Miljøkonsekvensvurdering af kabelprojekt over Storstrøm

Background report: Sediment spill

Energinet Eltransmission A/S

Date: 10.02.2025

Contents

Appendix

REVISION HISTORY

Document	Revision	Date	Prepared	Verified	Approved	Comments
Final Report	1.0	20/02/2024	FRGR	AIRN	KAED	
Final Report	2.0	25/06/2024	FRGR	AIRN	KAED	Comments from client addressed
Final Report	3.0	10/02/2025	AIRN	KLBU	KAED	Comments from the EPA

NOMENCLATURE

Abbreviation	Description
CF	Coming From
DDM	Denmark's Depth Model
DEM	Digital Elevation Model
DMI	Danish Meteorological Institute
DTM	Digital Terrain Model
ECMWF	European Centre for Medium-Range Forecasts
EEA	European Environmental Agency
ERA5	ECMWF ReAnalysis v5
GT	Going Towards
HD	Hydrodynamic
HD2D	Hydrodynamic 2-Dimensional (depth-averaged)
HD3D	Hydrodynamic 3-Dimensional
HSWL	Highest Still Water Level
LAT	Lowest Astronomical Tide
LSWL	Lowest Still Water Level
ME	Mean Error
MEA	Mean Absolute Error
MSL	Mean Sea Level
MSLP	Mean Sea Level Pressure
MT	Mud Transport (DHI MIKE module)
RMSE	Root Mean Squared Error
SMHI	Swedish Meteorological and Hydrological Institute
SoW	Scope of Work
SSE	Sea Surface Elevation
STD	Standard Deviation
UTM	Universal Transverse Mercator
VD	Vertical Datum
WGS84	World Geodetic System 1984
WSxx (W_s xx)	Wind Speed at xx mMSL
WL	(Total) Water Level
WD_{xx}, (W_D xx)	Wind direction at xx mMSL

1. Introduction

Scheduled for 2025, the planning for the installation of two power cables that will connect the Zealand municipalities of Vordingborg and Guldborgsund via StorStrømmen is currently being assessed by ***Energinet El-transmission A/S*** ('The Client').

One of the main concerns regarding both the environmental impact and construction works is the amount of sediment that will be released into the water as well as how much it will be dispersed due to tidal currents and local wind effects.

Figure 1.1 shows a map of the Vordingborg, Guldborgsund and Storstrømmen areas along with the currently proposed layout of the two power cables to be installed. Storstrømmen is approx. 10 km long with varying depths of 5 to 36m and 1 to 2km wide.

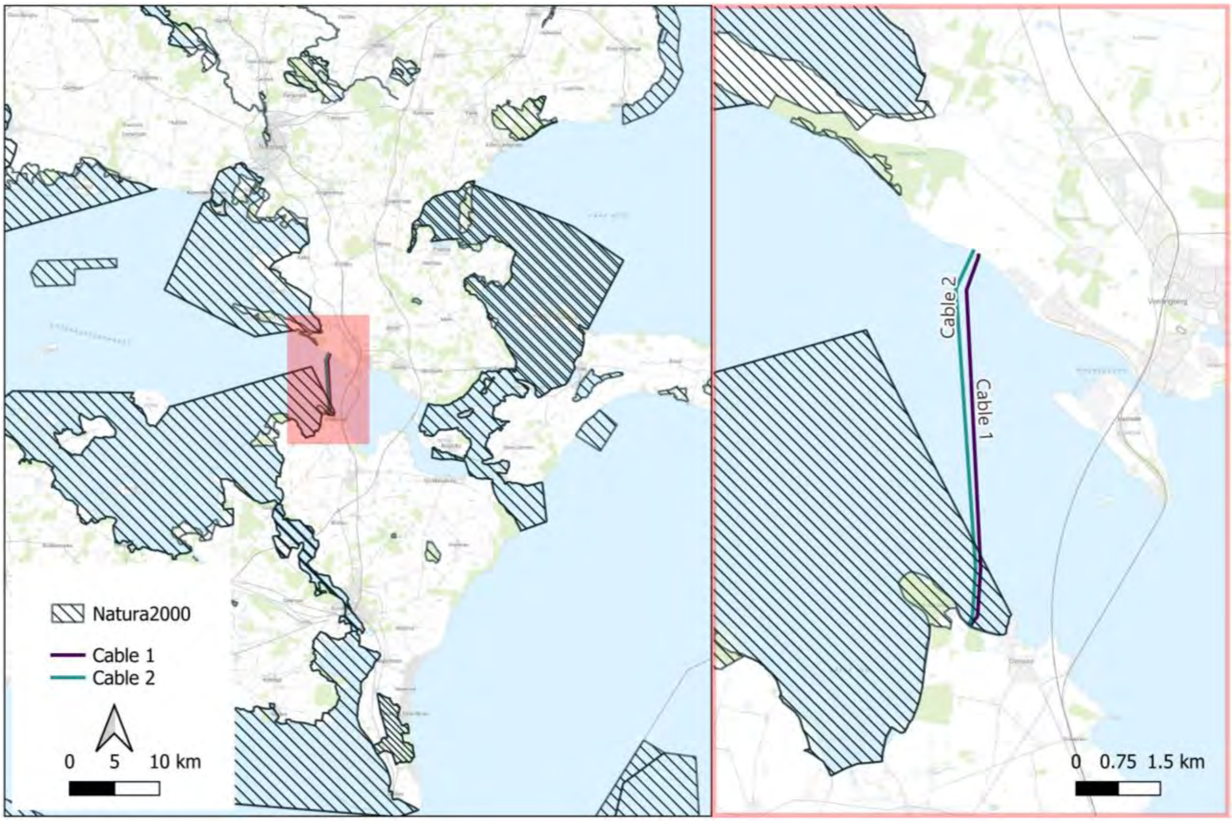


Figure 1.1: Overview of the planned power cables routes accross Storstrømmen.

The associated potential impacts on the physical environment in terms of sediment concentrations, sedimentation heights, and light attenuation, are documented in this report.

1.1. Scope of work

The purpose of the present sediment spill study is to present the potential extent of increased sediment concentrations and sedimentation, and thus, the impact due to dredging works during the installation period of the two power cables between Ore and Orehoved within the Storstømmen region.

When cables are dug, flushed or plowed into the seabed, sediment is dispersed and distributed in the water column. The coarser sediments such as sand, quickly settles again, while the finer particles such as silt and clay, stay in suspension in the water phase for a longer time period. The spilled sediment will initially contribute to a higher turbidity and thus potentially a greater attenuation of light at the bottom, where it can therefore dampen growth of e.g. eelgrass. Secondly, it can potentially cover bottom habitats resulting in that eelgrass and mussels may have more difficult growing conditions.

Secondary, in connection with the sediment spill, release of nutrients may occur such as N and P as well as organic matter. If environmentally hazardous substances are bound to the sediment, they can also be released.

It is therefore important to keep track of what types of sediment are being dredged and what the consequences of dispersing the sediment are for the area it spreads into (impact area). The method for mapping the spread of the sediment is initially numerical modelling of the hydrodynamics relationship. It is the current velocities and the particle settling velocities that determine how far the sediment can spread and where it can settle.

The activities agreed upon in the Scope of Work (***SoW***) entail:

- The setup and validation of the underlaying, driving 3D Hydrodynamic (***HD3D***) model
- Sediment spill, dispersal and deposit modelling via a Mud Transport (***MT***) model, post-processing of results and QA
- Reporting of results

1.2. Coordinate system

Unless stated otherwise, the Vertical Datum (***VD***) throughout the report is Mean Sea Level (***MSL***), while the geographic coordinate system is WGS84 EPSG:7416 ETRS89 UTM32N.

2. Summary of tasks undertaken

The potential effects are analysed based on excess suspended sediment concentrations, sedimentation and extent, and corresponding light attenuation. Due to the strong temporal variation of the sediment concentration, the maximum or the temporal average is not representative to describe the processes on the one hand and the impact on the ecology on the other. For this reason, exceedance durations (both cumulative and consecutive) are calculated and discussed.

2.1. Suspended sediment concentrations

The dredged and spilled sediments are transported and dispersed with currents while settling through the water column, leading to a decrease in sediment concentration the greater the distance from the source.

The simulation results revealed the following main findings:

- As the majority of the sediment is released at the bottom, the highest concentrations, exceeded over the longest period of time, can be observed at the bottom.
- In the deeper parts, the highest concentrations are observed. This is consistent with larger water depths and thus a longer settling time for the suspended sediment and resuspension from the bottom because stronger horizontal currents.
- Due to the temporal and spatial fluctuations of activities, sediment is not released at a constant rate, causing the sediment concentration to vary over time and across different locations. As a result, when considering the duration for which a threshold is exceeded, the threshold may be reached multiple times and then decline again during the activity period. Therefore, the longest consecutive period a certain

threshold is reached or exceeded is significantly smaller than the cumulative period (e.g. 5 mg/l is reached or exceeded over a period of a total of 2.6 days, whereas the corresponding consecutive period only accounts to 0.6 days.)

2.2. Light attenuation

As the background concentration is not known, only the additional light attenuation caused by the construction work is estimated. The resulting light attenuation estimates show that:

- For example, a light attenuation of 40% at the bottom is to be expected during 8-9 days in total (cumulative duration) in a contained area surrounding the dredged area.
- The longest consecutive period, during which the light at the bottom is reduced, is considerably shorter than the cumulative period.

2.3. Sedimentation

The height of the deposited sediment layer is estimated for three sediment densities in order to account for different consolidation states and sediment properties. The numerical simulations provided the following insights:

- The largest sedimentation occurs in the close vicinity of the cables
- Within the deepest parts, where strongest horizontal currents occur, the settled material is resuspended and transported to the north-west.
- Based on the distribution of the sediment, the Northwest direction can be recognized as the dominant direction where a net sediment transport is observed.

2.4. Assessment

The established model provides a conservative estimate of light attenuation at the seabed and the dispersion of suspended sediment due to the following assumptions:

- No consideration of consolidation (increasing density) of the settled sediment.
- No consideration of the background concentration and the effect of organic matter.
- No consideration of organic processes

3. Scenarios to be assessed

Two different scenarios were initially considered for the construction phase:

1) **Scenario 1**
   - Jetting in waters deeper than 6 m and where no moraine clay (till) is present
   - Pre-excavation and backfilling in water depths less than 6 m and where moraine clay is present
2) **Scenario 2**
   - Dredging: Pre-excavation and backfilling along the entire route

In both cases, a spill rate of 5% is assumed (Box 3.1 in [1]). In Scenario 1, 3,638 m^3 of sediment is released compared to 5,360 m^3 in Scenario 2. Because significantly more sediment is released in scenario 2, only the second scenario is analysed in the numerical simulations (see Table 3.1).

In general, it is assumed that the coarse sediment fraction settles next to the source, and that the finer fractions are available for transport in the surrounding waters. Sediment is released near the bottom (approx. 2 m above the ground). In areas where the water depth is < 6 m, the spill is evenly distributed over the entire depth. A potential installation program is described in Table 3.2.

Table 3.1: Sediment sources, spill percentage and gross spill

Case specification		Excavating along entire cable length		
Excavating (North, shallower than 6 m)		**Total**	**Cable 1**	**Cabe 2**
Total length	m	1,305	657	648
Vol. to be removed (2 x 2 m^2)	m^3	5,220	2,628	2,592
Capacity	m/day	300	300	300
Spill percentage, bottom	%	0%	0%	0%
Spill percentage - entire water column	%	5%	5%	5%
Spill gross	m^3	261	131	130
Backfilling (North, shallower than 6 m)		**Total**	**Cable 1**	**Cabe 2**
Total length	m	1,305	657	648
Vol. to be removed (2 x 2 m^2)	m^3	5,220	2,628	2,592
Capacity	m/day	300	300	300
Spill percentage, bottom	%	0%	0%	0%
Spill percentage - entire water column	%	5%	5%	5%
Spill gross	m^3	261	131	130
Excavating (South, shallower than 6 m)		**Total**	**Cable 1**	**Cabe 2**
Total length	m	2,778	1,366	1,412
Vol. to be removed (2 x 2 m^2)	m^3	11,112	5,464	5,648
Capacity	m/day	300	300	300
Spill percentage, bottom	%	0%	0%	0%
Spill percentage, top	%	5%	5%	5%
Spill gross	m^3	556	273	282
Backfilling (South, shallower than 6 m)		**Total**	**Cable 1**	**Cabe 2**
Total length	m	2,778	1,366	1,412
Vol. to be removed (2 x 2 m^2)	m^3	11,112	5,464	5,648
Capacity	m/day	300	300	300
Spill percentage, bottom	%	0%	0%	0%
Spill percentage - entire water column	%	5%	5%	5%
Spill gross	m^3	556	273	282
Excavating (deeper than 6 m)		**Total**	**Cable 1**	**Cabe 2**
Total length	m	9,318	4,642	4,676
Vol. to be removed (2 x 2 m^2)	m^3	37,272	18,568	18,704
Capacity	m/day	300	300	300
Spill percentage, bottom	%	5%	5%	5%
Spill percentage, top	%	0%	0%	0%
Spill gross	m^3	1,864	928	935
Backfilling (deeper than 6 m)		**Total**	**Cable 1**	**Cabe 2**
Total length	m	9,318	4,642	4,676
Vol. to be removed (2 x 2 m^2)	m^3	37,272	18,568	18,704
Capacity	m/day	300	300	300
Spill percentage, bottom	%	5%	5%	5%
Spill percentage - entire water column	%	0%	0%	0%
Spill gross	m^3	1,864	928	935
Volume to be moved, total	m^3	107,208	53,320	53,888
Spill gross, total	m^3	5,360	2,666	2,694
Spill percentage overall	%	5%		

Table 3.2: Installation program.

Setup, Activity	Cable No.	Amount	Unit	Capacity	Unit	Days	Start	End
Excavating (North, shallower than 6 m) - Cable 1	1	657	m	300	m/day	2.2	01.05.2027	03.05.2027
Excavating (deeper than 6 m) - Cable 1	1	4'642	m	300	m/day	15.5	03.05.2027	18.05.2027
Excavating (South, shallower than 6 m) - Cable 1	1	1'366	m	300	m/day	4.6	18.05.2027	23.05.2027
Excavating (North, shallower than 6 m) - Cabe 2	1	648	m	300	m/day	2.2	23.05.2027	25.05.2027
Excavating (deeper than 6 m) - Cabe 2	1	4'676	m	300	m/day	15.6	25.05.2027	09.06.2027
Excavating (South, shallower than 6 m) - Cabe 2	1	1'412	m	300	m/day	4.7	09.06.2027	14.06.2027
Laying out the cable in July								
Backfilling (North, shallower than 6 m) - Cable 1	1	657	m	300	m/day	2.2	01.08.2027	03.08.2027
Backfilling (deeper than 6 m) - Cable 1	1	4'642	m	300	m/day	15.5	03.08.2027	18.08.2027
Backfilling (South, shallower than 6 m) - Cable 1	1	1'366	m	300	m/day	4.6	18.08.2027	23.08.2027
Backfilling (North, shallower than 6 m) - Cabe 2	1	648	m	300	m/day	2.2	23.08.2027	25.08.2027
Backfilling (deeper than 6 m) - Cabe 2	1	4'676	m	300	m/day	15.6	25.08.2027	09.09.2027
Backfilling (South, shallower than 6 m) - Cabe 2	1	1'412	m	300	m/day	4.7	09.09.2027	14.09.2027

4. Data basis

This section presents the sources of data considered in the study, including bathymetry, metocean hindcast databases for model forcing (hydrodynamic and atmospheric), measurements/observations for validation, type of sediment available within the Storstrømmen area, and work plan/installation sequence.

4.1. Bathymetry

One of the main constituents of the HD3D model is the Digital Terrain Model (***DTM***). A DTM is a digital representation of the terrain or ground surface of a specific area or location. It is a three-dimensional model that provides information about the elevation, slope, and other topographic features of the terrain.

DTMs are created using Digital Elevation Models (***DEM***s), which are datasets that provide information about the elevation of the ground surface.

For this project, no site-specific survey data provided by the client was available by the time of undertaking the numerical modelling. Thus, the DTM built for Storstrømmen relies on publicly available data:

- Regarding bathymetric information, we considered the Denmark's Depth Model[1] [2] (***DDM)*** which is based on a regularly spaced grid with resolution of 50 x 50 meters and is part of the free marine data. Vertical datum is approx. equal to MSL.

- The coastline, which serves as water/land limit in the model (boundaries) has been retrieved from the European Environment Agency database [3][2].

Figure 4.1 shows the DDM bathymetry over the entire domain of the HD3D model, as well as a zoom-in of the bathymetry around the construction area within Storstrømmen.

