal daily water level change (Daily water level change)

Average daily water level change for all stations is 9.7 cm/d (SD = 1,7; n = 14). The highest water level change was detected at the Simrishamn station in Sweden, where the highest measured single daily water level change was 113 cm. Extreme variations are, however, rarely observed and typical detected water level changes are from 5 to 15 cm/d (Figure 7 and Figure 8). The highest average daily water level change was detected in Simrishamn (avg. 12.4 cm/d) and Kungholmsfort (avg. 11.6 cm/d) and the lowest in Skagsudde (avg. 7.3 cm/d) and in Pori (avg. 7.8 cm/d).

In the Excel Tool Baltic scenario, the non-tidal water level change value is 7.6 cm/d. This is an average value from the Finnish (11 cm/d) and Swedish (4.8 cm/d) national AF scenarios chosen to be used in the MAM-PEC workshop. In the Finnish national scenario, the value of 11 cm/d is based on a narrow dataset from a single measurement station. Based on more comprehensive data above it seems that this value could be higher. Therefore, it could be justifiable to use a non-tidal water level change of 9.7 cm/d in the Baltic regional scenario.

Figure 7. Daily water level changes in Finland during boating seasons in the years 2010-2017.

Figure 8. Daily water level changes in Sweden during boating seasons in the years 2000-2017.

2.2. Wind speed

Average wind speeds from 1 May to 31 October were 3.5 m/s (SD = 0.8; n = 11) in sheltered stations and 5.5 m/s (SD = 1.1; n = 16) in open stations (Figure 9). Wind speed in open stations was significantly higher than in sheltered stations ($t(25) = -5.7$; $p = 0.00$). The highest average wind speed was detected at the Rauma station (7.2 m/s) and the lowest at the Turku station (2.6 m/s). Station-specific results are shown in Appendix 2 and Appendix 3.

Wind speed is a very site-specific factor, which is affected by landform and vegetation. The width of the surrounding archipelago also affects the wind speed, e.g. the lowest measured average wind speed was measured at the Turku station, which is located in the archipelago where it is wider than 70 km. In Karlskrona there are only a few islands before the open sea (Figure 10). Significant negative correlation between average wind speed and distance from the open sea was detected ($r = -0.56$; $n = 14$; $p = 0.039$).

Figure 9. Average wind speeds at sheltered ($n = 11$) and open stations ($n = 16$) from 1 May to 31 October in the years 2010-2017.

Figure 10. Average wind speed (m/s) in relation to distance from the open sea.

In the Excel Tool Baltic scenario, the wind speed value is 3.8 m/s. This is an average value from Finnish (4 m/s) and Swedish (3.6 m/s) national AF scenarios, chosen to be used in the MAM-PEC workshop. Both values are determined for marinas situated in sheltered areas in the archipelago, based on single weather station measurements. The value used in the scenario is rather higher than the average wind speed of sheltered stations (3.5 m/s), but remarkably lower than at open stations (5.5 m/s). Consequently, it can be assumed that 3.8 m/s is sufficiently representative for sheltered marinas, and changes are not recommended. However, it could be considered to use a wind speed of 5.5 m/s for non-sheltered marinas in the Baltic regional scenario.

2.3. Flow velocity

According to the information received from FMI, average flow velocities at the stations were 1.6-7.4 cm/s (SD = 1.8-5.4) (Pekka Alenius, personal comm. 2018). Similar results have also been reported in other studies in the Archipelago Sea area (Suominen 2003). Flow velocity is a very site-specific parameter, which is affected by several factors e.g. flow direction, wind speed, river flows, seafloor topography and stratification. All measurements have been made in the archipelago area and flow velocities in open coastal or estuary areas might be very different. Based on available information it is not possible to determine typical flow velocities for different types of marinas in the Excel Tool Baltic.

In the Excel Tool Baltic scenario, the flow velocity value is 2.9 cm/s. This is an average value from the Finnish (1 cm/s) and Swedish (4.8 cm/s) national AF scenarios, chosen to be used in the MAM-PEC workshop. Based on measurements made in the Archipelago Sea, it can be assumed that 2.9 m/s is sufficiently representative, and changes are not recommended.

2.4. Temperature

The average water temperature during the boating season from 1 May to 31 October was 13.9 °C (SD = 3.7; n = 101666). The average monthly water temperatures were about 1 °C lower in the northernmost station (Forsmark) than in the southernmost station (Kungsholmsfort) (Figure 11).

In the Excel Tool Baltic scenario, a marina-specific water temperature value based on the Newcastle report (Thomason & Prowse 2013) is used. Annual average temperatures varied in the Excel tool marinas from 8.5 to 16.25 °C, but in most marinas the temperature was below 12 °C. These values were collected from marine weather websites and reports from environmental research websites. No actual measurements in marinas were made, and in some cases the data was collected in open sea areas.

Based on the data above it seems that the water temperature could be higher in most marinas, to reflect better the situation during the boating season when emissions are highest in marinas. It was assumed that monitoring data collected in coastal areas and average values based on the season from 1 May to 31 October will represent better the situation in marinas. Therefore, a water temperature value of 14 °C can be proposed to be used in all marinas in the Baltic regional scenario.

Figure 11. Average water temperature at 3 measurement stations in the Baltic Sea in the years 2010-2017.

2.5. Suspended particulate matter (SPM)

SPM values were lower in non-estuary than estuary areas in Finland. The average SPM concentration in non-estuary areas was 8.7 mg/l (SD = 4.2; n = 11) and in estuary areas 15.9 mg/l (SD = 13.1; n = 13) (Figure 12). However, no statistically significant difference between the areas was detected. The comparison was made using the independent-samples t-test ($t(14) = -1.9$; $p = 0.08$).

High variation in SPM concentrations was detected. The lowest average concentration of 4.0 mg/l (SD = 3.4; n = 154) was detected in a non-estuary area in Rauma (avg. 4.0 mg/l) and the highest, 57.5 mg/l (SD = 58.6; n = 98), in an estuary area in Salo. Municipality level results are shown in Appendix 4 and Appendix 5.

Figure 12. Average SPM concentration in municipalities in a non-estuary area (n = 11) and an estuary area (n = 13). Measurements were made in coastal areas during the years 2010-2017.

A strong negative relationship between Secchi depth and concentration of SPM was detected (Håkanson 2006). As long as no measured data is available, Secchi depth data could be used to estimate differences in SPM concentration. The average Secchi depth of 2.6 m (SD = 1.3; n = 11) in coastal areas of Sweden was significantly higher than the average value of 1.8 m (SD = 0.8; n = 10) in coastal areas of Finland. The comparison was made using the independent-samples t-test ($t(23) = 2.4$; $p = 0.03$). It also seems that Secchi depths in Lithuania, Latvia and Estonia are higher than in Finland (Fleming-Lehtinen et al. 2010). Based on the difference in Secchi depth values between coastal waters of Finland and Sweden, it is assumed that the concentration of SPM is lower in the Swedish coastal area than in Finland. It is reasonable to assume that SPM data from Finland will represent the worst case condition in the Baltic Sea. As long as measured data from Sweden is not available, SPM data from Finland must be used, although this might overestimate SPM concentrations in Sweden and other countries in the Baltic Sea.

In the Excel Tool Baltic scenario, the SPM concentration is 35 mg/l. This is the default value used in the OECD EU Marina scenario. No site-specific value for the Baltic Sea area is used. Ambrosson (2008) also noted that concentrations as high as 35 mg/l are rarely detected in the Baltic Sea area. Based on the data above, the SPM value in the Excel Tool Baltic scenario could be lower. Therefore, an SPM concentration of 16 mg/l in estuary and 9 mg/l in non-estuary marinas can be proposed to be used in the Baltic regional scenario.

2.6. Particulate organic carbon (POC)

In Finland the average TOC concentration was 6.6 mg/l (SD = 1.7; n = 8) in non-estuary areas and 11.1 mg/l (SD = 6.3; n = 10) in estuary areas (Figure 13). In Sweden no difference between estuary and non-estuary areas was detected, and therefore all data were analysed together. In Sweden the average concentration of TOC was 5.1 mg/l (SD = 0.6; n = 15) (Figure 13). Variation between sampling stations was higher in Finland than in Sweden. Municipality level results are shown in Appendix 6, Appendix 7 and Appendix 8.

In Finland there are three municipalities, i.e. Kristiinankaupunki, Maalahti and Vöyri, where estuary TOC concentrations are significantly higher than in other municipalities (Appendix 6). These municipalities are situated in the catchment areas of three rivers (Teuvanajoki in Kristiinankaupunki, Maalahdenjoki in Maalahti and Kyrönjoki in Vöyri), which flow through an area containing many ditched bogs. The very coloured water (200-500 mgPt/l) in the rivers indicates the high amount of humus, which increased the concentration of TOC. These three areas can be categorized as special cases and can therefore be excluded. If these three municipalities are excluded from the calculation, the average concentration is 7.2 mg/l (SD = 1.7; n = 7) and no significant difference was detected between estuary and non-estuary stations in Finland either.

Figure 13. Average TOC concentration in municipalities in non-estuary areas ($n = 8$) and in estuary areas ($n = 10$) in Finland and in municipalities in Sweden ($n = 13$). Measurements were made in coastal areas in the years 2010-2017.

In the Excel Tool Baltic scenario, POC concentration is 1 mg/l and DOC concentration 5.4 mg/l. The sum of POC and DOC is 6.4 mg/l, which corresponds well to TOC concentrations in the coastal areas of Finland but is rather higher than the average concentration along the coast of Sweden. The concentration of POC in Maalahti and Vöyri varied from 0.6 to 1.3 mg/l. It seems that the POC concentration of 1 mg/l used in the Excel Tool Baltic is probably sufficiently representative, and no changes are proposed.

2.7. Net sedimentation velocity

In the Excel Tool Baltic scenario net sedimentation velocity is 0.5 m/d. With an SPM concentration of 9 mg/l the net sedimentation velocity 0.5 m/d corresponds to a sediment accumulation rate of 1640 g/m²/a, and with an SPM concentration of 16 mg/l the corresponding accumulation rate is 2920 g/m²/a. Accumulation rates were calculated using the formula (van Hattum et al. 2016):

$$M = v_{sn} * AS_s$$

V_{sn} = net sedimentation velocity (m d⁻¹)

M = mass of accumulated sediment per day (g d⁻¹)

A = accumulation area (m²)

S_s = Average concentration of suspended matter (g m⁻³)

Marinas are situated in shallow areas, where erosion and transportation of sediment are typically high. The main factors regulating sediment resuspension in shallow coastal are waves and currents (Sanford and Maa 2001; Ziervogel and Bohling 2003; Jönsson 2005; Danielsson et al. 2007; Green and Coco 2014). Seiches, animal activity or turbulence caused by boats can also cause sediment resuspension. If marinas are not protected by breakwaters, waves and currents will transport SPM out of marinas and only slight or negligible sedimentation may be detected. Higher net sedimentation velocity could be assumed in marinas protected by breakwaters. The net sedimentation velocity depends on how

sheltered the marinas are, and a higher net sedimentation rate could be assumed in marinas protected by breakwaters.