[1] https://dataforsyningen.dk/data/4817
[2] https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-1/gis-data/europe-coastline-shapefile

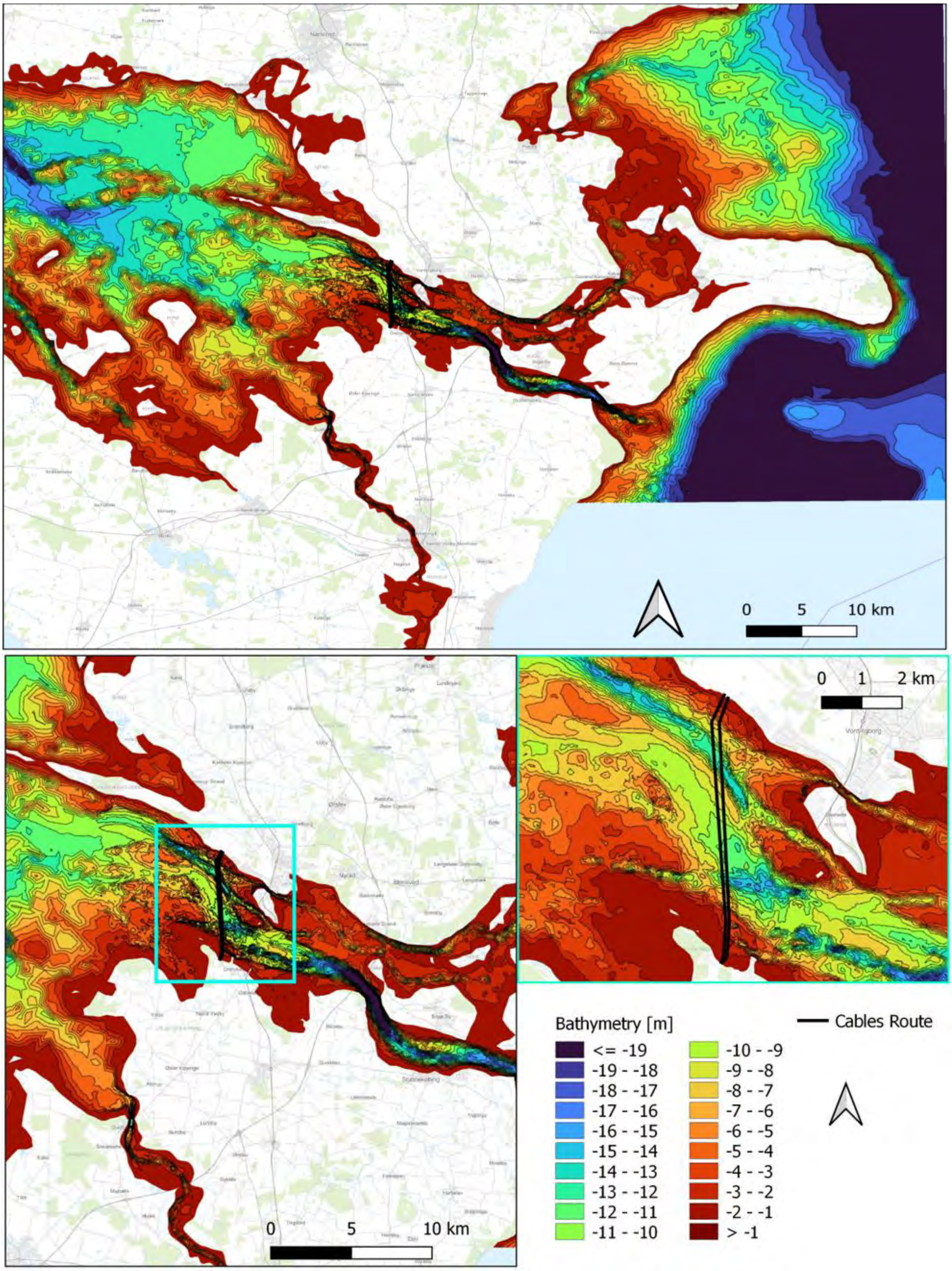


Figure 4.1: Denmark's Depth Model in Danish Waters bathymetry data around the approaches to StorStrømmen. Top: general view of the HD3D model domain. Bottom: zoom-in around the project site. Vertical datum shown in both pictures is MSL.

4.2. Hydrodynamic and atmospheric forcing data

The HD3D numerical model is forced by both hydrodynamic and atmospheric initial conditions; timeseries of sea surface elevation (***SSE***), water salinity and temperature profiles, 10mMSL winds and Mean Sea Level Pressure (***MSLP***). Such boundary conditions have been retrieved from the Swedish Meteorological and Hydrological Institute (***SMHI***) and European Centre for Medium-Range Forecasts' (***ECMWF***) ECMWF ReAnalysis v5 (***ERA5***) databases.

4.2.1. SMHI

SMHI's Baltic Sea Physics Analysis and Forecast 3D model [4] [3] covers the entire Baltic Sea (latitude range [53.01° , 65.89°] and longitude range [9.04° , 30.21°], including the transition area towards the North Sea i.e. the Danish Belts, the Kattegat and Skagerrak) in a regular grid fashion with spatial resolution 2x2 km, and has been run from October 2nd 2020 to present (ongoing) with 1-hourly output time step.

The model provides forecasts for the physical conditions in the Baltic Sea. The Baltic forecast is updated twice daily providing a new six days forecast. Several datasets are available from the SMHI website:

- One with hourly instantaneous values
- One with daily mean values
- One with monthly mean values

All datasets contain - among others - the following parameters: sea level variations, ice concentration and thickness at the surface, and temperature, salinity and horizontal and vertical velocities for the 3D field. Model output is provided at the models native grid with a resolution of 1 nautical mile in the horizontal, and up to 56 vertical depth levels.

4.2.2. ERA5

Wind, pressure and wave fields were adopted from the Atmospheric Re-Analysis 5 (ERA5) [5] developed by the European Centre for Medium Range Weather Forecasts (ECMWF)[4].

The ERA5 dataset is a reanalysis of hourly meteorological conditions with available data since 1940. It combines a weather model with observational data from satellites and ground sensors to build a consistent long-term record of our climate. Such reanalysis data allows to get the best possible understanding of the past climate and relate current conditions for comprehensive analyses. It contains not only wind fields at different altitudes but also other atmospheric variables such as air temperature, atmospheric pressure, rainfall, soil moisture, among others.

ERA5 offers a grid resolution of 0.25 degrees for wind (atmospheric) parameters and 0.5 degrees for wave parameters, and assimilates more observational datasets than previous ECMWF's reanalyses, which makes it significantly more accurate.

Herein, the 10mMSL wind and MSLP fields were retrieved from ECMWF's database between October 2020 and Dec 2023, inclusive.

[3] https://resources.marine.copernicus.eu/product-detail/BALTICSEA_ANALYSISFORECAST_PHY_003_006/INFORMATION

[4] https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5

4.3. Water level and seawater properties measurements

Data for calibration of the model were extracted from DMI's online Open Data Server[5] and the Aarhus University database[6]. Three types of observations have been retrieved from the mentioned sources:

- Water levels at three (3) stations – DMI Open Data [6]
- Water salinity profiles at eleven (11) stations – Aarhus University [7]
- Water temperature profiles at eleven (11) stations – Aarhus University [7]

It shall be noted that the stations measuring salinity and temperature profiles are the same, but different from the three water level stations. Figure 4.2 presents the geographical location of the before mentioned stations within the area of interest, while Table 4.1 shows the geographic coordinates for each station.

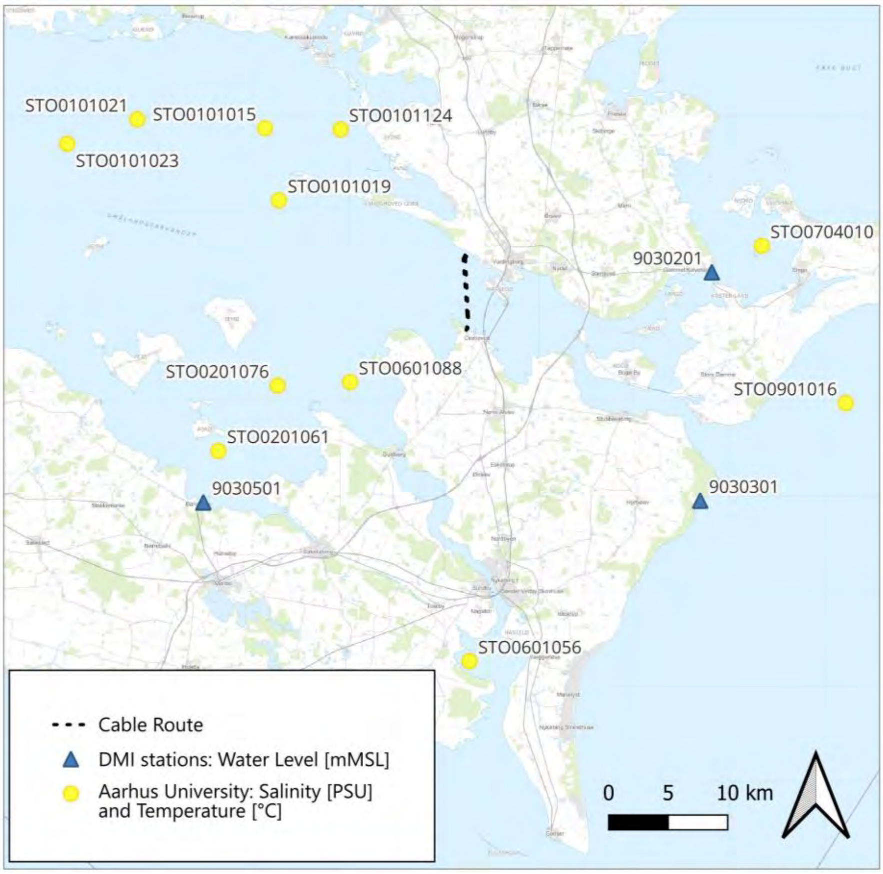


Figure 4.2: Overview of stations where data on water level, salinity and temperature are extracted from.

The results of the comparison between measured and simulated parameters are reported in Section 5.3.2.

[5] https://opendatadocs.dmi.govcloud.dk/DMIOpenData
[6] Overfladevandsdatabasen (au.dk)

Table 4.1: Summary of the available data collected for the validation of the model.

Data for verification					
Source	ID	Name	Descripton	Location - X [m]	Location - Y [m]
DMI Open Data	9030501	-	Station - Water Level measurements [mMSL]	659776	6079468
DMI Open Data	9030301	-	Station - Water Level measurements [mMSL]	701537	6079618
DMI Open Data	9030201	-	Station - Water Level measurements [mMSL]	702514	6098820
DCE - Nationalt Center for Miljø og Energi	STO0101023	Vejrø	Station - Salinity [PSU] and Temperature [°C]	648323	6109613
DCE - Nationalt Center for Miljø og Energi	STO0101015	Karrebæksminde Bugt	Station - Salinity [PSU] and Temperature [°C]	664962	6110922
DCE - Nationalt Center for Miljø og Energi	STO0601056	Kejlsø	Station - Salinity [PSU] and Temperature [°C]	682140	6066118
DCE - Nationalt Center for Miljø og Energi	STO0201061	Askø	Station - Salinity [PSU] and Temperature [°C]	661040	6083806
DCE - Nationalt Center for Miljø og Energi	STO0704010	Nordre Løb	Station - Salinity [PSU] and Temperature [°C]	706716	6101037
DCE - Nationalt Center for Miljø og Energi	STO0901016	Darss Tærsklen	Station - Salinity [PSU] and Temperature [°C]	713762	6087825
DCE - Nationalt Center for Miljø og Energi	STO0201076	Stemmetoften	Station - Salinity [PSU] and Temperature [°C]	666019	6089296
DCE - Nationalt Center for Miljø og Energi	STO0601088	Vigsø Skal	Station - Salinity [PSU] and Temperature [°C]	672114	6089581
DCE - Nationalt Center for Miljø og Energi	STO0101124	Svinø	Station - Salinity [PSU] and Temperature [°C]	671303	6110822
DCE - Nationalt Center for Miljø og Energi	STO0101021	Kirkegrund	Station - Salinity [PSU] and Temperature [°C]	654222	6111670
DCE - Nationalt Center for Miljø og Energi	STO0101019	Knudshoved Odde	Station - Salinity [PSU] and Temperature [°C]	666122	6104861

4.4. Local sediment samples

Figure 4.3 provides an overview of the locations along the proposed cable layout at which sediment samples were acquired during the geological survey conducted by Rambøll, as detailed in [8]. Table 4.2 shows the geographic coordinates of each of the sediment sampling locations. In Appendix 3, the granulometric characteristics of the samples are shown.

Table 4.2: Summary of the available grab samples collected by Rambøll during the cable route survey – see [8].

Survey Data					
Source	Survey ID	Point ID	Descripton	Location - X [m]	Location - Y [m]
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE1	Survey - Grab Sample	681934	6095299
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE2	Survey - Grab Sample	682090	6095450
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE4	Survey - Grab Sample	681871	6099326
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE5	Survey - Grab Sample	681714	6098854
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE6	Survey - Grab Sample	681920	6097472
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE7	Survey - Grab Sample	681910	6098092
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE7	Survey - Grab Sample	681911	6098093
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE8	Survey - Grab Sample	681740	6099231
Ramboll Denmark A/S - Cable Route Survey	SN2023_015	SE10	Survey - Grab Sample	681777	6099792

4.5. Seabed sediment

In relation to the properties of the sediment in the Storstrømmen area, and in addition to the local sediment samples survey by Rambøll, a geological map of the seabed was obtained from the online source GEUS [9]. The map was enhanced through the knowledge gained from the geotechnical and geophysical investigations [8].

The final results are depicted in Figure 4.3 the alongside the geological map retrieved from GEUS. A summary of the used results of the geotechnical survey carried out in 2023 is reported in Table 4.2.

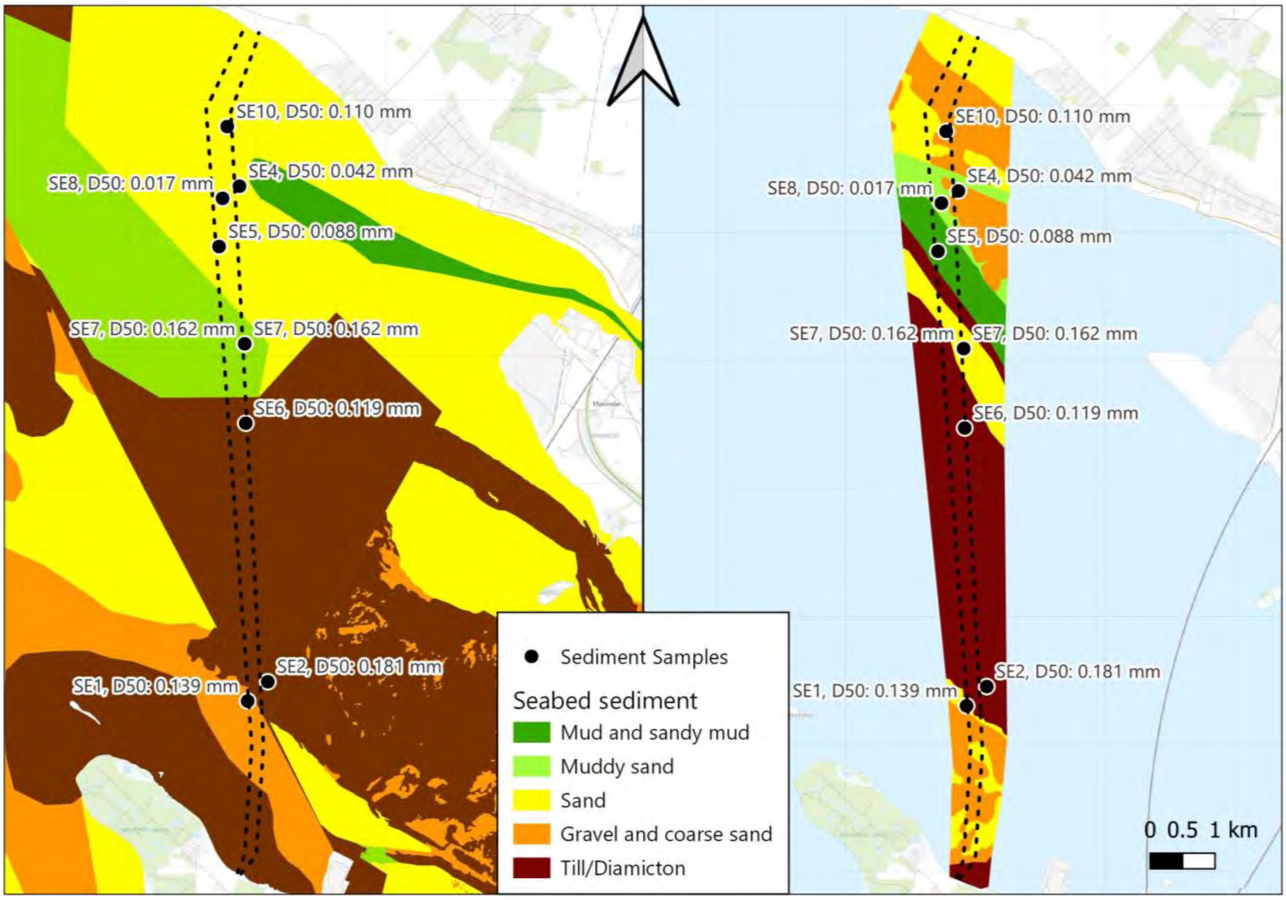


Figure 4.3: Geological map retrieved from GUES [9] on the left and higher resolution sediment distribution in the area along the cables's route on the right [8] along with grab samples locations.

4.6. Background concentration

Until recently, the standard approach for small and midsize infrastructure projects—such as this cable crossing and the nearby Storstrømmen Bridge—has been to use available data on background concentrations. Therefore, this project has used data from the Fehmarnbelt Fixed Link project [10] as a proxy for the background concentration. To further strengthen the interpretation, local data from Aarhus University database [7] [7] has been used as verification together with satellite images from varying dates [10] [11]. These data all show comparable levels and variation patterns and therefore are deemed representative for the background concentration in the area.

The observations from the Fehmarn Belt are considered representative for the Storstrømmen based on the following considerations:

a) They are the best available detailed data in the vicinity of the site.
b) The close proximity of the two water bodies, which share comparable hydrodynamic conditions.

[7] Overfladevandsdatabasen (au.dk)

c) A comparison of turbidity profiles measured by Aarhus University database [7] at Storstrømmen and within the Fehmarn Belt on the same day (Figure 4.5) indicates turbidity levels of the same order of magnitude.
d) Maps of total suspended matter derived from MERIS satellite data [10] and from OLCI data on Sentinel-A [11] (S3A, processed using the C2RCC neural network) , demonstrate comparable suspended sediment concentrations (SSC) between the Fehmarn Belt and Storstrømmen.

In the scope of the Fehmarnbelt Fixed Link projects [10], intensive measurements with respect to the sediment concentrations have been carried out at the Fehmarn between February 2009 until the end of May 2011.

Concentration levels: Median concentrations were typically low, less than 2 mg/l for water depths deeper than 6m, and less than 5. mg/l for shallower waters. However, the 95th percentile levels could be quite high, ranging from 30 mg/l to 330 mg/l in shallow waters, indicating significant re-suspension during dynamic conditions.

Spatial variation: Nearshore stations (e.g., NS01-NS03) show higher SSC levels due to wave-induced re-suspension, while offshore stations (e.g., MS01-MS02) experienced lower SSC levels. In addition, SCC levels varied geographically, with Danish nearshore stations being more exposed to common wind directions, leading to higher SSC levels compared to the more sheltered German nearshore stations. A similar behaviour is observed in the remotely sensed concentrations in Storstrømmen.

Temporal variation -Nearshore: SSC levels experienced high temporal variations (see Figure 4.4), whereas higher SSC levels were observed in autumn and winter due to increased storm activity and wave action, while spring and summer generally show lower SSC levels. Significant SSC peaks are often associated with specific storm events, with SSC levels rising rapidly during high wind and wave conditions and decreasing slowly afterward. Thus, nearshore stations showed a strong correlation with wind speed and direction, speeds above 8 m/s typically result in higher SSC levels. A similar behaviour is expected in Storstrømmen though only sparse remotely sensed data is available nearshore.

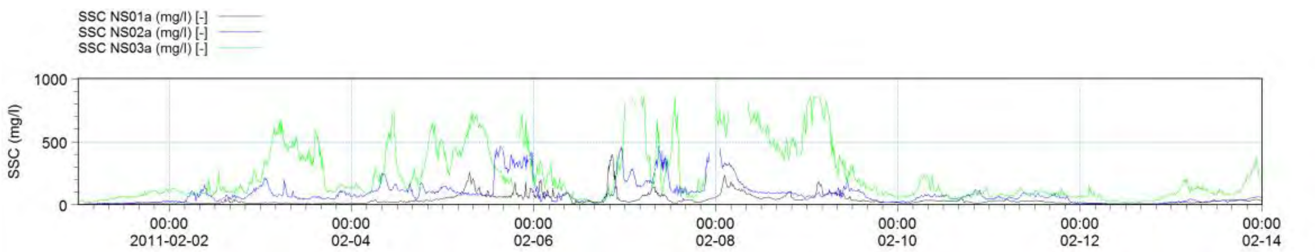


Figure 4.4: SSC measured at the nearshore stations NS01a, NS02a, NS03a in the scope of the of the Fehmarnbelt Fixed Link project [10] (copied from Figure 6.12 in [10])

Temporal variation - Offshore: Offshore SSC levels are influenced by current speeds and directions, with regional circulation patterns affecting sediment transport. However, background concentrations of suspended sediment were generally low, ranging between 1–2 mg/l throughout the water column similar to the measurements carried out by Århus University in Storstrømmen. However, during the autumn and winter months, the frequency of higher concentration events increased. Suspension events with suspended sediment concentrations (SSC) of up to 30-50 mg/l were observed several times between September 2009 and January 2010 (depending on the specific station). During this period, the concentrations were generally higher at the bottom and at the mid water level compared to the surface level. This is consistent with data observed in the Århus university data from Storstrømmen.

Since the information from the Fehmarn Belt is considered representative and the data measurements show in general very low concentrations, the current study focuses solely on modelling the excess concentration resulting from the spill caused by the construction work.

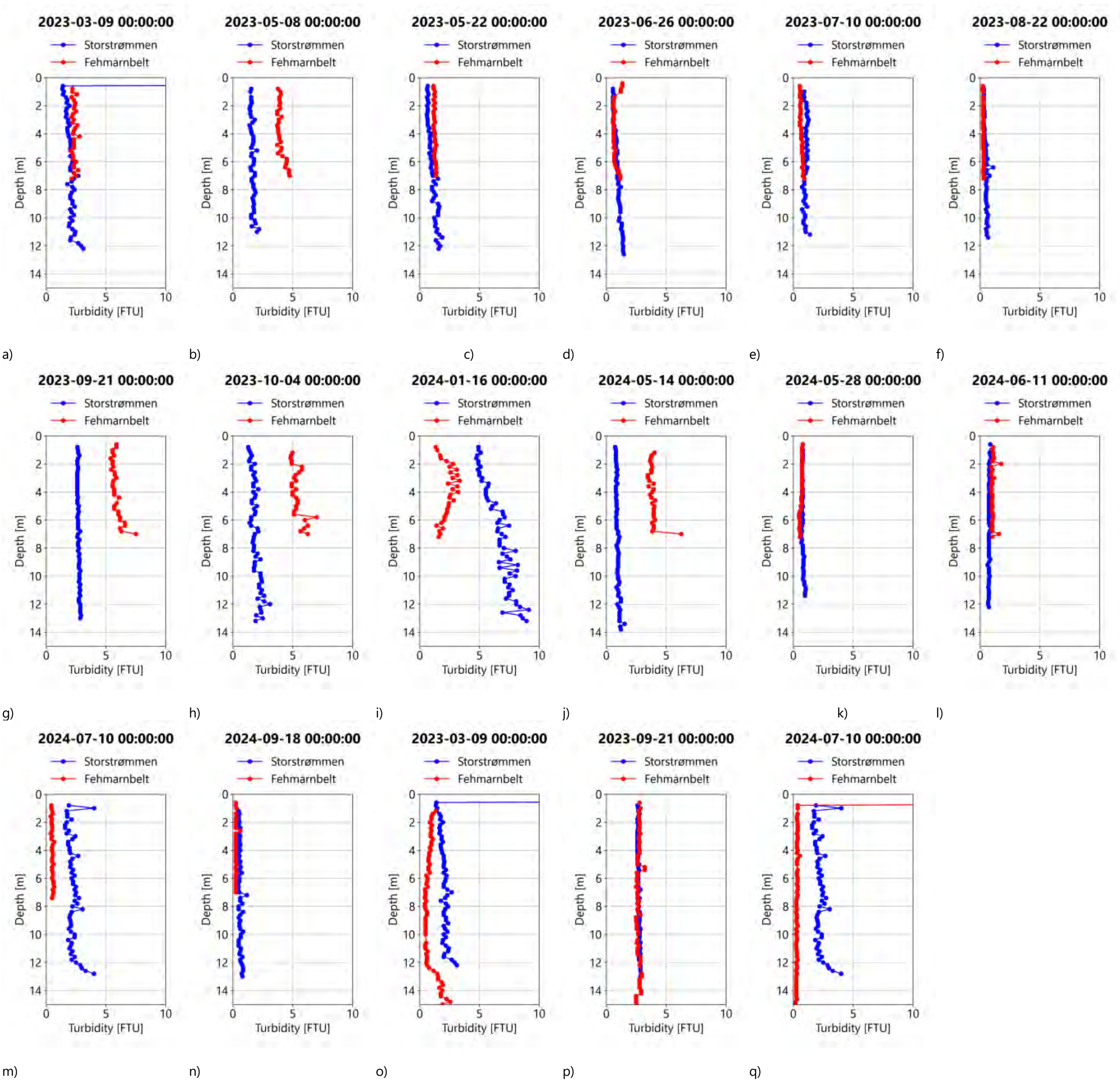
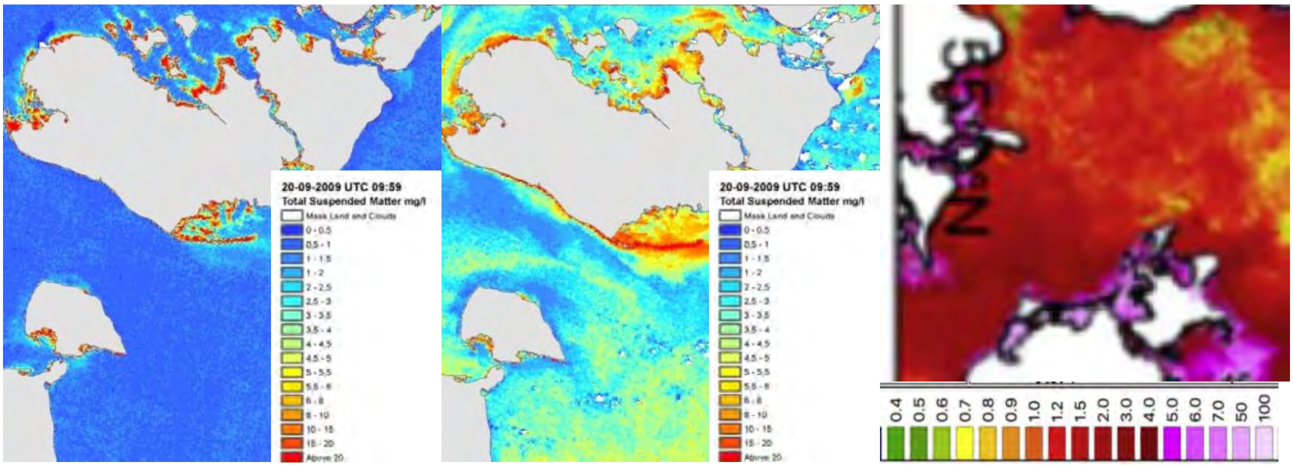


Figure 4.5: Turbidity profiles measured by Aarhus University [7] in Storstrømmen (96310031), and Fehmarnbelt (a-n: 98210002 (nearshore), o-q: 98200048 (open water))



Map of TSM derived from MERIS satellite image on 20/9-09 [10]

Map of TSM derived from MERIS satellite image on 5/10-09 [10]

Monthly composite from April 2018 of total suspended particulate matter [11]

Figure 4.6: Maps of total suspended matter derived from MERIS satellite data [10] and from OLCI data on Sentinel-A [11] (S3A, processed using the C2RCC neural network)

5. Methodology

To estimate the dispersion of sediment, two types of numerical models are used:

- An HD3D model describing the hydrodynamics.
- A MT model to simulate the dispersal and deposit of the sediments dispersed due to the installation

This section introduces the methodology and set-up of the models listed above.

5.1. Identification of the representative year

Regarding the period of time to be simulated with the model(s), the following topics had to be considered;

1) The currently planned installation period will start in May and finish by mid of September
2) Generally, an HD3D model demands intense computational power to carry out the simulations, with computational-to-real time ratios of 30[8]
3) In order to optimize the numerical modelling part, it was decided to simulate the environmental conditions over the planned installation period for a year that showed average hydrodynamic conditions for all the years available in the SMHI Baltic Sea model (2019-2022).

As a result of the sequence of considerations listed above, it was decided to simulate the period mid-April to end of October[9] of a representative year.

2020 was selected as a representative (*'average'*) year of hydrodynamic behaviour within the Storstrømmen area. The hydrodynamic and seawater property conditions (retrieved from the different[10] strategic model nodes of the SMHI Baltic Sea model, see detailed discussion in section 5.1.1 to 5.1.3) are comparable with the other years considered.

It is worth pointing out at this point that due to the coarse resolution of the SMHI data, the effect of the narrow straits are not represented properly in the SMHI data. The general validity of the parameters presented below is therefore limited, although it is considered sufficient to give an idea of the processes. Furthermore, the SMHI data are only used for illustrative purposes; for a detailed description of the currents and sediment dispersion, a detailed, fine-resolution model was set up as part of the project (see chapters 5.3 and 5.4.).

5.1.1. Current

The direction of current at the extraction sites is influenced by the geographical layout of the area. The overall current pattern in the area is governed by both the tidal component and the meteorological conditions. The tidal component is driving the flow on average through the entire water column, while currents at the surface are strongly influenced by the surface wind.

Regarding Point 1, Figure 5.1 illustrates that the primary current directions are Northwest and Southeast. This pattern is consistent across the other selected locations, as depicted in Appendix 1.

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[8] E.g. for the HD3D model set up for this project, one full month (720 hours) requires nearly 24 hours of actual computational time.

[9] Although the planned installation period runs from April to September, it was decided to run the HD3D and MT models from April 15th (allowing for 15 days of model spin-up time to provide meaningful values by 1st May) and October 30th (1 month after the expected end of installation works, to assess the resilience of the suspended sediment within the area)

[10] Six model nodes were analysed. For the sake of clarity, Section 5.1.1 to 5.1.3 present model data for one of the locations only.

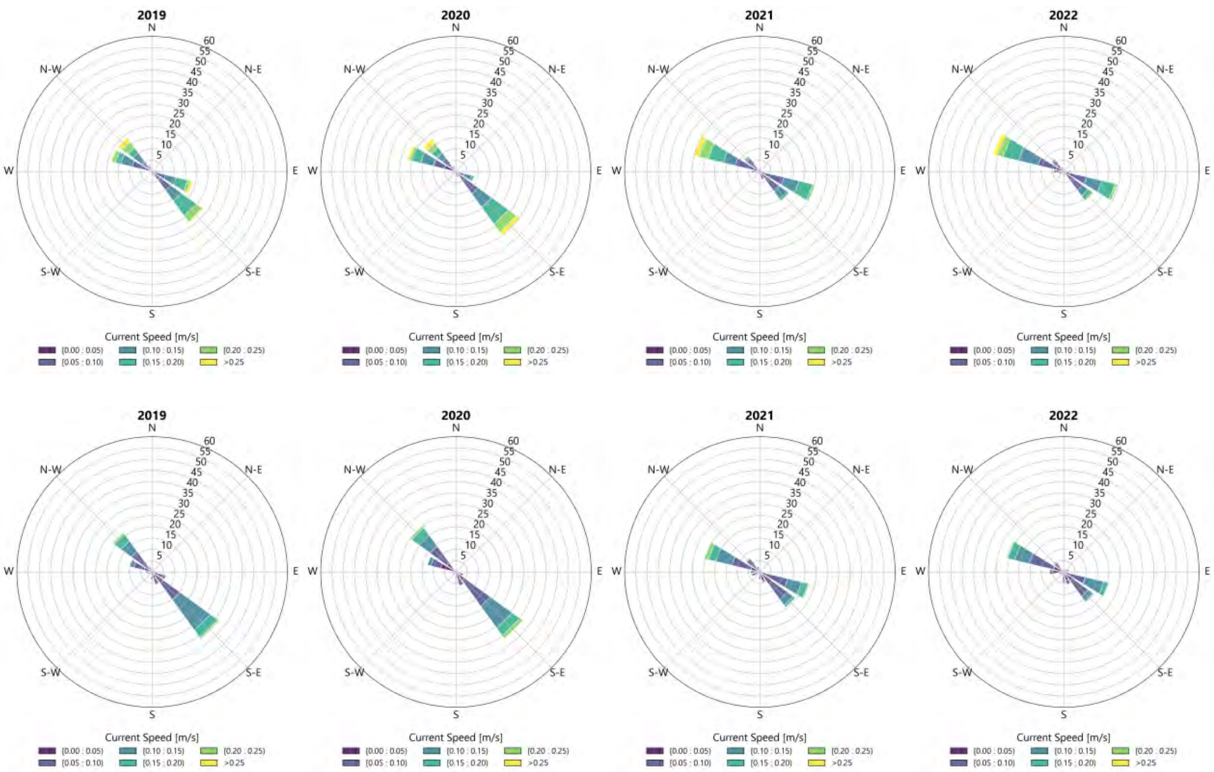

Figure 5.1: Annual Current roses extracted from SMHI-Data at Point 1 (see Figure 30 *in Appendix 1) at two distinct water depths: at the surface (top row) and at -4m (bottom row).*

5.1.2. Temperature

In Figure 5.2, the annual temperature variation along the depth at Point 1 (in Appendix 1) is depicted for four consecutive years, spanning from 2019 to 2022. The graphs distinctly illustrate that temperature fluctuations solely correlate with seasonal cycles: higher water temperatures are noticeable during the summer months, while lower temperatures prevail in the winter months. However, no discernible layering across the water column is evident in any of the presented series.

Plots extracted from locations further from the cable route, both to the East and to the West of the project area, are provided in Appendix 1. None of the extracted datasets exhibit observable layering attributed to temperature gradients.