According to Mattila et. al. (2006), sediment accumulation rate varies between 90 and 6160 g/m²/a in the Baltic Sea area. The highest average sedimentation rate of 1200 g/m²/a was detected in the Bothnia Sea and the lowest in the Baltic Proper, where it was 180 g/m²/a. Accumulation rates in the Gulf of Finland vary between 110 and 6160 g/m²/a (Mattila et. al. 2006) or between 100 and 3000 g/m²/a (Kankaanpää et. al.1997). Highest accumulation rates were detected in front of the river Kymijoki. However, these measurements are made in the deep sea water area, where sediment accumulation is high and consequently does not directly represent conditions in shallow marinas. It seems that calculated sediment accumulation rates of 1640 or 2920 g/m²/d can be considered representative for deep sea areas. However, marinas are situated in shallow coastal areas which are typically classified as erosion or transportation basins, where sedimentation is negligible. Therefore, a lower net sedimentation velocity than 0.5 m/d could be considered in the Excel Tool Baltic scenario. Monitoring data from marinas is not available, and it is not possible to determine an accurate value for net sedimentation velocity. However, the net sedimentation velocity of 0.1 m/d from the EU fish farming scenario could be used. This value corresponds to a sediment accumulation rate of 330 g/m²/a with an SPM concentration of 9 mg/l and to 580 g/m²/a with an SPM concentration of 16 mg/l. These values are probably more realistic for marinas with high resuspension.

3. Impact of proposed parameter changes on PECs

In order to analyse the impact of proposed changes, PECs were modelled in Hasle marina (DK15) and Åminne marina (FI5). These marinas represent different type of marinas (sheltered vs. non-sheltered and estuary vs. non-estuary). Analyses were made with copper and dichlofluanid. The impacts on PECs in these two marinas are indicative. In the Excel Tool Baltic scenario there are, however, 38 marinas and the impacts are different in each of them.

Results are shown with and without a change in net sedimentation velocity. Net sedimentation velocity is one of the key parameters in MAMPEC, and has a remarkable impact on PECs. However, no accurate value could be determined and therefore comparisons were made with and without a change in net sedimentation velocity.

3.1. Non-estuary and non-sheltered marina (Hasle marina, Excel Tool marina DK15)

The original key parameters in the Excel Tool Baltic and proposed values for a non-estuary and non-sheltered marina are presented in Table 2.

Table 2. Value of changed parameters in the Hasle marina in the Excel Tool.

	Original	Changed value	Unit
Non-tidal water level change	0.073	0.098	m
SPM concentration	35	9	mg/l
Temperature	11	14	C
Net sedimentation velocity	0.5	0.1	m/d
Average wind speed	3.8	5.5	m/s

If all parameters are changed the PEC of copper will be 4.5 times higher in the water column, i.e. the average copper concentration increases from 1.8 to 8.1 µg/l (Figure 14). PECs in sediment (SPM)

will increase in the same proportion from 240 to 1100 $\mu\text{g/g dw}$. If all other parameters but not the net sedimentation velocity are changed, PEC in water will increase from 1.8 to 5.3 $\mu\text{g/l}$ and in sediment (SPM) from 240 to 700 $\mu\text{g/g dw}$. It is clear that the proposed changes will produce higher PECs with copper.

Temperature has negligible impact on copper concentration, but may have a remarkable impact on organic active substances. With dichlofluanid, the PEC in water will decrease by 20 % from 0.63 to 0.57 $\mu\text{g/l}$ when all the proposed changes are made. In sediment (SPM), PEC will be 3 times higher, increasing from 0.024 to 0.078 $\mu\text{g/g dw}$, if all the changes are made. The impact of change in net sedimentation velocity is negligible (Figure 15).

Figure 14. PECs of copper in water and in sediment in the Hasle Marina (Excel Tool marina DK15), modelled by the Excel Tool Baltic scenario with the proposed more accurate key parameter values.

Figure 15. PECs of dichlofluanid in water and in sediment in the Hasle Marina (Excel Tool marina DK15), modelled by the Excel Tool Baltic scenario with the proposed more accurate key parameter values.

3.2. Estuary and sheltered marina (Åminne marina, Excel Tool marina FI15)

The original key parameters in the Excel Tool Baltic and proposed values for an estuary and sheltered marina are presented in Table 3.

Table 3. Value of changed parameters in the Åminne marina in the Excel Tool.

	Original	Changed value	Unit
Non-tidal water level change	0.073	0.098	m
SPM concentration	35	16	mg/l
Temperature	9.5	14	C
Net sedimentation velocity	0.5	0.1	m/d

If all parameters are changed the PEC of copper will be 3 times higher in the water column, i.e. the average copper concentration increases from 1.4 to 4.4 $\mu\text{g/l}$ (Figure 16). PECs in sediment (SPM) will increase in the same proportion from 180 to 350 $\mu\text{g/g dw}$. If all other parameters but not the net sedimentation velocity are changed, the PEC in water will increase from 1.4 to 2.6 $\mu\text{g/l}$ and in sediment (SPM) from 180 to 350 $\mu\text{g/g dw}$. It is clear that the proposed changes will produce higher PECs with copper.

Temperature has negligible impact on copper concentration but may have a remarkable impact on organic active substances. With dichlofluanid, the PEC in water will decrease by 28 % from 0.18 to 0.13 $\mu\text{g/l}$ when all proposed changes are made. In sediment (SPM), PEC will be 60 % higher, increasing from 0.0069 to 0.011 $\mu\text{g/g dw}$, if all changes are made. The impact of change in net sedimentation velocity is negligible (Figure 17).

Figure 16. PECs of copper in water and sediment in the Åminne marina (Excel Tool marina FI15), modelled using the Excel Tool Baltic scenario and the proposed more accurate key parameter values

Figure 17. PECs of dichlofluanid in water and sediment in the Āminne marina (Excel Tool marina FI5), modelled using the Excel Tool Baltic scenario and the proposed more accurate key parameter values

4. Conclusion

Marinas are situated in different areas and environmental conditions vary between marinas. Thus, it is not possible to determine one single key parameter value which would be representative for all marinas. In order to determine more accurate key parameter values, marinas should be divided into groups, i.e. estuary vs. non-estuary and sheltered vs. non-sheltered marinas. Thereafter, specific key parameter values should be determined for each different group of marinas. Based on monitoring and modelled data from the Baltic Sea area, some key parameter values used in Excel Tool Baltic scenario appear not to be sufficiently accurate and representative for marinas in the Baltic Sea.

The non-tidal water level change of 7.6 cm/d in the Excel Tool Baltic seems to be too low, and therefore 9.7 cm/d could be considered for use in the scenario. Higher non-tidal water level change values will increase the total water exchange in the marinas, which will decrease PECs in the marinas.

The SPM concentration of 35 mg/l used in the Excel Tool Baltic is not representative for the Baltic Sea. Only in one estuary measurement station was the average SPM concentration higher than 35 mg/l. Usually the concentrations were much lower. It could be considered to use an SPM concentration of 16 mg/l in estuary and 9 mg/l in non-estuary marinas. The use of lower SPM concentrations will significantly increase copper PECs in marinas.

Taking into account the fact that the marinas are located in a shallow coastal area where resuspension is high, the net sedimentation velocity of 0.5 m/d might be too high. Lower net sedimentation velocity could be used. Net sedimentation velocity is a very important key parameter in the scenario. However, insufficient data is available about sedimentation in marinas, and more information about sedimentation is needed in order to determine more representative values for the scenario.

Taking into account the fact that boats are mainly in marinas from May to October, the Excel Tool Baltic default temperatures seem to be too low, and they could underestimate the degradation of organic substances. Therefore, it could be considered to use a mean water temperature of 14 °C to better reflect the conditions during the boating season from 1 May to 31 October.

The Excel Tool Baltic average wind speed of 3.8 m/s seems to be sufficiently representative for sheltered marinas. However, it might be too low for non-sheltered marinas. Therefore, it could be considered to use an average wind speed of 5.5 m/s for non-sheltered marinas in the Excel Tool Baltic scenario.

If the proposed environmental parameters are used in modelling, PECs will be higher. It is important to examine the Excel Tool Baltic scenario as a whole and not only certain input parameters separately. The model is quite complex and other input parameters should also be considered, such as the wetted surface area of boats and background concentrations. For example an average wetted surface area of 27.5 m² is used in the Excel Tool Baltic scenario. This value is remarkably higher than the value of 19.75 m² used in the Swedish national scenario (Ambrosson 2008) and 22 m² used in the Finnish national scenario (Hanninen 2017). It is probable that in the Baltic Sea area the average wetted surface area of boats is smaller than 27.5 m². Inaccuracy in other parameters may distort the results of modelling. It is possible that no more accurate results are achieved even if more representative environmental parameters are used.

In order to justify the proposed changes, results of modelling should be compared to monitoring data from marinas. Monitoring data is available only from the Bullandö marina (Baltic marina 33, SE 9). However, the Excel Tool Baltic scenario includes of 38 marinas, and no reliable conclusion can be made based on monitoring data from a single marina only. Therefore, it would be very important to obtain more monitoring data from other marinas.

Part IB: Determination of the values of key parameters for the Baltic sea transition scenario

1. Material and methods

Data is mainly collected from open databases. The Swedish Meteorological and Hydrological Institute (SMHI) provides physical measurement data about water level, flow velocity, sea water temperature and wind speed. All data is available for download from the websites of the institute.

The Swedish Ocean Archive database (SHARK) also provides physical and chemical environmental monitoring data from Sweden. The data were collected by several institutes and non-governmental organisations. The SHARK database is maintained by SMHI. Data is available for downloading from the websites of the institutes.

The databases contain a lot of data, but only a part of it can be considered as representative. Marinas in the Excel Tool Baltic transition scenario are situated in shallow coastal areas, where e.g. the impact of resuspension and primary production might be different from that in open sea areas. Therefore, data collected from shallow coastal areas was used. More specific criteria are mentioned in the parameter discussion paragraphs

Temporal variation is assumed for all key parameters discussed in this document. It was assumed that the length of the boating season is about 6 months, from May 1 to October 31. In order to obtain more realistic values for exposure scenarios, all parameters were determined to correspond to the situation between May and October, when boats are in the marinas. Data later than October or earlier than May was not taken into account.

In cases of no or limited raw data availability about parameters, scientific publications and experts' personal comments were used. All statistical analyses were made using Excel (Microsoft Excel 2016).

Environmental conditions vary considerably between marinas and it is not possible to determine one key parameter value which would be representative for all marinas. It would be ideal to use marina-specific values. However, it is difficult to determine specific values for each marina, because monitoring data from marinas is not available and regional coverage of available data is usually poor. It was assumed that the most important factors affecting environmental parameters are how open the location of the marina is, and whether they are located in estuary or non-estuary areas. Therefore, marinas in the Excel Tool Transition scenario were divided into sheltered or non-sheltered marinas and estuary or non-estuary marinas. The division was based on aerial photographs. Sheltered marinas were surrounded by islands or situated in small bays, whereas non-sheltered marinas were situated along the seashore where there were no islands (Figure 18). Non-estuary marinas were situated in areas where significant impact of rivers is not assumed. In the Excel Tool Transition scenario there are 17 marinas, which are mainly located in non-sheltered and non-estuary locations (Table 14). In order to take into account the differences between different marinas, it was aimed to determine the values of parameters for each type of marinas. General values were used if no marina type-specific values could be determined.

Table 14. Type of location of marinas from the Baltic transition scenario.

Marina	Type of location		Marina	Type of location	
DE 10	Non-Sheltered	Non-Estuary	DK 11	Sheltered	Non-Estuary
DE 11	Non-Sheltered	Non-Estuary	DK 2	Non-Sheltered	Non-Estuary
DE 2	Non-Sheltered	Non-Estuary	DK 3	Non-Sheltered	Non-Estuary
DE 3	Sheltered	Non-Estuary	DK 4	Non-Sheltered	Non-Estuary
DE 6	Sheltered	Non-Estuary	DK 5	Non-Sheltered	Non-Estuary
DE 7	Non-Sheltered	Non-Estuary	DK 9	Non-Sheltered	Non-Estuary
DE 9	Non-Sheltered	Non-Estuary	SE 15	Sheltered	Non-Estuary
DK 1	Sheltered	Non-Estuary	SE 3	Non-Sheltered	Non-Estuary
DK 10	Non-Sheltered	Non-Estuary

Figure 18. Examples of different types of marinas. A: Estuary marina (FI 5), B: Sheltered marina (FI 7) and C: non-sheltered marina (DK 5)

1.1. Tidal difference (Daily water level change)

Daily water level change was determined using water level data provided by SMHI and the Federal Maritime and Hydrographic Agency of Germany. Data from 11 tide gauges was used, located in different parts of the coast of Sweden (Figure 19). Data from the years 2000-2017 was used. Water levels were measured once per hour, and so the regional and temporal coverage of data is good. The daily water level change was determined by calculating the difference between the daily maximum and minimum values of water level.

Daily water level change includes the of impacts of tides and non-tidal water level changes. Based on water level data, semi-diurnal tides can be detected and the impact of tides is dominant. However, it is not possible to identify the absolute height of tides or the impact of non-tidal water level change from the data. For simplicity, daily water level change was used to represent tidal difference and it was assumed that the non-tidal daily water level change was 0 cm.

Figure 19. The location of tide gauges.

1.2. Wind speed

Wind speed was determined based on data provided by SMHI. Data from 9 weather stations situated in different parts of the coast of Sweden was used (Figure 20). Data was collected between the years 2000 and 2017 and from the Helsingborg and Glommen stations the data was collected between 1985 and 1995. Measurements have been continuous and wind speeds are reported at average speeds over one hour to three hours. Totally, the data contains 437 000 measurements.

The location of all the stations was checked from aerial photographs. Stations were classified as open coastal, open sea and archipelago stations. Archipelago stations located in the inner archipelago were surrounded by islands. Open coastal stations were on the seashore where there were no islands. Open sea stations were located in the outer islets or small islands near the open sea area.

Figure 20. *The location of weather stations.*

1.3. Flow velocity

Current data from the SHARK database was used. All available data are from Sweden between the years 2000 and 2017. Totally, data from 29 sampling stations situated in the coastal area were chosen (Figure 21). It was assumed that flow velocity could be higher in the open coastal area than in the archipelago area. The location of all stations was checked from aerial photographs, and stations were divided into open coastal and archipelago stations based on their location. Stations located in the same municipality were grouped together and certain statistics were calculated for each municipality. Only municipalities with at least 10 samples were taken into account.

Long-term monitoring data from 4 sampling stations was provided by SMI. The data are from the years 1940 to 2004. One sampling station was situated in the archipelago area and the others were situated in the open coastal area.

Figure 21. The location of flow velocity measurements from the SHARK data base (red dots) and from SMHI (green dots).

1.4. Temperature

Water temperature was determined using water temperature data provided by SMHI. Data from 2 measurement stations located along the coast of Sweden was used. All stations were located near the coastline in the inner archipelago. The data collected between the years 2010 and 2017 was chosen, and water temperatures were measured every hour. Temporal coverage of the data is good. Average temperatures for each month and average temperatures for the whole boating season from 1 May to 31 October were calculated.

1.5. Suspended particulate matter (SPM)

Data on SPM is not available in the Baltic transition area. However, a strong negative relationship between Secchi depth and concentration of SPM has been detected (Håkanson 2006). If the impact of salinity is taken into account, Secchi depth data could be used to estimate a difference in SPM concentrations between Sweden and Finland. Secchi depth data from the SHARK and HERTTA databases was used. All analysed data from Sweden are between the years 2010 and 2017. In total, data from 72 sampling stations situated in shallow coastal waters was taken into account. Only data from stations where the water depth is less than 6 m was used (Figure 22). In total, the data contains 637 measurements from the Baltic Transition area. The data from Finland is from the same stations where SPM concentrations were measured between the years 2010 and 2017 (Part IA). Data from a total of 18 stations from Finland was analysed. All stations from Finland and Sweden were situated in non-estuary coastal areas. Stations located in the same municipality were grouped together and certain statistics were calculated for definition of the municipality level. Only municipalities with at least 10 samples were taken into account.

Figure 22. The location of Secchi Depth measurements.

1.6. Particulate organic carbon (POC)

Water quality data from SHARK was used. All available data between the years 2000 and 2017 was analysed from databases, but only sampling stations where the water depth is less than 15 m and distance from the coast is less than 2 km were chosen (Figure 23). POC (particulate organic carbon) is not a typical monitoring parameter, and so the available data was very limited. Therefore, data far from the coast was used. In total, data was available from 6 sampling stations.

Figure 23. The location of POC measurements.

1.7. Max. density difference tide

Density difference was determined based on data provided by SMHI. Surface salinity data from 5 sampling stations situated in different parts of the Baltic transition area was used (Figure 24). Data was collected between the years 1922 and 1965. Measurements have been made once per day.

Figure 24. The location of salinity measurements.

2. Results and Discussion

2.1. Tidal difference (Daily water level change)

Average daily water level change for all the stations was 25.5 cm/d (SD = 5.4; n = 9). Typical daily water level change varied from 15 to 38 cm/d (Figure 25), but high variation between stations was detected. The highest average daily water level change was detected at Stenungsund station (avg. 34.4 cm/d; SD = 9.8; n = 3312) and the lowest at the Klagshamn station (avg. 20.1 cm/d; SD = 10; n = 3312).

Figure 25. Daily water level change (difference between daily maximum and minimum water levels) in the years 2010-2017.

Daily water level change was higher in the northern part of the Kattegat, where the impact of tides from the Atlantic and the North Sea is stronger (Figure 26). However, no positive correlation between latitude and average daily water level change was detected ($r = 0.44$; $n = 11$; $p = 0.13$).

In the Excel Tool Baltic Transition scenario, tidal difference is 0.4 m. Based on the data above it seems that a tidal difference of 40 cm/day is too high. Most of the marinas in the Excel Tool Baltic Transition are situated in the southern part of the Baltic Transition area, where the tidal phenomenon is not as strong as in northern parts. Therefore, it could be justified to use a tidal difference of 0.24 m in the Baltic transition regional scenario, which would correspond to the average daily water level change of all the measurement stations.

Figure 26. Median daily water level change (cm/d) in relation to latitude.

2.2. Wind speed

The average wind speed in open coastal stations was 5.6 m/s ($SD = 0.8$; $n = 5$), which is the same as the average wind speed of open stations in the Baltic Sea (Part IA). The average wind speed of all stations was 5.8 m/s ($SD = 0.9$; $n = 9$) (Table 5).

In the Excel Tool Baltic Transition scenario the wind speed value is 6.5 m/s. This value comes from the Swedish national scenario and is based on an average wind speed from April to September at the Måseskär weather station. This station could be classified as an open sea station. However, most marinas in the Baltic transition scenario are situated in open coastal area and therefore the average wind speed in open coastal stations of 5.6 m/s is proposed to be used in the Baltic Transitions scenario.

Table 5. Wind measurement stations and measured wind speeds from May to October.

Municipality	Wind speed (m/s)			n	Type of station
	Median	Mean	SD		
Barkåkra	4.0	4.2	2.6	74486	Open coastal
Falsterbo	6.0	6.1	3.1	33037	Open coastal
Glommen	6.0	6.4	3.6	17961	Open coastal
Hallands Väderö A	5.3	5.9	3.2	101930	Open coastal
Helsingborg	5.2	5.5	3.1	31226	Open coastal
Ljungkile	5	4.7	3.8	16599	Archipelago
Nordkoster A	5.2	5.5	2.8	78952	Open sea
Vinga A	6.3	6.7	3.4	47799	Open sea
Väderöarna A	6.7	7.2	3.8	75687	Open sea
Average*	5.5	5.8			

* Value based on average values of each station (n = 9)

2.3. Flow velocity

Based on data from SHARK the average flow velocity of 15 cm/s (SD = 7; n = 15) in an open coastal area (Figure 27) was significantly higher than the flow velocity of 8 cm/s in the archipelago area (SD = 5.5; n = 15). The comparison was made using the independent-samples t-test ($t(23) = -2.9$; $p = 0.008$). Municipality level results are shown in Appendix 9 and Appendix 10. In many municipalities the numbers of samples are very low, which decreases the reliability of the results. However, remarkable differences between open coastal and archipelago areas could be seen in the current models provided by DMI (Danish Meteorological Institute) (Appendix 11).

Figure 27. Flow velocities in an open coastal area and an archipelago area from May to October in the years 2010-2017. Based on data from the SHARK database.

Long term data is provided by SMI (Table 6). The lowest measured average flow velocity of 3 cm/s (SD = 2; n = 348) was detected at the Dynekil Hydstn station, which is situated in a more sheltered spot in the archipelago than the other three stations. Other stations were in the open coastal area or in Öresund. In the open coastal area the average flow velocity was 21 cm/s (SD = 9; n = 2017) at the Svinbådan Fyrskepp station and 18 cm/s (SD = 10; n = 65500) at the Trubaduren boj station. The results are consistent with data from SHARK.

In Öresund (Oskarsgrundet boj), the average velocity was 32 cm/s (SD = 29; n = 57562). Higher flow velocities could be assumed in the straits, because a large amount of water passes through them. Probably the location of Oskarsgrundet boj is not highly representative for marinas in the Baltic transition scenario, because most of the marinas are not located in straits. However, higher flow velocities were not detected in Öresund in analyses based on data from SHARK, in which flow velocities were 9-17 cm/s (Malmö, Lomma, Vellinge from Appendix 9). The stations in Malmö, Lomma and Vellinge are situated closer to the coast, which may explain the difference.

Table 6. Measurement stations and flow velocities from May to October in the years 2010-2017.

Station	Flow velocity (cm/s)				No of samples	Type of stations
	Mean	SD	Min	Max		
DYNEKIL HYDSTN	3	2	0	21	348	Archipelago
OSKARSGRUNDET BOJ	32	29	1	200	57562	Open coastal
SVINBÅDAN FYRSKEPP	12	9	1	67	2017	Open coastal
TRUBADUREN BOJ	18	10	1	116	65500	Open coastal
Average*	16	12				

* Value based on average values of each station (n = 4)

In the Excel Tool Baltic Transition scenario the flow velocity value is 20 cm/s. It is not known where this value comes from. Usually the environmental key parameters in the Excel tool Baltic Transition scenario come from the Swedish national scenario. However, the flow velocity of 20 cm/s is remarkably higher than the value of 4.8 cm/s used in the Swedish national scenario. Based on the data above it seems that the value of 20 cm/s might be too high. Therefore, it could be considered to use a flow velocity of 15 cm/s for non-sheltered marinas in the Baltic transition scenario. A flow velocity of 15 cm/s is more realistic for marinas which are situated in open coastal areas, but it may be too high for sheltered marinas located in the inner archipelago or in sheltered bays. Therefore, it could be justified to use a flow velocity of 8 cm/s for sheltered marinas (Table 4) in the Baltic Transition scenario.

2.4. Temperature

The average water temperature during the boating season from 1 May to 31 October was 15.3 °C (SD = 3.2; n = 45683) (Figure 28).