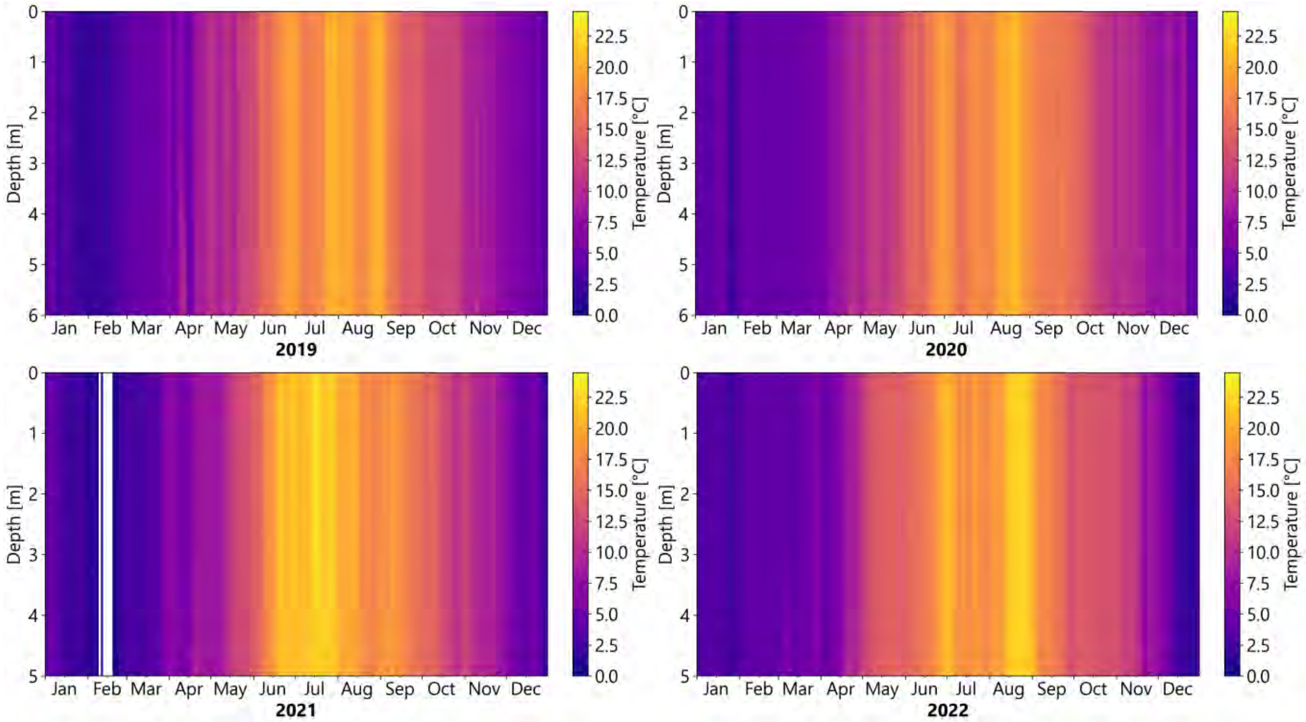

Figure 5.2: Temperature profiles extracted from SMHI-Data at Point 1 (location in Figure 30 *in Appendix 1)*

5.1.3. Salinity

In *Figure 5.3*, the annual temperature variation with depth at Point 1 (location see *Figure 30* in Appendix 1) is depicted for four consecutive years, spanning from 2019 to 2022. Contrary to what could be observed in Figure 5.2 for the temperature, a slight layering along the water column is noticed during the spring and fall periods.

Plots extracted from locations further from the cable route, both to the East and to the West of the project area, are provided in Appendix 1. Sites in deeper waters show temporal peaks in salinity at the bottom during the winter months, which can be attributed to the inflow of water with high salinity from the Kattegat/North Sea.

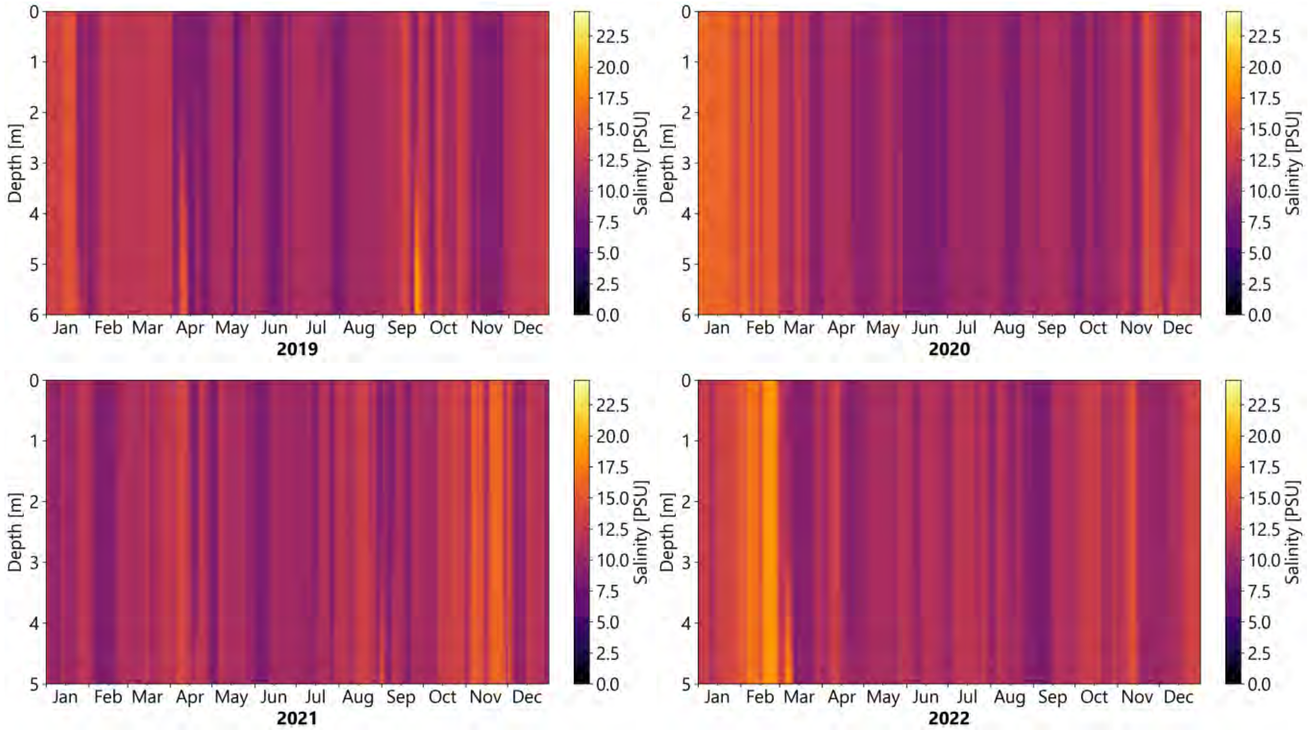

Figure 5.3: Salinity profiles extracted from SMHI-Data at Point 1 (location see Figure 30 in Appendix 1)

5.2. Computational grid

The mesh used in this study covers an area of 2,857 km^2 set between Sjælland, Fyn and Lolland.

The model incorporates varying horizontal resolutions to consider regional circulation patterns and local effects. It comprises 72,694 elements and 37,774 nodes. The mesh is coarser further away from the project area, with a coarsest element size of 5 km² reached on the East side of the project site. Here, the expected impact of sediment dispersal is minimal due to low currents. The mesh resolution gradually increases to 0.001 km² in the close vicinity of the planned construction work.

The vertical domain is described by 10 equidistant sigma layers (see visualisation of layer thickness in Appendix 4).

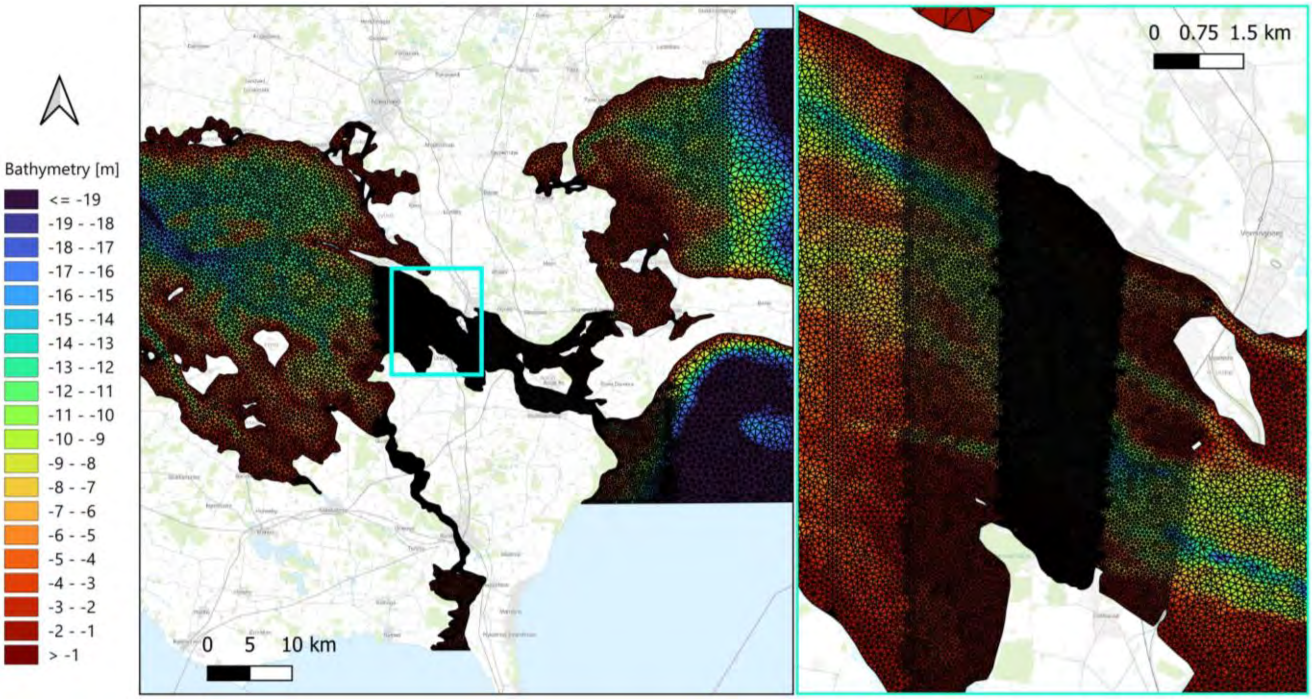

Figure 5.4: Zoom of the mesh and associated bathymetry of the sediment model for analysis of sediment dispersal.

5.3. HD3D Model

The hydrodynamic regime within the Storstrømmen area is modelled with MIKE 3 HD FM [12][11], which is a hydrodynamic model with a flexible mesh. The model simulates tide, surge, current speed and direction, temperature, and salinity throughout the model domain. The model is based on tidal, current, salinity and temperature inputs along the open boundaries together with the meteorological conditions at the sea surface, and across the water column.

The benefit of a flexible mesh is that - among others – it allows for the possibility of using varying sizes of the mesh across the domain. Therefore, the focus area can have a high resolution and more distant areas can have a coarser resolution to increase the efficiency of the model.

Section 5.3.1 to Section 5.3.3 present the details of the hydrodynamic and atmospheric forcing imposed on the HD3D model.

5.3.1. Hydrodynamic and atmospheric forcing

As introduced in Section 4.2 earlier, the HD3D model was forced hydrodynamically along its water boundaries by hourly values of water salinity and temperature profiles as well as Sea Surface Elevation (***SSE***) (or water levels) from the SMHI Baltic Sea hydrodynamic model. The atmospheric forcing originated from hourly values of 10mMSL wind and sea level pressure fields from ERA5.

The time period considered was April 15th 2020 00:00 to October 30th 2020 23:00.

[11] For more information about the MIKE 3D HD FM modelling suite, see https://manuals.mikepoweredbydhi.help/latest/Coast_and_Sea/MIKE_FM_HD_3D.pdf

5.3.2. Calibration / Verification

With regards to the validation process carried out in terms of water level, temperature and salinity, simulated data were compared to data collected at stations located within a 35km radius from the project site. The location of above-mentioned stations is shown in Figure 4.2.

5.3.2.1. Water levels

The water levels computed by the hydrodynamic model were validated against the water levels recorded by tide gauges at the stations within the model domain. With mean errors (***ME***, Table 5.1) varying between -0.01 m and -0.04 m and mean absolute errors accounting to maximum 0.06 m (***MAE***, Table 5.1), the quality of the hydrodynamic model in respect of the water levels is assessed to be satisfactory.

In Figure 5.5 and Figure 5.6, the measurements extracted for one of the stations, ID station 9030201, are compared to the simulated water level. Additional comparisons can be found in Appendix 2.

The comparison of observations and model output during the period April 2020 to October 2020 shows a correlation coefficient of 0.94, which is assessed to be a good correlation. The model satisfactorily captures the tidal signal even if certain periods of the simulation show differences in magnitude up to 10 cm (Figure 5.6). Even if the significance of the validation for the project area itself is limited due to the large distance between the measurement sites and the project site, the results presented emphasize the general quality of the HD model.

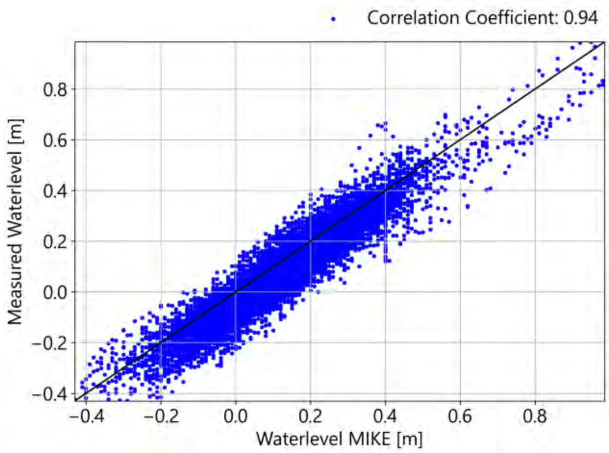

Figure 5.5: Comparison between modelled and measured water level time series at station 9030201.

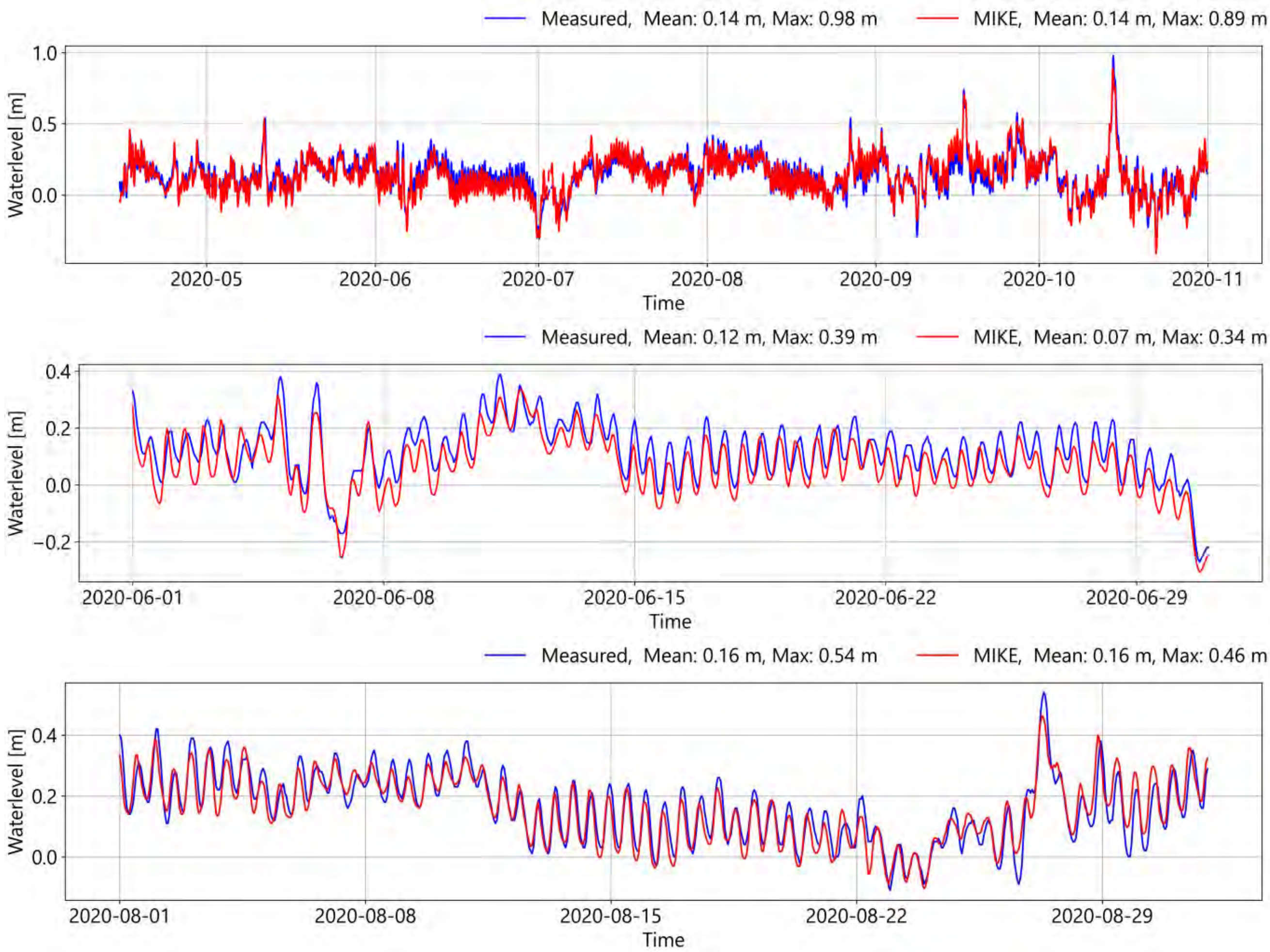

Figure 5.6: Comparison between modelled and measured water level time series at station 9030201. Top: entire simulation period. Middle and bottom: extracted months respectively June and August.

Table 5.1: Performance Metrics of the HD-Model in respect to the Water levels (between 15th of April to 31st of October 2020).

Station-ID	ME [m]	MAE [m]	RMSE [m]	STD of Residuals [m]	Correlation Coefficients [-]
9030501	-0.03	0.06	0.07	0.06	0.94
9030301	-0.04	0.05	0.06	0.04	0.94
9030201	-0.01	0.03	0.04	0.04	0.92

5.3.2.2. Temperature profiles

In the context of comparing recorded temperature vertical profiles with simulated profiles, as depicted in Figure 5.7, Figure 5.8 and Figure 5.9, it is evident that the modelled profiles exhibit a similar overall trend to the recorded ones. For instance, there are small gradients along the depth for stations STO-0101015 and STO-0201076, and some slight stratification for STO-0901016, which are consistent with the recorded data.

However, the vertical resolution of the model (10 equidistant layers covering the entire depth at any location within the domain) is not always able to adequately replicate the temperature vertical gradients that can be observed in the first two shown time steps in Figure 5.9. There is no consistent pattern in the differences between simulated and recorded temperature values. At certain time steps, the model underestimates the temperatures, while at other times, the modelled results are higher than the measured ones.

Overall, the comparison is considered satisfactory, as the model accurately represents the vertical profiles at lower water depths (i.e. no thermocline within the project area), and an offset in terms of the absolute temperature does not have any impact on the model results. The complete set of results obtained for the above-mentioned stations and the comparison of modelled against measured parameters for the remaining stations are reported in Appendix 2.

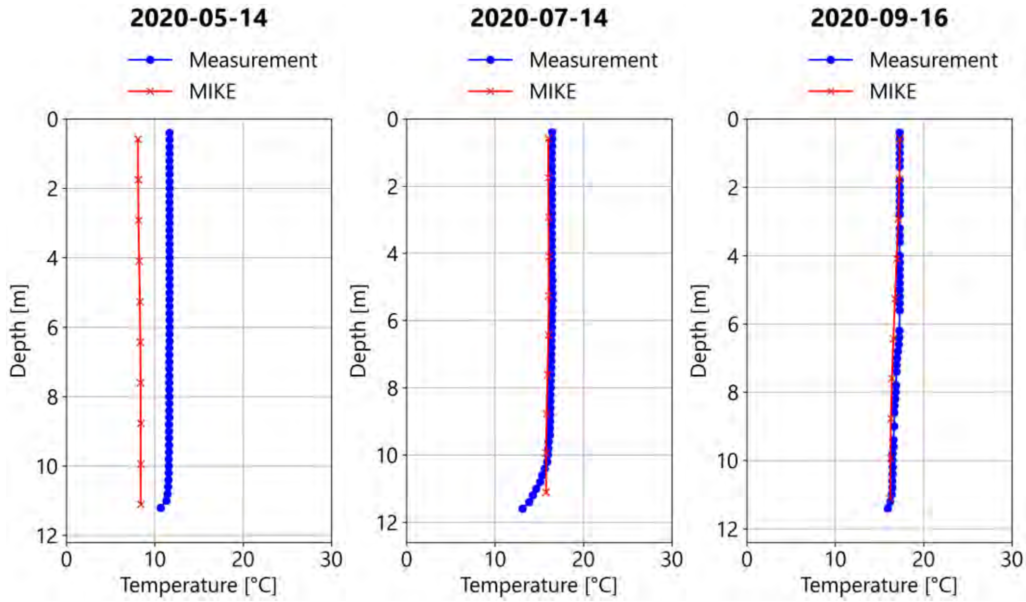

Figure 5.7: Comparison between modelled and measured temperature profiles at the station STO-0101015

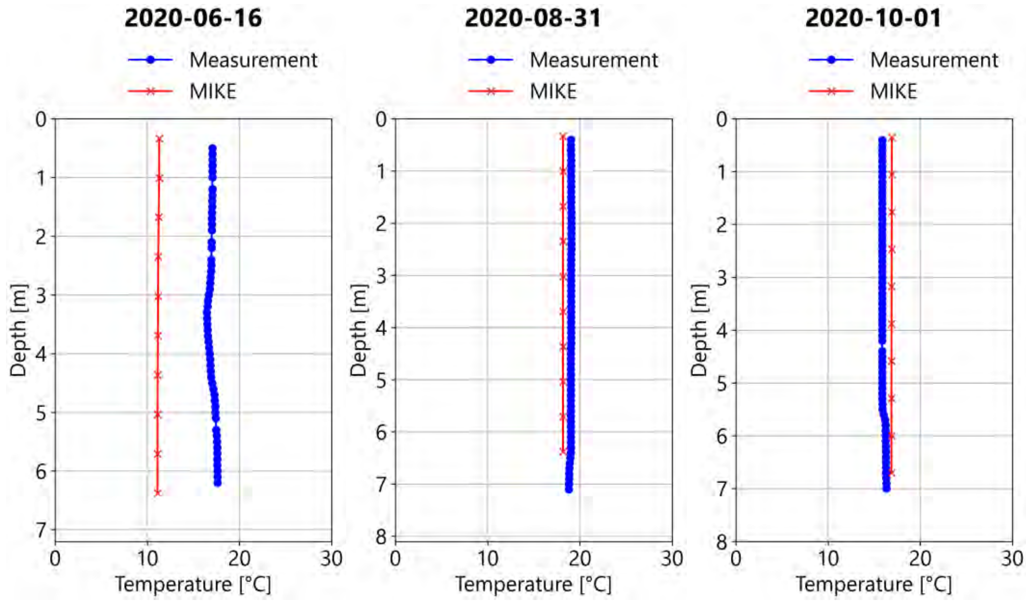

Figure 5.8: Comparison between modelled and measured temperature profiles at the station STO-0201076

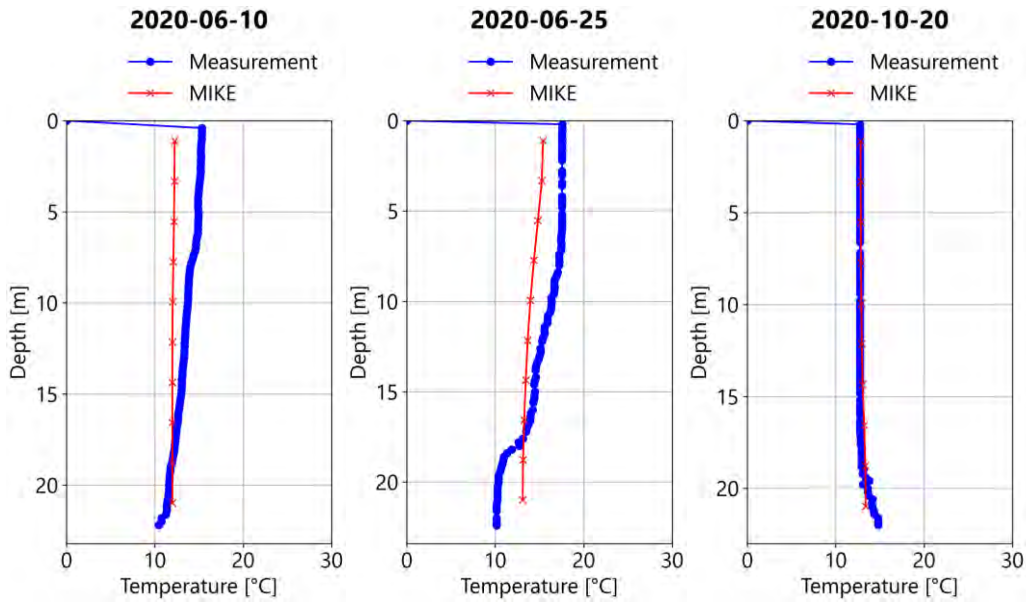

Figure 5.9: Comparison between modelled and measured temperature profiles at the station STO-0901016

5.3.2.3. Salinity profiles

The model performance with respect to the variation of salinity compared to depth is based on the vertical profiles retrieved from Aarhus University (see location and source, Table 4.1).

The analysis of the vertical salinity profiles suggests a generally good agreement across most profiles for both calculated and measured data (depicted in Figure 5.10, Figure 5.11 and Figure 5.12, along with additional figures in the Appendix 2). There are instances of minor stratification in the measurements, notably at stations STO-0101015 and STO-0901016, which becomes more pronounced during summer. This stratification is not adequately captured by the model due to limitations in the vertical resolution, particularly in reproducing salinity gradients in deeper areas of the domain.

Since the depth in the vicinity of the project area, where sediment is released, is limited to less than 15 m, a halocline is not to be expected in these areas and therefore the inadequate reproducibility of the model with regard to the salinity gradient is not a significant concern.

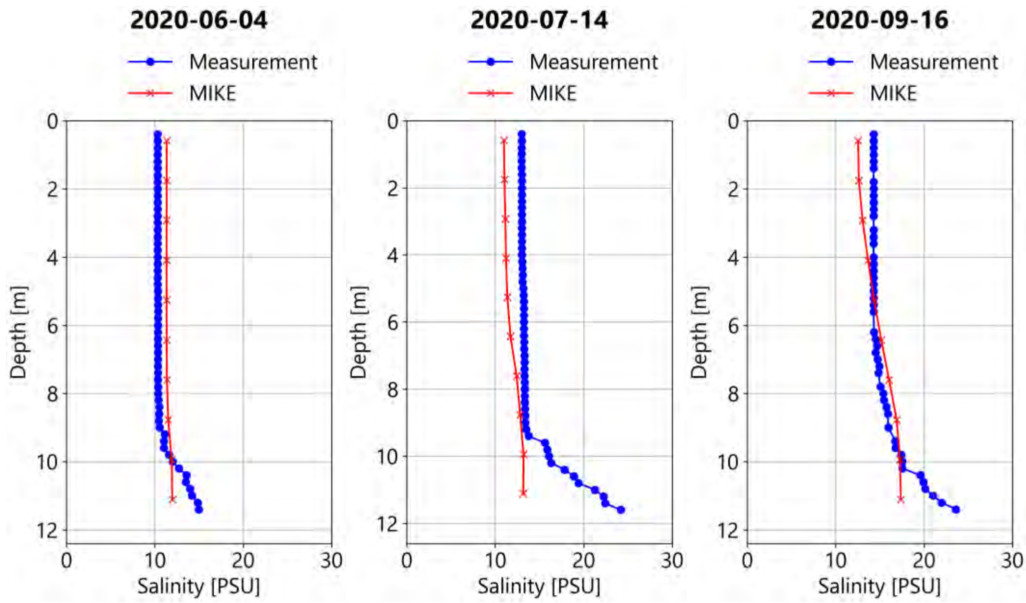

Figure 5.10: Comparison between modelled and measured salinity profiles at the station STO-0101015

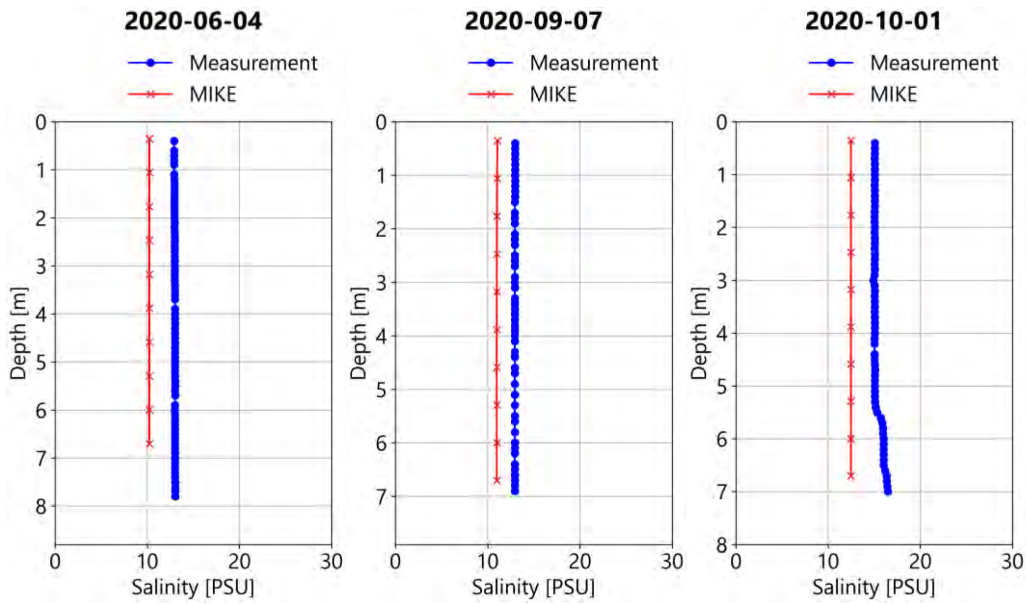

Figure 5.11: Comparison between modelled and measured salinity profiles at the station STO-0201076

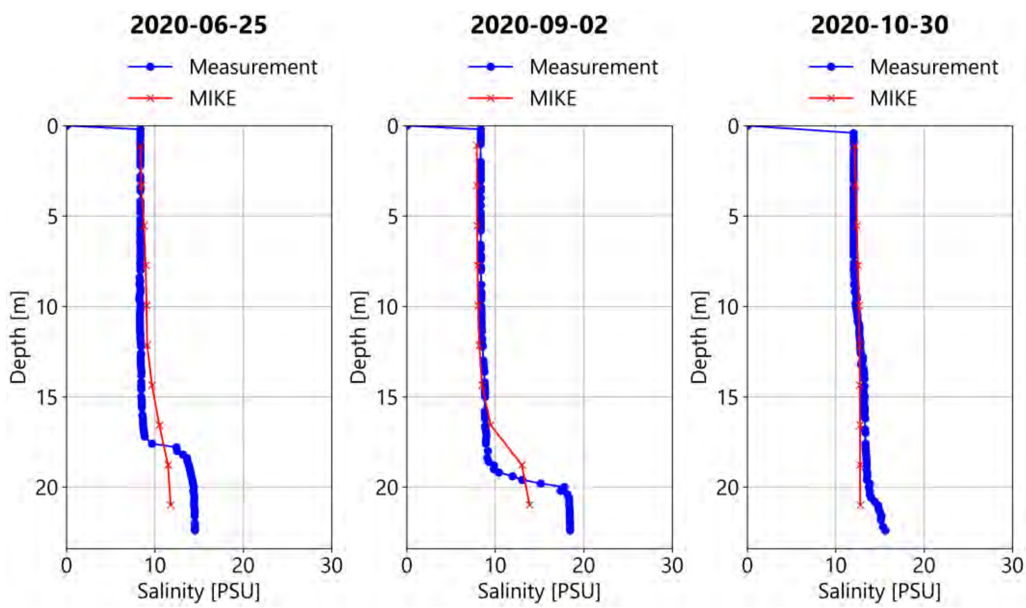

Figure 5.12: Comparison between modelled and measured salinity profiles at the station STO-0901016

5.3.3. Model setup

The HD3D model settings that led to the outcome shown in Section 5.3.2, then applied to the production simulation period is shown in Table 5.2

Table 5.2: Summary of the HD3D model settings applied for the production simulation period.

Setting	Value
Mesh resolution	5 km^2 (at the boundaries) to 0.001 km^2 (at the project area)
Simulation period	Apr 15th 2020 00:00 to Oct 30th 2020 23:00
Governing Eq.	Shallow water equations
Sol. Technique	Time/Space integration: Low/High order
Min/Max timestep	0.01/1800 s
Density type	As function of salinity and temperature
Eddy viscosity	Smagorinski formulation
Bed resistance	Roughness height 0.05m
Ice coverage	None
Precipitation/evaporation	No precipitation/evaporation varying in time and space (ERA5)
Atmospheric forcing	Wind speed/direction at 10mMSL and mean sea level pressure fields. (ERA5) Wind friction factor constant 0.001255
Hydrodynamic forcing	Water levels along water boundaries. Water salinity and temperature profiles along and across water boundaries (SMHI)

5.4. Sediment model (MT)

Spill modelling is conducted using DHI's fine sediment model MIKE3 MT. Since the sediment model is an add-on to the hydrodynamic model, current and water level data are transferred per 30 minute-time step for the advective transport of the sediment and deposition/resuspension of near-bottom sediments.

5.4.1. Model setup

The sediment model itself contains information as follow:

1) The sediment types are split into 6 categories based on the diameter, whereas coarse sediment is not modelled as it is assumed to settle close to the source (Table 5.4).
2) For erosion a critical shear stress is applied e.g., 0.3 N/m^2 [13].
3) Vertical and Horizontal dispersion coefficient are set to 0.01
4) A description of the sediment source in time and space is applied.

In addition, the model can be described by the following characteristics.

Excess model: The model is designed as an excess model, focusing solely on the spilled material. As earlier described, the background concentration is generally low with values around 1- 2 mg/l.during the period of activity (May-September Table 3.2, details in respect to the background concentration see chapter 4.6). The background concentration and the interaction with it is not included in this model as the concentrations considered insignificant. Flocculation of suspended material are generally seen at higher concentration above 10 mg/l. This argument holds for the majority of the area.. Nearshore background concentrations can become high during storms. However, in these areas the seabed mostly consist of coarser materials like sand and silt which do not interact with the cohesive sediments treated in this model.. Therefore, only one layer of sediment is included at the bottom, assuming that the sediment layer is newly deposited.