In the Excel Tool Baltic Transition scenario, a marina-specific water temperature value based on the Newcastle report (Thomason & Prowse 2013) is used. Annual average water temperature varied from 10 to 13.5°C. Marina-specific surface temperatures were collected from marine weather websites and reports from environmental research websites. No actual measurements in marinas were made, and in some cases the data was collected in open sea areas. Temperatures used in the Excel Tool scenarios are annual average temperatures, which is one factor which may explain the lower temperature used in the Excel Tool Baltic transition scenario.

Based on the data above it seems that the water temperature could be higher in all the marinas, to reflect better the situation during the boating season when emissions are highest in the marinas. It was assumed that monitoring data collected in the coastal area and the average value based on the boating season from 1 May to 31 October would be more representative. Therefore, a water temperature value of 15 °C can be proposed to be used in all marinas in the Baltic regional scenario.

Figure 28. Average water temperature at 2 measurement stations in the Baltic transition area in the years 2010-2017.

2.5. Suspended particulate matter (SPM)

The average Secchi depth value of 3.9 m (SD = 1.3; n = 8) in the coastal area of the Baltic transition area and the area of the Skagerrak was significantly higher than the average value of 1.6 m (SD = 0.8; n = 10) in the coastal area of Finland (Figure 29). The comparison was made using the independent-samples t-test ($t(14) = 5.6$; $p = 0.001$). Municipality level results are shown in Appendix 12.

Most of the samples were collected in the archipelago area of the Skagerrak. Based on other studies, it seems that Secchi depth in the Danish straits may be even higher, and the Secchi depth in Finland is remarkably lower (Aarup 2002, Fleming-Lehtinen et al. 2010). Higher salinity will increase flocculation of particles, which increases the transparency of water (Figure 30). When the impact of salinity is taken into account, it is reasonable to assume that the SPM concentration was lower in the Baltic transition area than in the coastal area of Finland. Comparing the measured average Secchi depth of 3.9 m to the results of Håkanson (2006), the Secchi depth corresponds to an SPM concentration of 7.5 mg/l.

Figure 29. Secchi depth in the areas of municipalities in the Baltic transition ($n = 8$), in Finland ($n = 10$) and on the east coast of Sweden ($n = 11$). Measurements were made in coastal areas in the years 2000-2017. Water depths at the measurement stations were less than 6m.

Figure 30. Relationship between Secchi depth, SPM in surface water and salinity (PSU) (Håkanson 2006)

In the Excel Tool Baltic Transition scenario, SPM concentration is 35 mg/l. This is the default value used in the OECD EU Marina scenario. No site-specific value for the Baltic Sea transition area is used. Ambrosson (2008) also noted that concentrations as high as 35 mg/l are rarely detected in the Baltic sea area, and therefore the value of 10 mg/l is used in Swedish national scenario. Based on the analyses above, it is reasonable to assume that the SPM concentration is lower in the Baltic Sea transition area than in the coastal area of Finland. Therefore, it was assumed that an SPM concentration of 35 mg/l is not representative for non-estuary marinas in the Baltic transition area

either. As long as no monitoring data from the Baltic transition area is available, an SPM concentration of 7.5 mg/l could be used in the Baltic transition scenario.

2.6. Particulate organic carbon (POC)

The lowest average concentration of POC of 0.2 mg/l (SD = 0.07; n = 14) was detected in the area of the Kattegat and the highest average concentration of 0.4 mg/l (SD = 0.3; n = 148) in the area of Öresund (Figure 31). The average concentration of all stations was 0.3 mg/l (SD = 0.04; n = 6).

In the Excel Tool Baltic Transition scenario, POC concentration is 1 mg/l. This is the default value and no site-specific values are used in the scenario. Based on the data above it seems that the value could be lower. Regional coverage of measurements is very weak, and only the area of Öresund is well represented. It is not possible to make a reliable generalization on the basis of the data above. However, until more data is available a POC concentration of 0.3 mg/l can be proposed to be used in the Baltic Transition regional scenario.

Figure 31. POC concentration in measurement stations in the areas of Öresund (ÖVF 1:1, n = 152; ÖVF 4:11, n = 148; ÖVF 3:2, n = 150; ÖVF 4:8, n = 152 and ÖVF 5:2, n = 151), and Kattegat (N5, n = 14)

2.7. Net sedimentation velocity

In part 1A it was considered that a net sedimentation velocity of 0.5 m/d in Excel Tool scenarios might be too high to represent the situation in coastal areas of the Baltic Sea. A stronger erosion and transportation phenomenon is assumed in the Baltic Transition area, where currents are stronger, water level change is higher and coastal areas are less sheltered. Therefore, it is reasonable to assume that a sedimentation velocity of 0.5 m/d is too high. As in part 1A, a net sedimentation velocity of 0.1 m/d could also be used in the Baltic transition regional scenario.

2.8. Max. density difference tide

The daily change in salinity was determined by calculating the difference between two consecutive days. The highest median change of salinity was detected at the Bornö hydstrn station (1.5 PSU/d) and the lowest at the Falsreborev station (0.2 PSU/d) (Table 31). High daily changes were detected in the north side of Öresund. In the south side, the daily changes were remarkably lower (Falsreborev station in Figure 13).

Figure 31. Measurement stations and flow velocities from May to October in the years 2010-2017.

The parameter of max. density difference of tide is designed for marinas which are situated in estuary areas or near the river mouth, where the salt concentration varies between low and high tides (van Hattum et al. 2016). Marinas in the Excel Tool Transition scenario are situated in non-estuary areas. Therefore, no tide-related concentration differences can be assumed. However, more salty water from the North Sea and less salty water from the Baltic Sea are mixing in the Baltic transition area, and salinity will therefore vary remarkably. The most important factor is the direction of flow. The variation is not regular, but the changes can take place very rapidly and may be remarkable (Figure 32). This variation should be taken into account when water exchange is considered for marinas.

Figure 32. Salinity in 4 measurement stations in the Baltic transition area.

Because the max. density difference tide is a tide-related parameter, the model assumes that the change of density occurs four times per day. The accuracy of available data is not sufficient for consideration of short-term changes. However, the changes are based mainly on flow direction, and it could be assumed that often a period of change may be longer than the tidal period of 12.41 h. Therefore the max. density difference tide is poorly adapted to reflecting salinity changes in the Baltic transition area.

In the Excel Tool Baltic Transition scenario the max. density difference tide value is 0.1 kg/m^3 . Based on the analysis above, the lowest median daily density difference was two times higher and the highest 15 times higher. It is unclear how these different parameters should be compared, although it seems that the value of max. density difference tide used in the Excel Tool Baltic Transition scenario could be higher. Max. density difference is a very site-specific factor. If more data from Germany and Denmark is used, it might be possible to determine more representative values for each marina based on marina location. Before that, it would be important to decide how the module should be used for the Baltic Sea transition area, where density changes are not linked to tidal phenomena.

3. Impact of proposed parameter changes on PECs

In order to analyse the impact of proposed changes, PECs were modelled in Jyllinge marina (DK11) and Skagen marina (DK10). These marinas represent different types of marinas (sheltered vs. non-sheltered). Analyses were made with copper and dichlofluanid. Impacts on PECs in these two marinas are indicative. In the Excel Tool Baltic Transition scenario there are, however, a total of 17 marinas and the impacts are different in each of them.

Results are shown with and without a change of net sedimentation velocity. Net sedimentation velocity is one of the key parameters in MAMPEC which has a remarkable impact on PECs. However, no accurate value could be determined and therefore comparisons are made with and without a change in net sedimentation velocity.

3.1. Sheltered marina (Jyllinge marina, Excel Tool marina DK11)

The original key parameters in the Excel Tool Baltic Transition and proposed values for a sheltered marina are presented in Table 6.

Table 6. Values of changed parameters in the Jyllinge marina in the Excel Tool

	Original	Changed value	Unit
Tidal difference	0.4	0.24	m
Max. Density difference tide	0.1	0.2	kg/m^3
Flow velocity	0.2	0.08	m/s
SPM concentration	35	7.5	mg/l
POC concentration	1	0.3	mg/l
Temperature	12.5	15	$^{\circ}\text{C}$
Net sedimentation velocity	0.5	0.1	m/d
Average wind speed	6.5	5.6	m/s

If all parameters are changed, the PEC of copper will be 7.5 times higher in the water column, i.e. the average copper concentration increases from 0.4 to 3.0 $\mu\text{g/l}$ (Figure 33). PECs in sediment (SPM) will increase in the same proportion from 54 to 400 $\mu\text{g/g dw}$. If all parameters other than the net sedimentation velocity are changed, PEC in water will increase from 0.4 to 1.6 $\mu\text{g/l}$ and in sediment (SPM) from 54 to 210 $\mu\text{g/g dw}$. It is clear that the proposed changes will produce higher PECs with copper.

Temperature has a negligible impact on copper concentration but may have a remarkable impact on organic active substances. With dichlofluanid the PEC in water will be 10 % lower, from 0.1 to 0.09 $\mu\text{g/l}$, when all the proposed changes are made. In sediment, (SPM) PEC will be 25 % higher, from 0.004 to 0.005 $\mu\text{g/g dw}$, if all the changes are made. The impact of the changes on net sedimentation velocity is negligible (Figure 34).

Figure 33. PECs of copper in water and in sediment in Jyllinge Marina (Excel Tool marina DK11) modelled by the Excel Tool Baltic Transition scenario with the proposed more accurate key parameter values.

Figure 34. *PECs of dichlofluanid in water and in sediment in Jyllinge Marina (Excel Tool marina DK11) modelled by the Excel Tool Baltic Transition scenario with the proposed more accurate key parameter values.*

3.2. Non-sheltered marina (Skagen marina, Excel Tool marina DK10)

The original key parameters in the Excel Tool Baltic Transition and proposed values for a non-sheltered marina are presented in Table 7.

Table 7. *Values of altered parameters in the Skagen marina in the Excel Tool*

	Original	Changed value	Unit
Tidal difference	0.4	0.24	m
Max. Density difference tide	0.1	0.2	kg/m ³
Flow velocity	0.2	0.15	m/s
SPM concentration	35	7.5	mg/l
POC concentration	1	0.3	mg/l
Temperature	11.25	15	°C
Net sedimentation velocity	0.5	0.1	m/d
Average wind speed	6.5	5.6	m/s

If all parameters are changed, the PEC of copper will be 2 times higher in the water column, i.e. the average copper concentration increases from 0.15 to 0.30 µg/l (Figure 35). PECs in sediment (SPM) will increase in the same proportion from 20 to 40 µg/g dw. If all other parameters other than the net sedimentation velocity are changed, PEC in water will increase from 0.15 to 0.29 µg/l and in sediment (SPM) from 240 to 700 µg/g dw. It is clear that the proposed changes will produce higher PECs with copper.

Temperature has a negligible impact on copper concentration but may have a remarkable impact on organic active substances. With dichlofluanid the PEC in water will be 17 % lower, from 0.043 to 0.036 µg/l, when all the proposed changes are made. In sediment, (SPM) PEC will be 6 % lower, from 0.0017 to 0.0016 µg/g dw, if all the changes are made. The impact of the changes on net sedimentation velocity is negligible (Figure 36).

Figure 35. PECs of copper in water and in sediment in Skagen Marina (Excel Tool marina DK10) modelled by the Excel Tool Baltic Transition scenario with the proposed more accurate key parameter values.

Figure 36. PECs of dichlofluanid in water and in sediment in Skagen Marina (Excel Tool marina DK10) modelled by the Excel Tool Baltic Transition scenario with the proposed more accurate key parameter values.

4. Conclusion

The marinas are situated in different areas, and environmental conditions vary between marinas. Thus, it is not possible to determine one single key parameter value which would be representative for all marinas. In order to determine more accurate key parameter values, the marinas should be divided into groups, i.e. estuary vs. non-estuary and sheltered vs. non-sheltered marinas. Thereafter, specific key parameter values should be determined for the different groups of marinas. Based on monitoring and modelled data from the Baltic Transition area, some key parameter values used in the Excel Tool Baltic Transition scenario appear to be insufficiently accurate and representative for marinas in the Baltic Transition area.

A tidal difference of 40 cm/d in the scenario is too high. In the area where the marinas are situated the average difference between daily maximum and minimum water level is significantly lower than 40 cm. Therefore, it could be considered to use a tidal difference of 24 cm/d. Lower tidal difference will decrease the total water exchange in marina, which will increase PECs in the marina area.

A maximum density difference tide of 0.1 kg/m^3 is used in the scenario. The parameter in MAMPEC is linked to the tidal phenomenon and will represent rather poorly density changes based on the direction of currents. However, the daily changes in salinity are remarkable, which should be taken into account. High daily changes were detected, and it could be more realistic to use a higher density difference than 0.1 kg/m^3 . A higher maximum density difference tide will increase the total water exchange in the marina, which will decrease PECs in the marina area. However, more information is needed concerning how the daily maximum density difference should be used in the model.

A flow velocity of 0.2 m/s in the scenario seems to be too high, especially for marinas which are situated in sheltered areas. Therefore, it could be considered to use a flow velocity of 0.15 m/s for non-sheltered marinas and 0.08 m/s for sheltered marinas. Lower values of flow velocity will decrease the total water exchange in the marinas, which will increase PECs.

SPM concentration is an important key parameter but there is insufficient data of SPM available. However, based on water transparency data, it seems that the SPM concentration of 35 mg/l used in the Excel Tool Baltic Transition scenario is not representative, and the use of an SPM concentration of 7.5 mg/l could be considered, which would represent better the situation in the Baltic transition area. The use of a lower SPM concentration would significantly increase copper PECs in the marinas.

POC concentration is an important key parameter for a few organic substances only. The measured data of POC is limited and regional coverage is poor. However, it seems that the default POC concentration of 1 mg/l used in the Excel Tool Baltic Transition scenario might be too high, and that a lower concentration of POC could be used.

Taking into account the fact that boats are mainly in marinas from May to October, the Excel Tool Baltic Transition default water temperatures seem to be too low and could underestimate the degradation of organic substances. Therefore, it could be considered to use an average water temperature of 15 °C to reflect better the situation during the boating season from 1 May to 31 October.

Taking into account the fact that the marinas are located in a shallow coastal area where resuspension is high, the net sedimentation velocity of 0.5 m/d might be too high, and a lower net sedimentation velocity could be used. Net sedimentation velocity is a very important key parameter in the scenario. However, insufficient data is available about sedimentation in marinas and more information about sedimentation is needed in order to determine more representative values for the scenario.

The average wind speed of 6.5 m/s in the Excel Tool Baltic Transition scenario seems to be too high and it should be considered to use an average wind speed of 5.6 m/s, which corresponds to the average wind speed in non-sheltered coastal areas.

If the proposed environmental parameters are used in modelling, PECs will be higher. It is important to look at the scenario as a whole and not only at certain input parameters separately. The model is rather complex, and other input parameters should also be considered, such as wetted surface area of boats and background concentrations. Inaccuracy in these parameters may distort the results of modelling. It is possible that more accurate results would not be achieved even if more representative environmental parameters were used.

In order to justify the proposed changes, results of modelling should be compared to monitoring data from marinas. However, no monitoring data from marinas are available. Therefore, it would be very important to obtain such data.

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Appendix

Appendix 1. An example of how the stations were divided into estuary and non-estuary stations.
(Blue arrow = river flow direction)

Appendix 2. Sheltered wind measurement stations and measured wind speeds from 1 May to 31 October in the years 2010-2017 in the Baltic Sea.

Station	Wind speed (m/s)				n
	Mean	SD	Min	Max	
Berga Mo	2.9	1.9	0.0	14.0	33587
Helsinki Kumpula	4.2	1.9	0.0	14.4	85172
Karlskrona	4.9	3.0	0.0	22.0	34928
Kemiönsaari	3.1	2.1	0.0	13.6	134236
Porvoo Kilpilahti	4.3	2.1	0.0	13.8	24956
Skarpö A	3.5	1.9	0.0	14.4	30816
Sundsvalls Flygplats	2.9	2.0	0.0	16.0	35168
Turku	2.6	1.5	0.0	9.5	102301
Umeå Flygplats	3.0	2.0	0.0	14.0	34981
Vaasa	3.9	1.9	0.0	16.0	30344
Virolahti	2.7	1.8	0.0	11.4	35172

* Value is based on average values of each station (n = 11)

Appendix 3. Open wind measurement stations and measured wind speeds from 1 May to 31 October in the years 2010-2017.

Station	Wind speed (m/s)				n
	Average	SD	Min	Max	
Eggegrund A	5.1	2.7	0	20.9	33953
Hanö A	6.6	3.2	0	28.4	32801
Harstena A	4.0	2.0	0	14.4	29028
Helsinki Harmaja	5.5	2.9	0	18.3	30726
Järnäsclubb A	4.2	2.6	0	19.0	34633
Kemiönsaari Vänö	5.5	2.7	0	21.1	30871
Kotka Rankki	4.6	2.3	0	18.1	34135
Kumlinge kirkonkylä	4.6	2.3	0	20.6	35279
Kustavi Isokari	6.4	3.1	0	24.8	34934
Oskarham A	6.5	3.3	0	25.8	35181
Parainen Fagerholm	4.9	2.7	0	18.8	35062
Pori Tahkoluoto					
satama	6.0	3.2	0	20.1	35286
Porvoo Emäsalo	6.4	3.3	0	21.5	30768
Rauma Kylmäpihlaja	7.3	3.5	0	22.3	30590
Skillinge A	4.2	2.7	0	19.0	34616
Söderarm A	6.9	3.4	0	25.5	33998

* Value is based on average values of each station (n = 16)

Appendix 4. Estuary SPM concentrations from 1 May to 31 October in the years 2010-2017 in the Baltic sea.

Municipality	No. Of stations	No. of Samples	Concentration of SPM (mg/l)				
			Median	Mean	SD	Min	Max
Eurajoki	1	50	5.0	6.9	5.8	2.8	33.0
Inkoo	1	32	5.5	6.6	7.7	2.0	47.0
Kemiönsaari	1	24	10.5	11.4	3.4	6.7	19.0
Kristiinankaupunki	2	28	8.0	8.8	5.9	2.0	34.0
Loviisa	2	78	10.9	19.8	19.3	1.0	93.0
Maalahti	2	64	12.8	16.2	15.1	3.1	96.0
Mustasaari	1	48	12.5	13.0	5.5	3.5	32.0
Mynämäki	1	68	13.0	14.2	6.7	3.9	33.0
Pori	3	18	8.3	10.6	3.9	6	18
Salo	2	98	33.0	57.5	58.6	9.2	290.0
Sipoo	1	52	8.2	12.5	21.2	1.7	150.0
Vaasa	5	38	14.1	17.8	12.5	4.2	60.0
Vöyri	2	96	8.5	11.3	8.8	0.5	62.0
Average*			11.5	15.9			

* Value is based on average values of each municipality (n = 13).

Appendix 5. Non-estuary SPM concentrations from 1 May to 31 October in the years 2010-2017 in the Baltic Sea.

Municipality	No. Of stations	No. of Samples	Concentration of SPM (mg/l)				
			Median	Mean	SD	Min	Max
Espoo	2	55	12.0	12.8	4.3	5.2	27.0
Hanko	1	34	4.6	6.7	6.4	1.5	34.0
Helsinki	2	33	11.5	9.7	3.4	4.0	17.0
Kaskinen	2	146	5.8	6.7	3.9	1.0	23.0
Kemiönsaari	2	48	8.8	9.0	2.6	2.2	15.0
Kotka	1	19	10.0	14.4	12.7	3.8	58.0
Maalahti	2	34	7.5	7.1	2.8	2.8	14.0
Mynämäki	1	64	13.0	14.3	9.6	5.5	75.0
Rauma	4	154	3.0	4.0	3.5	1	19
Uusikaupunki	22	1372	4.8	5.7	4.3	1.0	60.0
Virolahti	1	48	4.9	5.4	2.9	0.5	13.0
Average*			7.8	8.7			

* Value is based on average values of each municipality (n = 11).

Appendix 6. Non-estuary TOC concentrations from 1 May to 31 October in the years 2010-2017 in Finland.

Municipality	No. Of stations	No. Of samples	Concentration of TOC (mg/l)				
			Median	mean	SD	Min	Max
Eurajoki	1	20	4.5	4.5	1.1		6.7
Maalahti	3	43	6.8	9.2	5.1	3.7	24.0
Mustasaari	2	38	7.2	7.7	1.9	5.9	18.0
Mynämäki	1	32	6.3	6.4	1.4	3.2	9.6
Naantali	1	34	5.8	5.9	1.2	3.7	10.0
Närpiö	2	35	6.2	7.2	2.0	4.3	17.0
Rauma	3	120	4.4	4.4	0.4	3.9	5.8
Virolahti	1	24	7.7	8.0	0.9	6.6	10.0
Average*			6.1	6.6			

* Value is based on average values of each municipality (n = 8).

Appendix 7. Estuary TOC concentrations from 1 May to 31 October in the years 2010-2017 in Finland.

Municipality	No. Of stations	No. Of samples	Concentration of TOC (mg/l)				
			Median	Mean	SD	Min	Max
Eurajoki	1	18	5.2	6.1	3.3	2.4	18.0
Inkoo	1	16	5.6	5.7	1.2	3.8	8.9
Kaarina	1	28	5.6	5.8	1.9	2.2	11.0
Kristiinankaupunki	1	29	19.0	19.1	7.1	6.6	33.0
Loviisa	2	52	8.9	9.2	3.2	4.2	20.0
Maalahti	1	64	19.0	20.7	9.3	7.6	46.0
Mynämäki	1	34	6.8	7.1	1.8	3.3	12.0
Salo	1	18	8.5	9.9	3.3	5.5	17.0
Sipoo	2	56	6.6	6.9	2.6	2.9	23.0
Vöyri	2	88	19.5	20.1	4.9	11.0	34.0
Average*			10.5	11.1			

* Value is based on average values of each municipality (n = 10).

Appendix 8. TOC concentrations from 1 May to 31 October in the years 2000-2017 in Sweden.

Municipality	No of stations	No of samples	Concentration of TOC (mg/l)				
			Median	Mean	SD	Min	Max
Borgholm	1	96	4.7	5.0	1.8	3.2	17.0
Hudiksvall	3	72	4.4	4.9	1.2	3.6	10.0
Kalmar	4	244	4.8	5.3	2.0	3.0	18.0
Karlshamn	2	25	4.6	4.5	0.6	3.7	5.9
Karlskrona	6	158	4.5	4.7	0.8	3.3	7.8
Mönsterås	7	489	5.4	5.4	1.8	2.9	18.0
Norrköping	4	223	5.8	5.8	1.5	3.9	21.0
Norrtälje	7	185	6.4	6.9	2.3	1.5	20.7
Oskarshamn	5	283	4.6	5.1	1.7	3.2	18.0
Ronneby	1	43	4.8	5.1	1.1	2.8	8.7
Sölvesborg	1	16	4.5	4.5	0.3	3.7	5.0
Umeå	7	225	5.5	5.0	2.2	2.3	19.0
Västervik	3	118	5.3	5.3	1.6	1.4	18
Average*			5.0	5.2			

* Value is based on average values of each municipality (n = 13).