Flocculation: As the fine-grained part of the suspended sediment is transported in the water column, it will flocculate and form larger particles with correspondingly higher settling velocities. The flocculation of sediment depends on various parameters such as type of sediment, sediment concentration, turbulence, salinity, and the amount of organic matter [14]. Organic matter acts as a glue between the free particles, and a mixture of organic and non-organic sediment will thus achieve higher settling velocities than purely organic and purely non-organic material [15]. Flocculation is included based on the settling velocities (see Table 5.4) from the field study of Fehmarn Belt [13] The exact increase in particle size as a result of flocculation is not modelled but represented by the settling velocity. Flocculation is included to some degree, but as the data is based on experiments, the simulation exhibit some uncertainty.

Consolidation: Once deposited, the sediment will begin to consolidate due to the weight of the sediment deposited above it, leading to a slow compaction of the sediment, an increase in density and strength over time, and thus a decrease in the bottom level if no further sediment is deposited. In the numerical simulation, a consolidation of the sediment is not considered, and the calculated sediment heights are based on a density of 180 kg/m^3. However, to account for the fact that consolidated sediments exhibit higher densities, the resulting sedimentation is shown by deposition heights calculated with three different densities, as shown in Table 5.3.

Table 5.3: Dry densities of different soil type and consolidation states

	Dry density range	Selected density	Source
Mud (weakly consolidated)	100 – 250 kg/m³	180 kg/m³	[16]
Mud (consolidated)	250 – 400 kg/m³	300 kg/m³	[16]
Sand		1,650 kg/m³	

5.4.2. Sensitivity of mesh

In the MIKE-Mud model, the sediment is always equally distributed within a cell (no concentration-gradient within the cell) and increasing cell volumes will result in lower concentrations. Consequently, a coarser mesh will lead to increased numerical dispersion. At the same time, the coarser the mesh resolution is selected, the faster the individual simulations can be calculated.

In order to optimize the mesh resolution with respect to the computational time required to perform the simulations, three different mesh resolutions are investigated. In this way, the numerical dispersion, sediment dispersal (based on a fictive point source of around 7.6 kg/s) is investigated (results in Figure 5.13).

The comparison of sediment plumes calculated with different mesh resolutions, shown in Figure 5.14 reveals that the coarse mesh leads to a more pronounced dispersion visible by the larger extent of the sediment plume with generally lower concentrations. In contrast, the sediment dispersal of the two finer meshes can be considered as comparable. Therefore, the gradually increasing mesh resolution towards the cable route is considered a suitable compromise between computational time and accuracy.

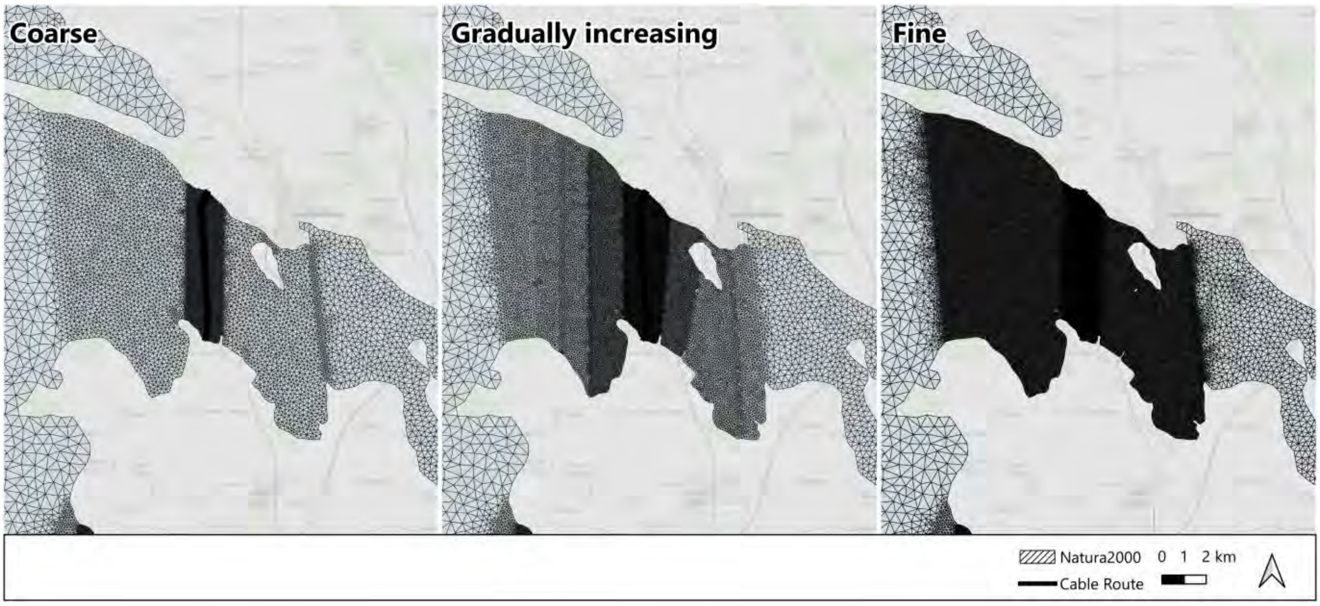

Figure 5.13: Mesh resolutions tested in order to find a suitable compromise between compuational time and numerical dispersion accepted. (The coarse mesh consists of 43'851 elements, gradually increasing to 37'774 elements; the fine mesh has 61'126 elements)

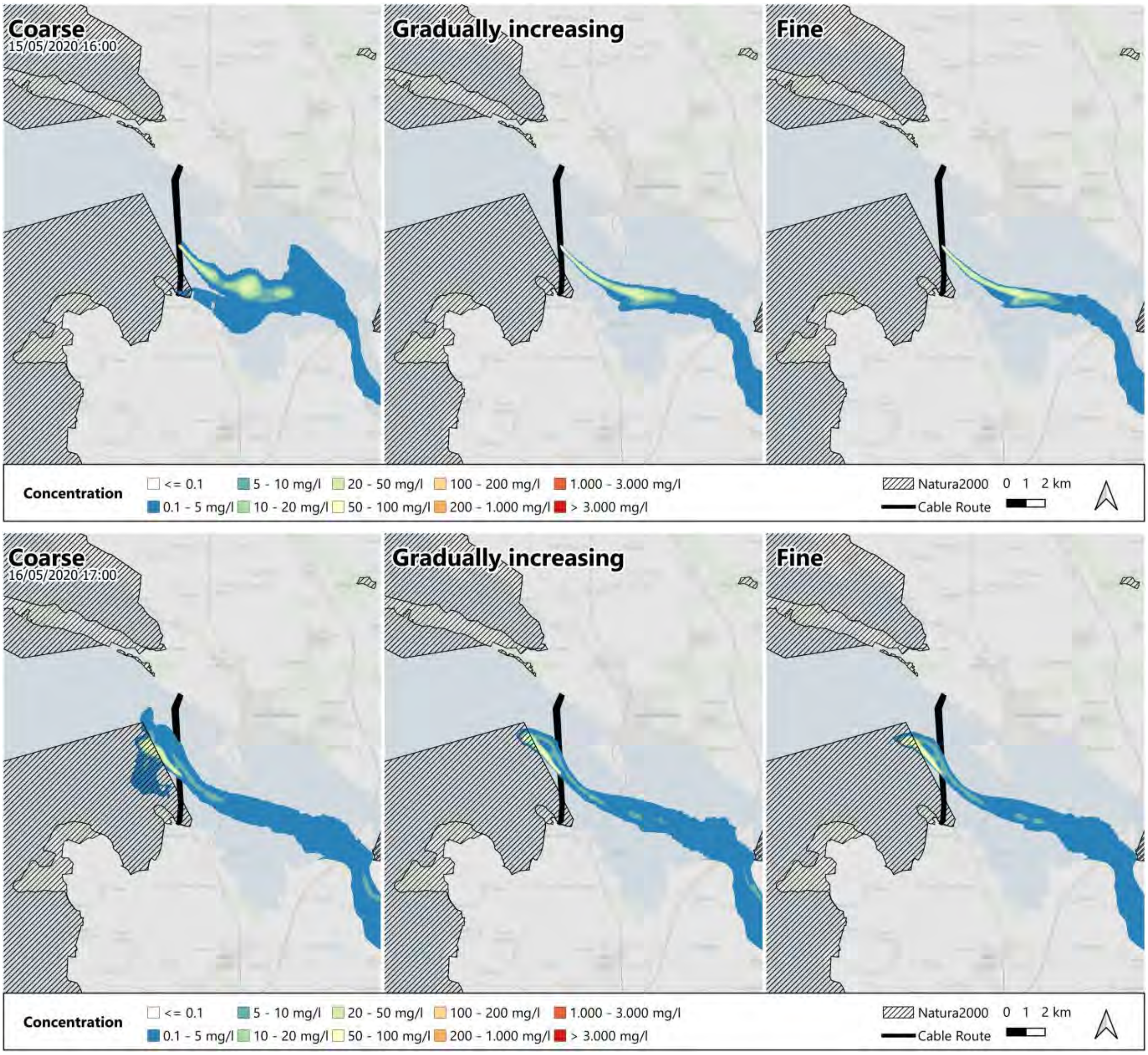

Figure 5.14: Comparison of the plume extent of the sediment concentration (SSC) due to different mesh resolutions simulated on two different dates, 15/05/2022 and 16/05/2022.

5.4.3. Sediment type

For the purpose of characterizing the sediment type, the average granulometric curves of the five categories of seabed interpreted geologically by Rambøll (see Figure 4.3, [8]) are derived by averaging the grab samples within the different geological categories. The sediment released is described by the geological category extracted along the cables within a 200 m-interval.

The sediment is described by six categories based on grain sizes and settling velocities, as shown in Table 5.4. Coarse sand larger than d=0.25 mm is assumed to settle next to the source and is therefore not included in the modelling, while the finer sediments are available for dispersion and transport.

Table 5.4: Sediment categories and settling velocities [13] used for the modelling of the sediment dispersion.

	coarse	fine sand	coarse silt	medium silt	fine silt	Clay
Settling velocity	-	15.0 mm/s	2.90 mm/s	0.560 mm/s	0.070 mm/s	0.030 mm/s
d, mean	-	0.1565 mm	0.0425 mm	0.0141 mm	0.0044 mm	0.0013 mm
d, minimum	-	0.0630 mm	0.0219 mm	0.0062 mm	0.0025 mm	0.0000 mm
d, maximum	-	0.2500 mm	0.0630 mm	0.0219 mm	0.0062 mm	0.0025 mm
Mud and sandy mud	21.8%	36.5%	10.8%	8.9%	6.5%	15.5%
Muddy sand	1.9%	28.0%	22.6%	20.0%	9.4%	18.1%
Sand	8.2%	89.8%	0.5%	0.5%	0.5%	0.5%
Gravel and coarse sand	2.1%	85.1%	5.8%	2.3%	1.9%	2.8%
Till/Diamicton	14.5%	63.6%	8.0%	5.3%	3.2%	5.4%

5.4.4. Estimated spill

Based on the program (Table 3.2) developed in consultation with the client, sediment is spilled between 1 May and 15 September. Two main phases (see program Table 3.2), namely excavation and backfilling, can be identified.

In order to describe the different activities and the depth of the spill, 12 different sources are included in the model (Table 3.1). A total of 5,365 m^3 of sediment is spilled, 13% of which is coarse material not modelled and assumed to settle next to the source.

Table 5.5: Total expected spill along cables

Sediment →	**coarse**	**fine sand**	**coarse silt**	**medium silt**	**fine silt**	**Clay**	**Sum**
Activity ↓	**m^3**	**m^3**	**m^3**	**m^3**	**m^3**	**m^3**	**m^3**
Excavating (North, shallower than 6 m) - Cable 1	5	114	6	2	2	3	**132**
Excavating (deeper than 6 m) - Cable 1	116	578	79	57	34	64	**929**
Excavating (South, shallower than 6 m) - Cable 1	15	229	12	6	5	7	**274**
Excavating (North, shallower than 6 m) - Cable 2	5	113	5	2	2	3	**130**
Excavating (deeper than 6 m) - Cable 2	124	576	80	58	34	63	**936**
Excavating (South, shallower than 6 m) - Cable 2	15	238	13	6	5	7	**283**
Backfilling (North, shallower than 6 m) - Cable 1	5	114	6	2	2	3	**132**
Backfilling (deeper than 6 m) - Cable 1	116	578	79	57	34	64	**929**
Backfilling (South, shallower than 6 m) - Cable 1	15	229	12	6	5	7	**274**
Backfilling (North, shallower than 6 m) - Cable 2	5	113	5	2	2	3	**130**
Backfilling (deeper than 6 m) - Cable 2	124	576	80	58	34	63	**936**
Backfilling (South, shallower than 6 m) - Cable 2	15	238	13	6	5	7	**283**
Sum	**560**	**3,696**	**389**	**264**	**163**	**293**	**5,365**
Proportion	**10%**	**69%**	**7%**	**5%**	**3%**	**5%**	**100%**

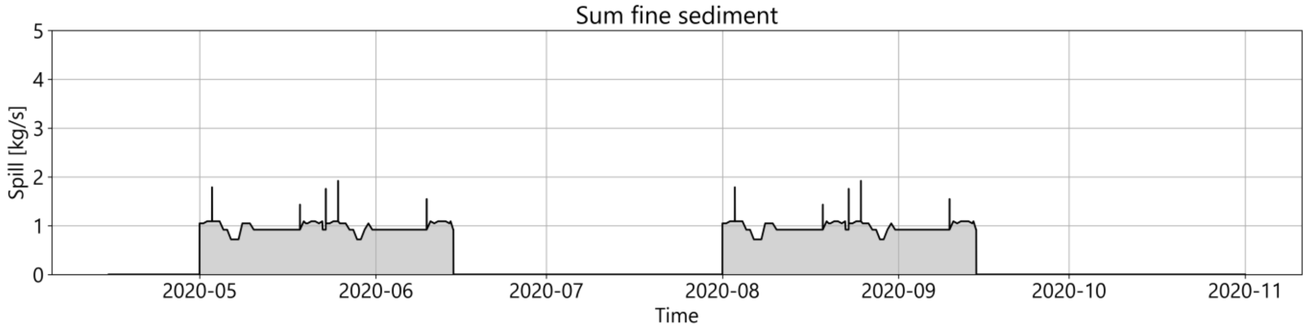

Figure 5.15: Timeseries of sediment spill due to the construction work (coarse material is neither included in the model nor in the plot above).

5.5. Light attenuation

5.5.1. Background concentration

The maximal water depth in close vicinity of the project area is approximately 15 m. Therefore, it can be assumed, that the background sediment concentration is likely to be controlled by current strength and other activities in the immediate area.

As described in chapter 4.6, no background measurements have been made for this project. But intensive measurements have been carried out at the Fehmarnbelt at similar water depths [17], and the turbidity conditions are deemed to be similar at Storstrømmen. The information on sediment properties at the Fehmarn Belt are also used to calculate the light attenuation. Also at the Fehmarn Belt [17] very low concentrations below 1-2 mg/l were observed 99% of the time and only very few events where the concentration exceeded this. Only near land, where the waves had a greater effect, periodically higher concentrations were observed.

5.5.2. Calculation of Light attenuation

The attenuation of light in the water column has a major impact on what life can exist in the ocean, as plant life at the bottom of the ocean depends on the amount of light that penetrates the water column. Aquatic plants use the light for photosynthesis, which also affects the oxygen content of the water. Aquatic plants grow at different depths depending on the natural amount of light at the bottom. They are stationary and therefore reduced light conditions can have a major impact on the distribution of certain plant species (e.g. seagrass). It is therefore important to investigate the effect of light attenuation as a result of sediment spreading in connection with dredging/jetting in the construction phase.

As light travels through a medium, the light intensity will decrease exponentially with the distance travelled. In water, the light intensity to a depth z will be given by I_z,

$$I_z = I_{z=0}\, e^{-z\, K_d}$$

With $I_{z=0}$ standing for the light intensity from the sun at the water surface and K_d is the attenuation coefficient in the water.

In connection with the EIA for the Fehmarn Belt Fixed Link, light attenuation tests were carried out [17] . The experiments showed that the attenuation coefficient can be described by the cross-sectional area, A (mm^2/l), of particles in the water column independently of the sediment grain size distribution:

$$K_d = 7.45 \cdot 10^{-4} A + K_{d0}$$

whereas K_{d0} is the attenuation coefficient for the background concentration. Without adding sediment to the water, the attenuation coefficient according to the Fehmarn Belt analyses is K_{d0} =0.0756 m^{-1}.

The light attenuation is calculated according to the following formula:

$$I_z = I_0\, e^{-z\, K_d}$$

where I stands for the light intensity and the index z the water depth.

Effect of flocculation: Light attenuation is mainly driven by the fine sediments. As the increase in settling velocity as a result of flocculation is not modelled, the proportion of the fine fraction tends to be overestimated, and consequently the light attenuation will be overestimated

6. Assessment of impacts during the construction phase

As demonstrated by the concentration measurements at the Fehmarnbelt [10], suspended sediment concentrations are generally very low in the period of activity. Therefore the present study only analyses the distribution of the sediment released during the construction phase (excess model) which could also be defined as the excess concentration. In this document is called the concentration. The impact of the construction activities is analysed by:

- Sediment concentrations and their duration
- The effect of the observed concentration on the light attenuation at the bottom
- Sedimentation heights and their duration

The results are presented in the report based on the example of one threshold in each case. For a detailed overview of all analysed thresholds, see the appendices mentioned in the individual chapters.

The time interval considered for the evaluation covers a period between 15th of April to 15th of October 2020 (1 month after the end of the spill).