Appendix 9. Flow velocities in open coastal areas from May to October in the years 2010-2017 in the Baltic transition area. Based on data from the SHARK database.

Municipality	Current velocity (cm/s)					No of stations	No of samples
	Median	Mean	SD	min	max		
Båstad	13	13	6	1	36	2	190
Falkenberg	12	14	8	9	38	1	12
Halmstad	17	20	13	0	85	2	98
Höganäs	12	16	11	0	50	1	164
Kungsbacka	21	23	12	5	77	1	95
Kävlinge	12	15	11	0	55	1	171
Lomma	8	11	11	0	84	2	286
Malmö	13	17	15	0	100	1	175
Skurup	8	9	6	1	20	1	24
Strömstad	25	29	24	0	102	1	59
Trelleborg	9	9	4	3	17	1	24
Varberg	21	29	17	0	75	1	94
Vellinge	8	9	5	1	22	1	55
Ängelholm	6	6	4	0	25	1	139
Öckerö	8	10	11	0	30	1	17
Average*	13	15	7				

* Value is based on average values of each municipality (n = 15)

Appendix 10. Flow velocities in the archipelago area from May to October in the years 2010-2017 in the Baltic transition area. Based on data from the SHARK database.

Municipality	Current velocity (cm/s)					No of stations	No of samples
	Median	Mean	SD	min	max		
Kungsbacka	10	12	6	3	36	2	182
Kungälv	5	10	15	0	51	1	22
Orust	0	5	10	0	25	1	11
Stenungsund	8	8	9	0	25	1	16
Uddevalla	0	5	12	0	50	2	25
Kaikki yhteensä	4	10	9	0	51	8	262
Average*	4	8	3				

* Value is based on average values of each municipality (n = 6)

Appendix 11. Modelled current velocities in the Baltic transition area.

Appendix 12. Secchi depths from 1 May to 31 October in the years 2010-2017 in the Baltic transition area.

Municipality	No. Of stations	No. of Samples	Secchi depth (m)			
			Average	SD	Min	Max
Göteborg	1	12	3.8	0.5	3.0	4.5
Kungälv	1	12	2.3	0.6	1.5	3.0
Lomma	2	110	3.9	1.3	2.8	6.0
Lysekil	4	74	3.8	1.5	1.5	6.0
Malmö	1	126	5.8	0.5	4.0	6.0
Orust	4	36	3.7	1.4	2.0	6.0
Strömstad	5	125	3.7	0.9	0.5	5.5
Tanum	4	138	4.4	1.1	2.0	6.0
Average*			3.9	1.0		

* Value is based on average values of each municipality (n = 8).

Part II: Fish farming in the Baltic area

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1. Introduction

The aim of this survey is to obtain an overview of the present state of fish farming in the Baltic Sea and to gather information about the size and type of fish farms as well as data on hydrological parameters of the Baltic Sea fish farms. In addition, the aim is to increase knowledge about suitability of the EU fish net emission scenario for the Baltic Sea region. The EU fish net emission scenario based on MAMPEC was published in 2015. The scenario was meant as a first tier approach for use during the biocide product authorisation stage. As stated in the scenario document it is obvious that some of the parameter values will vary greatly between the countries. Union authorisation is not foreseen for product type 21, but standard parameter values could be used for first tier exposure assessment of products if there is a lack of better suited regional values, and for first tier active substance evaluation. If there is knowledge within a specific country that the standard values do not represent the local conditions, the values could be adapted (in accordance with Article 37 of the BPR).

The Baltic Sea is a unique marine area and it was assumed that the input parameters used in the EU fish net scenario are not representative of the Baltic Sea area. One aim of this document is to provide information about fish farming in the Baltic Sea area. Based on the information gathered from Denmark, Sweden and Finland, three regional fish farm scenarios for the Baltic Sea region were developed. The scenarios were compared to the EU fish net scenario in order to obtain better knowledge about the EU fish net scenario.

2. Materials

Fish farming is classified as an activity with a risk of environmental pollution, and consequently fish farms in Finland, Denmark and Sweden need environmental permits. Environmental permits include environmental impact assessments of the farms, based primarily on nutrient load assessment. At least in Finnish fish farms, antifouling products used in the treatment of nets are not evaluated at all during environmental permit processes.

Environmental permits contain the main information about fish farms. This information, as well as information from fish farm registers and navigation charts, was used to evaluate typical location, depth of farming area, typical number of nets and net sizes. In many cases environmental permits were not publicly available. In these cases, farm data was determined on the basis of aerial photographs. Information about farming practice and type of nets was gathered from publications, national authorities and fish farming societies.

The outcome of the other Nordic antifouling sub-project (Part I), in which the aim was to check and determine the values of key parameters to be used in the EU Regional Baltic marina scenario, was also taken into account when considering hydrological parameters for the Baltic fish farms. Data from environmental databases was also used.

3. Fish farming in the Baltic

In Finland and Denmark, food fish production is about 12000 t/a (Denmark statistic 2018, Luke 2017). In Sweden the production is lower, i.e. 2400 t/a (Statistiska centralbyrån 2017) (Figure 1). Food fish production is the dominant activity, whereas juvenile fish production is focused mainly on inland farms. In all three countries most of the production consists of rainbow trout.

Figure 1. Annual food fish production in Denmark, Finland and Sweden (data from the year 2016).

Biofouling of fish nets will reduce waterflow through and oxygen levels in the cages and increase the disease risk in fish. Nets are treated with antifouling products in order to reduce fouling. When fish are taken out of nets, the nets are lifted out of the water and after washing, drying and repairing they are treated with antifouling products. Nets are typically treated every year or every second year (Irja Skytén-Suominen, Finlands Fiskodlarförbund rf, pers. comm.). Some farmers treat their nets themselves, but others use commercial treatment services.

Nets can also be cleaned with high pressure net cleaning systems in water during the season. It is not necessary to lift the nets out of the water. These systems are designed for large and depth nets and are therefore are not used in small farms in the Baltic Sea (Irja Skytén-Suominen, Finlands Fiskodlarförbund rf, pers. comm.).

In Denmark the main farming season is 7-9 months long, i.e. typically from April to October-November (Miljø- og Fødevareministeriet). In winter there is no fish farming activity and the nets are lifted out of the water. A detailed description of the production process of one fish farm in Denmark is presented below (Miljøministeriet 2014):

March: frames are installed

March / April: nets are installed

Mid April: fish are installed in the net cages

April - November: growth period

July / August: Nets are changed

November / December: the fish are removed

December: facilities (frames / nets) are removed

January - March: no production

Winter period: the networks are repaired and prepared on land.

In Finland the main farming season is shorter than in Denmark, i.e. 180 days long from May to October. It is assumed that the situation in Sweden is similar to that in Finland. In winter the water temperature is low, as is the growth of fish. Some fish are kept in the sea over the winter, but the number of nets and fish is lower in winter than in summer. In Finland there are specific winter storage places for fish and nets. Storage places are typically in bays and more sheltered sea areas. Thus, the highest active substance load is in summer, when the number of nets is highest. Based on this, the work and farm modelling is focused only on the farming season conditions in summer. Winter storage has not been considered, based on the assumption that the greatest risk occurs during the summer season.

3.1. Fish farms in Finland

According to Natural Resources Institute Finland (Luke 2017), in the year 2016 there were 50 fish farming companies and 106 fish farms in Finland. Most of the farms are situated in the Archipelago Sea. In the Åland Islands the production was 6700 t and in south-western Finland (also called Finland Proper) 4100 t in the year 2016 (Luke 2017). The production of these areas covers 90% of the total fish production in Finland. The average annual production of farms is 70 t/a in Finland Proper. Fish farms in the Åland Islands are typically larger than in Finland Proper. The average size of farms is 240 t/a in the Åland Islands.

Most of the fish farms in Finland are in the Archipelago Sea, which is a very fragmentary sea area. Farms are typically situated in the outer or middle part of the archipelago in quite open areas in straits or near islands (Figure 2). The average water depth in Finnish farms is 11 m (SD = 4; n = 41).

Figure 2. Fish farms in the Archipelago Sea in Finland.

3.2. Fish farms in Denmark

In Denmark there were 19 fish farms in 2016 and the average annual production was 654 t/a/farm (Denmark statistic 2018). Based on the CHR-register (Centrale HusdyrbrugsRegister) provided by Miljø- og Fødevareministeriet¹, the size of farms varies widely. There were two farms where annual

¹ https://chr.fvst.dk/chri/faces/frontpage?_adf.ctrl-state=c02h634h1_3

production was over 2200 t/a, but typical production was 150-800 t/a. The median production in Denmark was 380 t/a (Figure 3).

Figure 3. The annual fish production in 2016 in all 19 farms in Denmark. Data was provided by Miljø- og Fødevareministeriet (CHR-register).

In Denmark, fish farms are situated in the Great Belt and the Little Belt (Figure 4). These areas are less fragmented than the Archipelago Sea, and the typical location of farms is less sheltered than in Finland and Sweden. Based on the analyses of environmental permits and estimations from the topographic map, in Denmark the lowest water depth was 8 m and the highest was 26 m. The average water depth in fish farms in the area was 14 m (SD = 5; n = 17).

Figure 4. Location of 17 fish farms in Denmark.

3.3. Fish farms in Sweden

In the year 2016 there were 13 fish farms in Sweden and the average production was 170 t/a/farm (Statistiska centralbyrån 2017). The Swedish Board of Agriculture also delivered annual production data based on environmental permits of 12 fish farms. Based on this data the production capacity in farms varies considerably, with the lowest permitted annual production only 0.5 t/a and the highest 1800 t/a (Figure 5). Production capacity is based on the maximum permitted production mentioned in the environmental permits.

Figure 5. The maximum permitted annual fish production at 12 farms in Sweden based on the environmental permits.

Based on information from the aquaculture register, the farms are situated in the archipelago area (Figure 6). Farms are in straits or near islands and often at least one side is bordered by land or island. Water depths were estimated from navigation charts and the water depth in larger farms was over 20 m. However, most of the farms in Sweden are situated in areas where the water depth is 7-10 m.

Figure 6. Location of 13 fish farms in Sweden .

4. Building up regional fish farm scenarios

Regional fish farm scenarios were developed in the MAMPEC 3.1 open harbour module in order to simulate better the real environmental conditions in the Baltic Sea area fish farms. The aim is further to compare regional worst-case fish farm scenarios to the EU fish net scenario in order to generate better knowledge about the suitability of the EU fish net scenario for the Baltic Sea area. Three worst-case fish farm scenarios were developed which take into account local farming conditions in the Baltic Sea region.

4.1 Environmental parameters

The aim of this chapter is to identify environmental key parameters in the EU fish net scenario which are not representative for the Baltic Sea and Baltic transition area. More realistic values for these parameters were determined, which were used in regional fish farm scenarios. Fish farms are located over a wide area, and environmental parameters vary greatly between different fish farms. Based on the available data and limited resources, it is not possible to determine farm specific values for key parameters. Hence, this work aims to determine general realistic worst-case values that could be used in all farms. If possible, monitoring data from the same area where farms are situated was used.