6.1. Concentration

The sediment concentrations expected according to the simulated installation program and the associated periods during which they will be reached or exceeded are discussed hereafter. It is note-worthy to remember that the water column is vertically divided into 10 equally spaced sigma-layers (see visualisation of layer thickness layers in Appendix 4). The resulting concentration in each layer depends considerably on the variation in the represented water depth. Consequently, for a water depth of one metre, the layer thickness accounts for 10 cm. At a depth of 15 metres, one layer covers 1.5 metres. Thus, taking into account the bottom and top layer would lead to higher uncertainties, as the concentrations depicted in shallow waters are relatively higher when compared to those in deep waters, where the concentrations are averaged over a wider depth, i.e. the layer thickness.

A depth-independent approach was established for processing and analysing results, aiming to ensure consistency regardless of variations in water column depth. This method involves evaluating concentrations within fixed depth ranges, specifically targeting the first 2 meters from both the sea bottom (bottom of the water column) and the free surface (top of the water column). Where the depth is lower than 2 meters, the methods adapts the computation to the specific depth value averaging over a smaller range.

6.1.1. Maximum concentrations

The released sediments are transported and dispersed with the currents, leading to a decrease in sediment concentration with distance from the source. Table 6.1 shows the total area, where a certain maximum concentration is reached or exceeded.

Table 6.1: Area (ha) experiencing maximum sediment concentration equal or greater than 5, 10, 20, 50, 100, 200, 300 mg/l at different depth interval. For info: 100 ha = 1 km², top describes the uppermost 2 m of the water column and bottom, the 2 m above the ground. The brightness of the cell colour indicates the magnitude of the area (dark colour = large area).

		Maximum Concentration [mg/l]								Maximum [mg/l]
		5	10	15	20	50	100	200	300	
	Top	85 ha	44 ha	27 ha	22 ha	9 ha	4 ha	2 ha	1 ha	636
	Depth averaged	338 ha	113 ha	60 ha	41 ha	12 ha	4 ha	2 ha	1 ha	635.9
	Bottom	2,490 ha	969 ha	550 ha	373 ha	71 ha	23 ha	8 ha	4 ha	635.9

The maximum sediment concentrations shown in Table 6.1 represent only a snapshot, however, as the sediment is released close to the sea bottom, highest concentrations occur close to the bottom too.

To illustrate the temporal variations of the sediment concentrations, time series of the sediment concentration are extracted at 5 different locations, (Figure 6.1 and Appendix 7, points described in Table 6.2). The time series of concentration at the bottom of the water column (2 meters range) for point 1 and 3 are shown respectively in Figure 6.2 and Figure 6.3, revealing temporal fluctuations in the concentrations. The increase of sediment in suspension for each of the points corresponds to the spill period simulated in Figure 5.15, and once the activities cease, the concentration tends to decrease. The time series of the remaining points can be seen in Appendix 7. The examples clearly show that the suspended sediment concentrations are highest at the bottom, where the dredging takes place.

Figure 6.1: Overview of point location, where the timeseries of the concentrations are extracted from (see resulting time series in Appendix 7).

Table 6.2: Coordinates and water depth at the locations of extraction of the concentration time series (ee Figure 6.1 and timeseries in Appendix 7)

Extracted Points			
Point ID	**Location - X [m]**	**Location - Y [m]**	**Depth [m]**
1	679881	6097982	-8.40
2	692693	6093905	-2.66
3	676001	6102920	-9.62
4	686981	6094329	-12.03
5	692577	6089415	-16.09

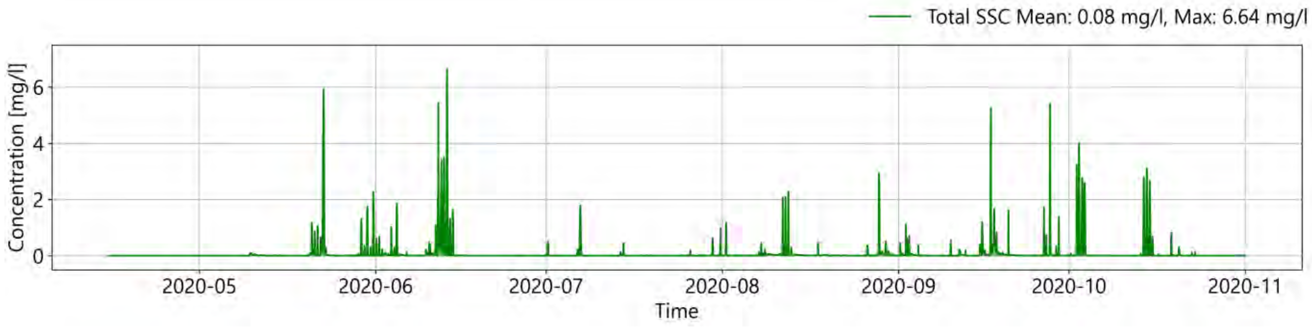

Figure 6.2: Timeseries of concentration at the bottom (averaged between 0 and 2m above ground) at point 1.

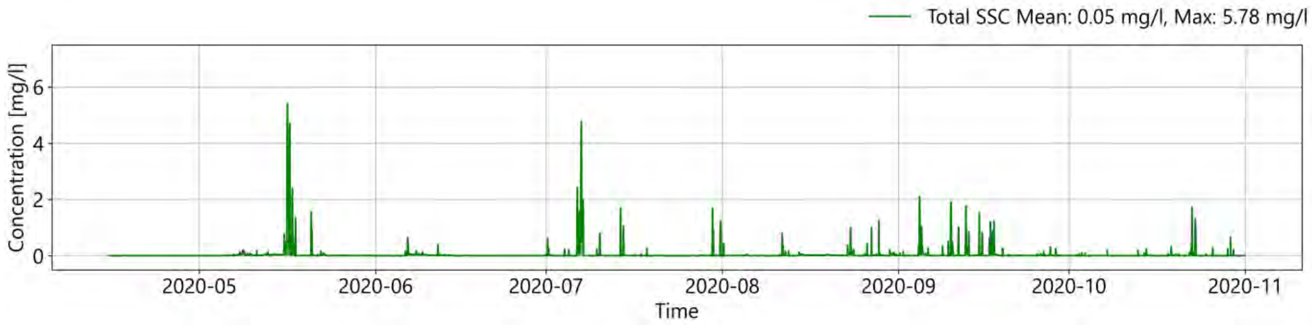

Figure 6.3: Timeseries of concentration at the bottom (averaged between 0 and 2m above ground) at point 3

6.1.2. Exceedance durations

The results are presented in terms of:

- The cumulative duration: a threshold is reached or exceeded (Figure 6.4, Table 6.3 and Appendix 5 where a comprehensive compilation of additional concentration thresholds and zooms are provided)
- The longest consecutive duration a threshold concentration is reached or exceeded (in Figure 6.5, Table 6.4 and Appendix 6)

The simulation results allow the following three main observations:

Vertical domain: Highest concentrations at the bottom

Since the sediment is released close to the bottom, the highest concentrations, exceeded over the longest period of time, can be observed within the 2 m above the bottom (bottom 2 m, Figure 6.4). For example, 5 mg/l is reached or exceeded in an area of 232 ha for at least 24 hours (1 day, cumulative duration), or in an area of 14 ha for 2 days (see Table 6.3). In contrast, the concentrations in the uppermost 2 m of the water column and averaged over the water column are significantly smaller. Sediment concentrations of 5 mg/l cannot be, independent of the vertical position, observed for a period longer than 2.6 days.

Horizontal domain: Highest concentrations in the deeper waters

Regarding the spatial pattern, the highest concentrations, reached or exceeded over the longest period, can be observed in areas with larger water depths (aligned with the observations at Fehmarn Belt, where , which can be explained by the high horizontal current speeds.

As the overlay with the horizontal current speeds (Figure 6.6) reveals, relative high current speeds occur mainly in areas with deeper water, indicating that the horizontal current velocities (the back and forth movement of the water) transport the sediment longer distances before it settles. In contrast, current speeds are much lower in shallower areas, so sediment settles close to the source (see section 6.3).

Considered periods: Significant difference between cumulative and consecutive periods
With regard to the cumulative period, a maximum of 5 mg/l is reached or exceeded over a period of 2.6 days. In contrast, the longest consecutive periods with maximum duration amounts to only 0.6 days. This is due to the spatially and temporally distributed activities. The sediment is not released continuously at one location, but the sediment release moves along the cables. Sediment is released at the same location (with an offset of more than one month) through excavation and backfilling. After release, the concentration of the suspended sediment decreases temporarily due to dispersion and settling. The sediment concentration can increase again as a result of the resuspension of the already settled material.

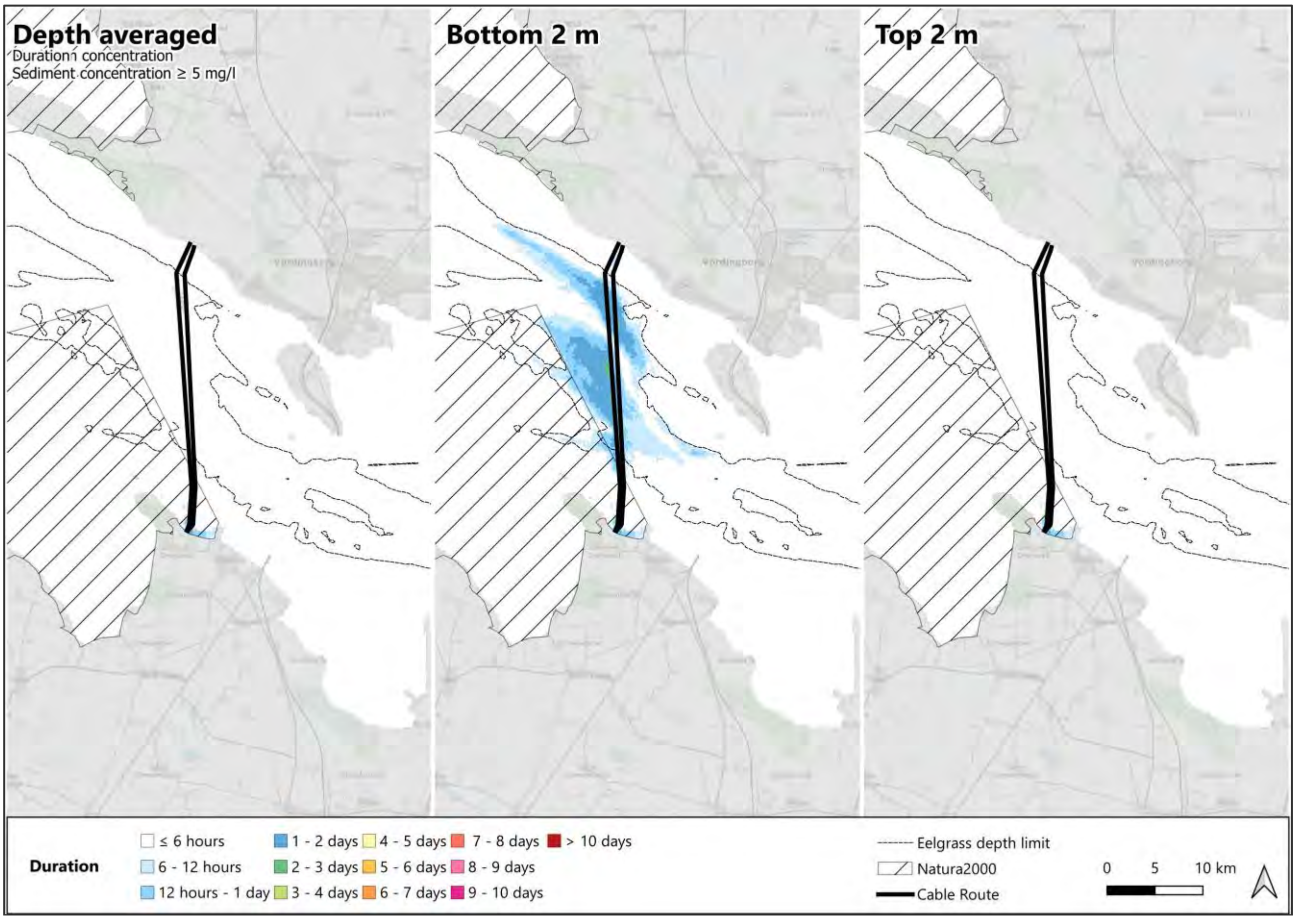

Figure 6.4: Cumulative duration during which a sediment concentration of 5 mg/l is reached or exceeded averaged over the entire water column (left); within the lowest 2 m of the water column (centre and within the uppermost 2 m of the water column (right). The eelgrass limit depth shown varies for the individual water bodies (see delimitation in Appendix 4).

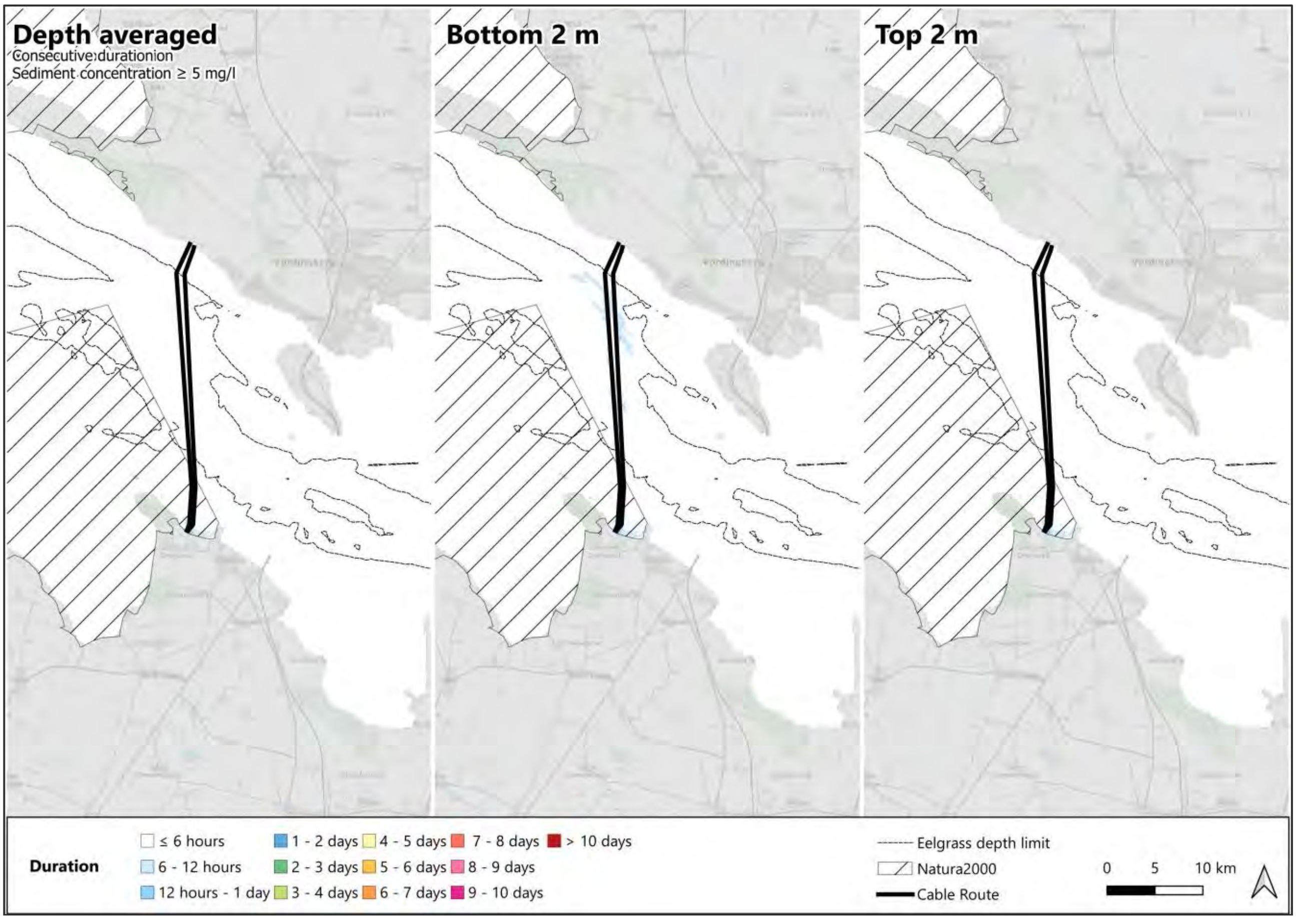

Figure 6.5: Longest consecutive duration during which a sediment concentration of 5 mg/l is reached or exceeded averaged over the entire water column (left); within the lowest 2m of the water column (centre;) and within the uppermost 2m of the water column (right). The eelgrass limit depth shown varies for the individual water bodies (see delimitation in Appendix 4).