In general, there is not much monitoring data available on the key parameters, especially from Sweden. Therefore, it was assumed that environmental conditions in Swedish and Finnish fish farms are similar and that common key parameter values can be determined. In Denmark, however,

environmental conditions are remarkably different from the east coast of Sweden and from Finland, and therefore specific Danish key parameter values were also determined.

Wind speed

In part I of the Nordic antifouling project it was determined that the average wind speed in the outer parts of the archipelago and at open coastal stations is 5.5 m/s in the Baltic Sea and the lowest measured average wind speed was 4.0 m/s. Considering a realistic worst-case scenario in the Baltic Sea, the wind speed should be lower than the typical wind speed in the area. Therefore, it was decided to use the 10th percentile value of 4.2 m/s, based on station specific average values, to represent realistic worst-case situations in the Baltic Sea area.

In part I of the Nordic antifouling project it was determined that in the Baltic Sea transition area, the average wind speed in open sea stations was 5.9 m/s and the lowest measured average wind speed in the open sea area was 5.5 m/s. Considering a realistic worst-case scenario in the Baltic Sea transition area, the wind speed should be lower than the typical wind speed in the area. Therefore, it was decided to use the 10th percentile value of 5.8 m/s based on station specific average values to represent realistic worst-case situations in the Baltic Sea transition area.

If one side of the farm is bordered by an island, there is a 180° angle when the wind blows perpendicular to the farm (Figure 7). It is assumed that every wind direction is equally likely, and therefore a value of 0.5 for the fraction of wind blowing perpendicular to the farms should be established in the fish net emission scenario.

The EU fish net scenario was developed for the older MAMPEC version 3.0.1. The parameter of wind speed was not available at that time in MAMPEC and the wind speed was not determined for the scenario.

Figure 7. Wind direction to fish farms.

Flow velocity

According to information received from the Finnish Meteorological Institute the average flow velocity in the Archipelago Sea (in 15 current measurement stations) varied between 1.6 and 7.4 cm/s. Some of the stations are situated in the same kind of areas as fish farms, but others are in the inner archipelago near the coast, which is not a very typical place for a farm. It should be noticed, however, that the measurements were made with equipment which could not detect low flow velocities (< 1.5 cm/s). Therefore, accurate averages cannot be determined. In studies in sheltered straits, average flow velocities of 2-3 cm/s have been measured, but in some areas, as in the strait of Ströömi, much higher average flow velocities of 7-10 cm/s were measured (Suominen 2003). The Strait of Ströömi is a traditional fish farming area in Finland, where there are several farms.

In environmental permits, it is commonly assumed that water exchange in the area of fish farms is good. Thus, it can be assumed that farms are usually located in areas where the water flow is quite strong and very low average flow rates are unlikely to be detected. However, permits are rarely based on actual current measurement data, and it is possible that the real water exchange is weaker than assumed during the permit process. Therefore, the worst-case value for flow velocity should be used.

It seems that an average flow velocity would typically be 3-10 cm/s. Lower average flow velocities can be detected in farms situated in sheltered straits, but the average is not expected to be below 2 cm/s. It is known that at least in Finland there are still some farms which are situated in quite sheltered straits and the flow velocity of 3 cm/s might be a realistic value for these farms. The value of 3 cm/s could be used as a representative realistic worst-case value for fish farms in the Baltic Sea area. The value is the same as used in the EU fish net scenario.

Water flow velocity is considerably higher in the area of the Belts than in the Archipelago Sea. The modelled water flow data provided by the Danish Meteorological Institute supports the understanding that fish farms are situated in areas where currents are quite strong (Figure 8). Modelled water flow in the area of fish farms varied from 10 cm/s to 50 cm/s during the observation time 3.-4.5.2018. Measured water flow from Østerrenden stations varied from 5 cm/s to 80 cm/s and in Vengeancegrund stations from 5 cm/s to 60 cm/s. In part I of the Nordic antifouling project it was proposed that flow velocity could be 15 cm/s for open coastal marinas and 8 cm/s for sheltered marinas in the Baltic Transition area. Based on the flow velocity data from the Baltic Transition area, a flow velocity of 3 cm/s in the EU fish net scenario seems to be too conservative. Therefore, it is suggested that in Denmark a flow velocity of 8 cm/s should be used as a representative worst-case flow velocity value for fish farms.

Figure 8. Modelled flow velocities in the Baltic transition area on 3.5.2018 provided by DMI.

Temperature

Surface water temperature was determined using water temperature data provided by the Swedish Meteorological and Hydrological Institute. Data from 2 measurement stations situated in the open sea area in the Baltic transition and from 1 measurement station in the Archipelago Sea was used. Data from stations close to the fish farms was chosen. (Figure 9). Temperatures were measured at a depth of 0.1 m. Data collected between the years 1973 and 2018 was used.

Surface temperature in the Baltic transition area was higher than in the Archipelago Sea (Figure 9). The average temperature from March to November was 12.2 °C (SD = 4.4; n = 10943) in the Baltic transition area, which can be considered to correspond to the average surface temperature during the typical farming season in Denmark. The average temperature from May to October was 11.5 °C (SD = 4.4; n = 10943) in the Archipelago Sea, which can be considered to correspond to the average surface temperature in a typical farming season in the Baltic Sea area.

Usually in midsummer, thermal stratification is strong in the Baltic Sea and the water temperature might be several degrees lower 5 meters below the surface than at the surface. Nets in fish farms are several meters deep, and temperature may vary at different sites in the net when the stratification is strong. Taking into account the temperature variation at different depths, the value of average surface temperature may be too high to represent the typical water temperature in fish farms. For this reason, it was decided to use lower temperatures of 10.5°C and 11.2°C as representative sea water temperatures in the Baltic Sea and in the Baltic transition area, respectively.

Figure 9. Average water temperature at 2 measurement stations in the Baltic Sea transition area (C5 and C6) and 1 measurement station in the Archipelago Sea (M0) in the years 1973-2018.

Suspended particulate matter (SPM)

To determine a representative value for SPM, water quality data from the Finnish environmental database (HERTTA) was used. Data on SPM from 7 sampling stations in the Archipelago Sea from May to October in the years 2010-2017 was analysed. Stations were chosen from the area where fish farms are situated (Figure 10). The average concentration of all stations was 2.7 mg/l (SD = 0.6; n = 7) and the highest average concentration in a single measurement station was 3.3 mg/l (SD = 6.0; n = 48).

It was assumed that the farm itself might increase the concentration of SPM in the farm area, when fish faeces and uneaten feed degrade to smaller particles. Based on this assumption, it was considered that the representative value of SPM should be higher than the typical value in the area. Therefore, it was decided to use the 90th percentile value of 3.3 mg/l based on station specific average values. An SPM concentration of 3.3 mg/l was used as a representative realistic worst-case value in fish farms in Finland and Sweden.

It was assumed that SPM concentration in the Danish Straits in the open sea area is lower than in the archipelago area of Finland. This assumption is also supported by the higher Secchi depth values in the Danish straits (Aarup 2002, Fleming-Lehtinen et al. 2010). No measured data on SPM was available. Concentration of SPM is one of the most important key parameters, because the use of too high values will underestimate PECs in the fish farms. Based on the assumption that SPM concentrations are lower in Denmark than in Finland, it was decided to use a lower value of 2 mg/l as a representative worst-case value for Danish fish farms.

Figure 10. Water quality sampling stations in the Archipelago Sea in Finland.

Particulate organic carbon (POC)

In order to determine a representative value for POC (particulate organic carbon), water quality data from the Finnish environmental database (HERTTA) was used. Data on TOC (total organic carbon) from 7 sampling stations in the Archipelago Sea from May to October in the years 2010-2017 was analysed. Stations were chosen from the area where fish farms are situated (Figure 10). The average concentration of TOC was 3.8 mg/l (SD = 0.4; n = 7) and the highest measured average concentration in a single station was 4.5 mg/l (SD = 3.4; n = 104).

It was assumed that the farm itself might increase the concentration of TOC in the farm area, when fish faeces and uneaten feed degrade to smaller particles in the water. Based on this assumption, it was considered that the representative value of TOC should be higher than the typical value in the area. Therefore, it was decided to use the 90th percentile value of 4.1 mg/l based on station specific average values as a representative worst-case value for Baltic sea fish farms.

It was assumed that the measured value of TOC is the sum of DOC and POC. The same POC : DOC ratio as used in the EU fish net scenario was used to determine POC concentration. Based on the POC : DOC ratio from the EU fish net scenario, the concentration of POC is 0.7 mg/l. This value was decided to be used as a representative worst-case POC concentration value in fish farms in Finland and Sweden.

In part I of the Nordic antifouling project the average concentration of POC was determined to be 0.3 mg/l in the Baltic transition area and the highest measured average concentration at a single station was 0.4 mg/l. Thus, it was decided to use the 90th percentile value of 0.38 mg/l based on station specific average values as a representative worst-case POC concentration in fish farms in Denmark.

Net sedimentation velocity

Data about sedimentation is very limited in the Baltic Sea area. Only the sediment quality is monitored in fish farms and surrounding areas. As stated earlier, fish farms are typically situated in areas with high currents. It could be assumed that farms are usually situated in erosion bottom areas where sedimentation is negligible (Jouni Vielma, personal comm. Luke 2018). Based on the mandatory monitoring program of several fish farms, the bottom quality is hard, sandy or contains small stones in the surrounding areas of fish farms. This supports the assumption that sedimentation would be very low (Räisänen 2013; Turkki 2017; Räisänen 2018). On the other hand, it was also found that sediment quality had deteriorated directly under the fish farms. This indicates that some sedimentation does in fact take place. It is possible that farming activity will increase sedimentation in the area of fish farms (Bannister, et al, 2014). Fish faeces and uneaten feed sink to the bottom and might increase the sediment accumulation rate under the fish nets in farms. However, without more detailed studies it is difficult to estimate how faeces and feed particles move on the bottom and how high is the real sediment accumulation rate under the nets in the farms.

Copper monitoring has been a part of the mandatory monitoring program of several fish farms in Finland (Räisänen 2013). However, the monitoring was stopped later because no impact on the sediment was detected. Copper concentrations in sediment were low, and no difference was detected between fish farms and reference areas.

In the EU fish net scenario, a net sedimentation velocity of 0.1 m/d was used. With an SPM concentration of 3.2 mg/l the net sedimentation velocity of 0.1 m/s corresponds to a sediment accumulation rate of 120 g/m²/a. Accumulation rates were calculated using the formula below (van Hattum et al. 2016):

$$M = v_{sn} * AS_s$$

V_{sn} = net sedimentation velocity (m d⁻¹)

M = mass of accumulated sediment per day (g d⁻¹)

A = accumulation area (m²)

S_s = Average concentration of suspended matter (g m⁻³)

In the typical situation in which farms are in relatively high current areas, it seems that the default sediment accumulation rate of 120 g/m²/a and net sedimentation velocity of 0.1 m/d might be realistic values where sedimentation is low. In the worst-case scenario, in which farms are situated in a sheltered area, the net sedimentation rate might be higher and therefore a net sedimentation velocity of 0.2 m/d might be used as a representative worst-case value in Finland and Sweden, where farms are situated in more sheltered areas than in Denmark. However, it was noticed that in the MAMPEC open harbour module the impact of net sedimentation velocity is negligible. Net sedimentation velocity is one of the key parameters in the MAMPEC marina module but not in the open harbour module which is a basis for the EU fish net scenario. It is unclear why the impact of the parameter is so different in these two modules. For the time being there is no need to consider the net sedimentation velocity value further, because it has no impact in fish farm scenarios using the open harbour module of MAMPEC.

4.2 Layout of fish farms

The aim of this chapter is to determine a representative layout for regional fish farm scenarios. Layouts (dimensions) of the farms were known to be an important factor in the MAMPEC calculations. The size and shape of farms and nets vary considerably, and it is difficult to determine one theoretical worst-case layout for fish farms. Therefore, the layout should be based on real fish farms.

Dimensions from real fish farms were used as a basis and they were modelled by using the MAMPEC 3.1.0.3 open harbour module. A total of 46 farms from Finland, 10 from Sweden and 15 farms from Denmark were modelled. Altogether 46 %, 77 % and 58 % of all farms in Finland, Sweden and Denmark were modelled, respectively. Farm specific layout and emission data was used (Table 1), with general realistic worst-case environmental key parameter values. Determination of environmental parameters was described in Chapter 4.1.

Table 1. Source of data used in modelling of real fish farms

Parameter	Type	Source of data
Layout of farm	Farm specific	Aerial photographs
Depth of farm	Farm specific	Environmental permits or navigation chart
Environmental parameters	General	Environmental monitoring data
Number of nets	Farm specific	Environmental permits or aerial photographs
Circumference of nets	Farm specific	Environmental permits or aerial photographs
Depth of nets	Farm specific	Environmental permits*

* If the value was not mentioned in permits, the worst-case assumption that nets are installed 2 meters above the bottom was used.

Data used in modelling

In order to identify farms causing the greatest risk, i.e. highest PECs in the environment in the Baltic Sea area, specific farm dimensions were determined from real fish farms. The length and width of fish farms were measured from aerial photographs. In some cases, no aerial photographs were available and these measurements could not be performed. In these cases, the size of the fish farm was calculated on the basis of the size and number of nets from environmental permits. It was identified that the most unfavourable shape of a fish farm, causing the highest PECs, is rectangular, with a length (x2) six times longer than the width (y1). This shape and size information from permits was used to calculate the length (x2) and the width (y1) of the farm.

The size of the surrounding area varies considerably and it is not possible to use the real size of the surrounding area of real fish farms because it is usually too large, i.e the ratio of x1:x2 or y2:y1 will be higher than recommended in MAMPEC (van Hattum et al. 2016). Therefore, the length of the surrounding area was set to correspond to the length of the fish farm ($x2 = x1$) and the width to correspond to the width ($y1 = y2$).

Based on the information from permits, the total area of fish nets was calculated. If the permits were not available, the number of nets and net dimensions were measured from aerial photographs. If it was not possible to measure the depth of the nets, the worst-case assumption that nets are installed 2 meters above the bottom was used. The worst-case assumption is based on Danish environmental permits, which require that the nets should be installed at least two meters above the bottom. The depth of the fish farm area was estimated from navigation charts.

Modelling of farms

The shape of fish farms is an important factor. Some of the farms are located very close to the coast, but often the distance between the farm and the coast is remarkable and fitting the layout of farms to the open harbour module in MAMPEC is challenging. The open harbour module assumes that the harbour (=fish farm) is situated close to the coast and that the flow direction is along the shore.

However, the direction of flow varies, and it is unrealistic to assume that fish farms are always located longitudinally relative to the direction of flow. It was found that if it was assumed that a farm's longer side represents its length (x_2) and the shorter side represents its width (y_1) in the harbour model, the model overestimates the risks in long and narrow fish farms.

In order to prevent over- and underestimation of risks and to obtain more realistic results, all real fish farms were modelled twice in the MAMPEC in relation to the wind direction (Figure 12). It was assumed that half of the time the flow was in the direction of the fish farm and half of the time transversely to the fish farm. Each farm was modelled twice, so that the length and width values were changed to reversed values. An average PEC in water was calculated for each farm based on the two modellings.

Figure 12. The idea for calculation of PECs twice for each farm depending on its position with regard to the direction of flow (F). Farms (OOO) were located sideways (A) and perpendicularly (B) towards the flow

Identified layouts for regional fish farm scenarios

After modelling, fish farms in all three countries were put in order from lowest to highest PECs and a fish farm corresponding to the 90th percentile in Finland, Sweden and Denmark was chosen to represent the realistic worst-case fish farm. Thus, this means that PECs in 90 % of the fish farms were lower than in these selected regional realistic worst-case fish farms.

The Finnish worst-case fish farm is situated in the Archipelago Sea in the Åland Islands. Compared to other fish farms in the Åland Islands, the farm is a middle- sized farm bordered by islands and the distance to the open sea is more than 20 km. The location represents quite well the typical location of fish farms in Finland (Figure 13). The length of the fish farm is 180 m and the width 45m. The farm has 5 nets with a diameter of 30 m. The depth of the nets is 7 m and the water depth in the area is 9 m.

Figure 13. The fish farm used to represent the realistic worst-case scenario in Finland.

The Swedish worst-case fish farm is situated in the archipelago near the land (Figure 14). The location is quite sheltered and the distance to the open sea is more than 15 km. The length of the fish farm is 125 m and the width 45 m. The farm consists of 22 square-shaped nets and the length of each side is 10 m. There are also 2 round nets with a diameter of 30 m. The depth of the nets is 5 m and the water depth in the area is 7 m.

Figure 14. The fish farm used to represent the realistic worst-case scenario in Sweden.

The Danish worst-case fish farm is situated in the open sea area in the Little Belt and the distance to land is about 2 km. The location is very open (Figure 15). The length of the fish farm is 180 m and the width 120 m. There are 18 circular shaped nets in the farm, with a diameter of 19 m. The depth of the nets is 13 m and the water depth in the area is 15 m.

Figure 15. The fish farm used to represent the realistic worst-case scenario in Denmark.

5. Comparison of regional fish farm scenarios with the EU fish net scenario

Regional fish farm scenarios differ considerably from the EU fish net scenario. Especially the size of the farms is significantly smaller in the Baltic Sea area than in the EU scenario. In the EU scenario, the total fish net area is 2.7 times greater than in the Danish and 7.5 times greater than in the Finnish and Swedish regional fish farm scenarios. The depth of the farm areas is also about 3 times greater in the EU fish net scenario than in regional Baltic Sea fish farms. Concentration of SPM is higher and concentration of POC is lower in the EU fish net scenario than in the Baltic Sea regional fish farms. The same flow velocity of 0.03 m/s was used in all scenarios, instead of the Danish regional scenario in which the flow velocity was adjusted to 0.08 m/s. Temperature is lower in the EU fish net scenario than in the Scandinavian scenarios. In the Baltic Sea regional fish farms only the summer farming season is represented, and therefore the water temperature is relatively high.

Table 2. Fish net scenario parameters.

		EU fish net scenario	Regional Finnish fish farm	Regional Danish fish farm	Regional Swedish fish farm
Layout of farm	x1 (m)	75	180/45***	180/120***	120/45***
	x2 (m)	300	180/45	180/120	120/45
	y1 (m)	150*	45/180	120/180	45/120
	y2 (m)	150*	45/180	120/180	45/120
	depth (m)	30	9	15	7
Environmental parameters	Flow velocity (m/s)	0.03	0.03	0.08	0.03
	SPM concentration (mg/l)	5	3.3	2	3.3
	POC concentration(mg/l)	0.3	0.7	0.38	0.7
	Temperature (°C)	9	10.5	11.2	10.5
	Net sedimentation velocity (m/d)	0.1	0.2	0.1	0.2
	Average wind speed (m/s)	4.2**	4.2	5.5	4.2
	Fraction of time wind perpendicular	0.5**	0.5	0.5	0.5
Net	Number of nets	10	5	18	22
	Circumference (m)	157	94	60	-
	Length of one side in square shaped nets (m)	-	-	-	10
	Depth of net (m)	20	7	13	5
	Area of net (m2)	5103	1365	1066	300
	Total area of nets (m2)	51030	6825	19188	6600
		16330	2184	6140	2112

* The older version of MAMPEC contains only one y-dimension. The width of the farm and its surrounding area was modified to fit to the new MAMPEC version and now the y1 will represent the actual width of the fish net.

** Wind speed and the fraction of the time the wind was blowing perpendicular to the farm was missing in the EU fish net scenario, because the older MAMPEC 3.0 version was used. For comparison, a wind speed of 4.2 m/s was set in the scenario, which is same as the worst-case wind speed used in Finnish and Swedish fish farm scenarios.

*** In order to obtain more realistic results, farms were modelled twice using different values.

The comparison shows that PECs in water and sediment inside fish farms using the EU fish net scenario were 4 % and 33 % lower in Finnish and in Swedish regional fish farm scenarios, respectively. By contrast, PECs in water and sediment using the EU fish net scenario were 196 % higher than in the Danish regional fish farm scenario (Figure 16).

Figure 16. PECs of copper inside farms in different fish net scenarios. Calculations were made using a dummy product containing 20 % of copper.

It seems that the EU fish net scenario will underestimate the risk in Sweden, where farms are situated in quite sheltered areas in the inner archipelago. The location and environmental conditions are quite similar in Sweden and Finland, but PECs are remarkable higher in Sweden. Swedish farms typically consist of a high number of small nets, which increases the total surface area of nets and emissions of active substances. Another difference is the size of farms. In Finland the nets are usually larger and the distance between nets is higher, which decreases the total net surface area per volume of water compared to Sweden.

In Finland, PECs are slightly higher than in the EU fish net scenario. However, based on the number of uncertainties and the low amount of data about key parameters, the difference in PECs can be considered negligible.

In Denmark, PECs are lower than in the EU fish net scenario. Fish farms in Denmark are situated in open sea areas, where high current velocities are assumed. For this reason, PECs in Denmark will be remarkably lower than in Finland and Sweden. The number of nets is usually high in Denmark, but they are grouped into several groups that are separated from each other, whereas in Sweden and Finland the nets are placed together. This also decreases PECs in Danish fish farms.

The open harbour module in MAMPEC 3.1 was used with all scenarios. In Finland and Sweden, the use of the open harbour module can be considered justified, because most of the farms are situated quite near the land. In Denmark, where farms are in the open sea area, the use of a shipping lane module might be more suitable than the open harbour module.

6. Conclusion

Regional fish farm scenarios were developed to represent local environmental conditions, and it is assumed that these scenarios simulate better real environmental exposure in the Baltic region. Based on the scenario comparison it can be concluded that the EU fish net scenario is sufficiently conservative for Danish and Finnish fish farms and that a high level of protection could be achieved by using it in Finland and Denmark. However, it seems that in Sweden it may underestimate the environmental exposure.

The EU fish net scenario was developed for the older MAMPEC version 3.0.1. The parameter of wind speed was not available at that time, and therefore it was not determined for the scenario. Furthermore, the original layout of the fish farm does not fit the updated MAMPEC. In order to use the latest version of MAMPEC (3.1.0.3), it must first be decided how to adapt the scenario to the updated version. If the adjustment is different from that used in this work, it will be necessary to make the scenario comparison again.

Many of the key parameters used in the EU fish net scenario are not representative of fish farms in the Baltic Sea area. Farm sizes are smaller and water areas shallower in the Baltic area than in the EU fish net scenario. Nevertheless, as long as the EU fish net scenario provides higher PECs than in the regional Danish and Finnish fish farm scenarios, there seems to be no need to change the parameters in the scenario or to use other scenarios. In the case of Sweden, it seems that the use of the EU fish net scenario underestimates PECs in Swedish fish farms. Thus, it is recommended that the more representative environmental key parameter values and the more representative layout presented above should be used when using the EU fish net scenario.

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