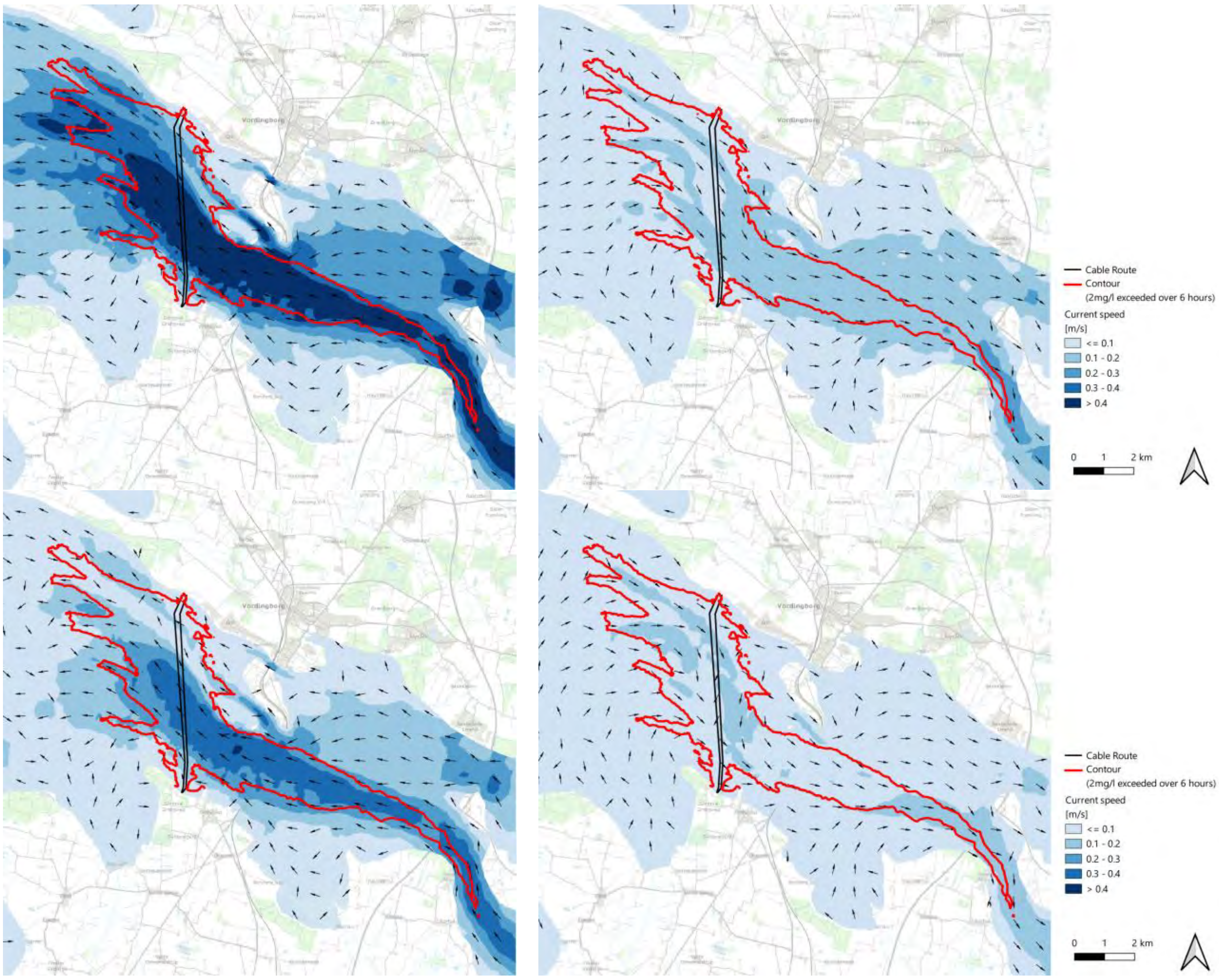

Figure 6.6: Simulated current speed at two distinct time steps on 1st of June 2020 with opposite current directions (The inversion of the current within the same day is due to the effect of the semi-diurnal tide). The figures on the same side of the page correspond to the same time step but depth averaged (upper figure) and bottom 2m (lower figure). The red line represents the area within which a concentration of 2 mg/l is reached or exceeded near the bottom (2 m watercolumn).

Table 6.3: Area (ha) experiencing sediment concentration equal or greater than 5, 10, 50, 100, 300, 500, and 1000 mg/l during varying durations (cumulative durations), top describes the uppermost 2 m of the water column and bottom, the 2m above the ground .For info: 100 ha = 1 km^2. The brightness of the cell colour indicates the magnitude of the area (dark colour = large area).

		Duration								Maximum
	Concentration	**6 h**	**12 h**	**24 h**	**2 d**	**7 d**	**14 d**	**21 d**	**28 d**	**duration [d]**
Top	**5 mg/l**	17 ha	2 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.7
	10 mg/l	5 ha	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.6
	50 mg/l	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.3
	100 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.2
	300 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.1
	500 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.0
	1000 mg /l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
Depth averaged	**5 mg/l**	65 ha	19 ha	2 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.2
	10 mg/l	20 ha	5 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.1
	50 mg/l	1 ha	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.5
	100 mg/l	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.3
	300 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.1
	500 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.0
	1000 mg /l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
Bottom	**5 mg/l**	850 ha	481 ha	232 ha	14 ha	0 ha	0 ha	0 ha	0 ha	2.6
	10 mg/l	194 ha	85 ha	19 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.6
	50 mg/l	10 ha	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.6
	100 mg/l	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.3
	300 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.1
	500 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.0
	1000 mg /l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-

Table 6.4: Area (ha) experiencing sediment concentration equal or greater than 5, 10, 50, 100, 300, 500, and 1000 mg/l for different longest consecutive periods, top describes the uppermost 2 m of the water column and bottom, the 2m above the ground. For info: 100 ha = 1 km^2. The brightness of the cell colour indicates the magnitude of the area (dark colour = large area).

		Consecutive Duration								Maximum
	Concentration	**6 h**	**12 h**	**24 h**	**2 d**	**7 d**	**14 d**	**21 d**	**28 d**	**duration [d]**
Top	**5 mg/l**	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
	10 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
	50 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
	100 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
	300 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
	500 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
	1000 mg /l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
Depth averaged	**5 mg/l**	20 ha	2 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.7
	10 mg/l	6 ha	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.6
	50 mg/l	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.3
	100 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.2
	300 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.1
	500 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.0
	1000 mg /l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-
Bottom	**5 mg/l**	117 ha	5 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.8
	10 mg/l	35 ha	2 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.6
	50 mg/l	2 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.3
	100 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.2
	300 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.1
	500 mg/l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.0
	1000 mg /l	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	-

6.2. Light attenuation

The approach described in chapter 5.5 and applied in the present study allows a simplified assessment of the light attenuation near the bottom, without considering the chemical composition of the sediment.

6.2.1. Background light attenuation

Due to the lack of in-situ measurements and for the purpose of gaining a first indication of light attenuation due to background concentration and water depth (thus before the activity), the light intensity at the bottom is calculated in a simplified manner on the basis of the measurements from Fehmarn Belt (K_{d0} =0.0756 m^{-1} , [17]). From the surface, the seabed can be seen down to a depth (visibility depth) where approximately 15% of the light remains [18]. This is an important indicator for the eelgrass conditions.

The light intensity at the bottom of the cable routes (Figure 6.7), derived based on the conditions from Fehmarn Belt [17] accounts for 40-50%. Light intensity at the bottom decreases with increasing depth (compare with bathymetry, Figure 4.1). However, it should be emphasised that the illustrated light intensity does not consider spatial variations in the background concentration or temporal variations due to resuspension, and therefore only represents a fundamental approximation.

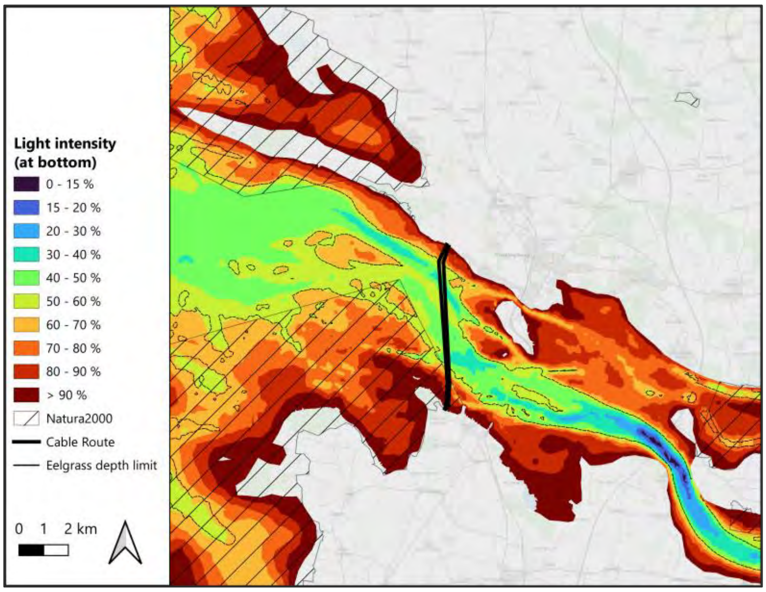

Figure 6.7: Rough estimation of the light attenuation (displayed as the light intensity at the bottom), based on background concentration from the Fehmarn Belt analyses (K_{d0} =0.0756 m^{-1}, [17]). The eelgrass limit depth shown varies for the individual water bodies (see delimitation in Appendix 4).

6.2.2. Exceedance duration

To ensure that the results are independent of the assumption regarding the background concentration, only the light attenuation for the "excess" sediment concentration caused by the construction work is determined.

Aligned with the concentrations, the exceedance durations are presented:

- for the cumulative period (Figure 6.8 and Appendix 8)
- for the longest consecutive period (Figure 6.9 and Appendix 9)

in which a light attenuation of a certain threshold value is reached or exceeded. In the sections below, a threshold of 40% is discussed. An overall overview can be found in Appendix 8.

The following maps represent a rough estimate and are intended to visualise the potential range of light attenuation to be expected.

6.2.3. Light attenuation

In Figure 6.8, the cumulative duration during which the light intensity is reduced by 40% or more is given. It is shown that the impacted areas are mainly within the deeper parts of the cable route extending to Northwest and Southeast following the bathymetry. The given areas is affected for approximately 9 days. The cumulative duration during which the light intensity is reduced by 40% or more reaches its maximum of 8.6 days in a very limited area (approximately 30 ha).

In contrast, the longest consecutive duration during which a light attenuation of at least 40% is expected (Figure 6.9 and Table 6.6) is significantly shorter, accounting for less than 2 consecutive days. The longest continuous duration can be observed north-west of the project area.

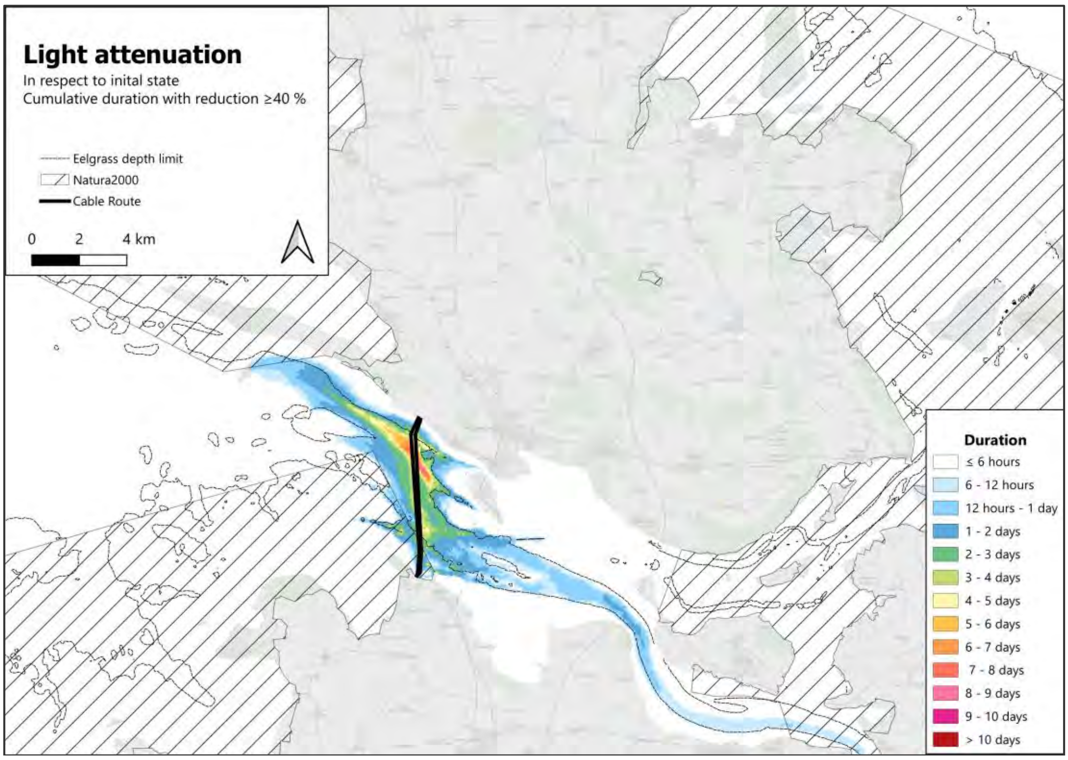

Figure 6.8: Cumulative duration during which a light attenuation of 40% (relative to the background concentration) is reached or exceeded at the bottom. The eelgrass limit depth shown varies for the individual water bodies (see delimitation in Appendix 4).

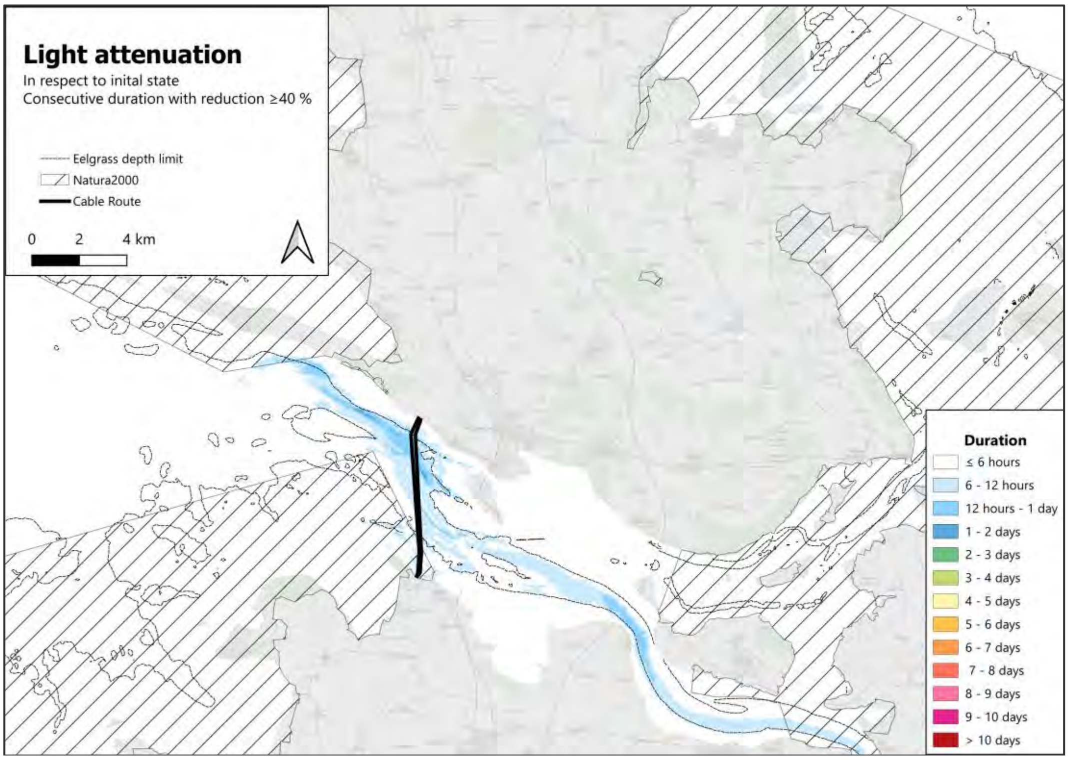

Figure 6.9: Longest consecutive duration, during which a light attenuation of 40% (relative to the background concentration) is reached or exceeded at the bottom. The eelgrass limit depth shown varies for the individual water bodies (see delimitation in Appendix 4).

Table 6.5: Area (ha) experiencing a light reduction of a specified percentage with varying durations (cumulative durations).

	Cumulative Duration								Maximum
Light Reduction	**6 h**	**12 h**	**24 h**	**2 d**	**7 d**	**14 d**	**21 d**	**28 d**	**duration [d]**
15%	11,360 ha	8,980 ha	6,918 ha	4,836 ha	1,295 ha	63 ha	0 ha	0 ha	17.0
20%	8,564 ha	6,787 ha	5,319 ha	3,346 ha	470 ha	0 ha	0 ha	0 ha	13.7
30%	5,761 ha	4,686 ha	3,213 ha	1,762 ha	88 ha	0 ha	0 ha	0 ha	10.2
40%	4,438 ha	3,219 ha	1,947 ha	998 ha	30 ha	0 ha	0 ha	0 ha	8.6
50%	3,253 ha	2,117 ha	1,259 ha	537 ha	1 ha	0 ha	0 ha	0 ha	7.2
60%	2,322 ha	1,404 ha	859 ha	283 ha	0 ha	0 ha	0 ha	0 ha	6.4
70%	1,618 ha	1,012 ha	529 ha	153 ha	0 ha	0 ha	0 ha	0 ha	5.3
80%	1,069 ha	690 ha	287 ha	78 ha	0 ha	0 ha	0 ha	0 ha	4.0
90%	672 ha	359 ha	137 ha	29 ha	0 ha	0 ha	0 ha	0 ha	2.8

Table 6.6: Area (ha) experiencing a light reduction of a specified percentage with varying durations (consecutive durations).

	Consecutive Duration								Maximum
Light Reduction	**6 h**	**12 h**	**24 h**	**2 d**	**7 d**	**14 d**	**21 d**	**28 d**	**duration [d]**
15%	9,168 ha	5,143 ha	1,842 ha	42 ha	0 ha	0 ha	0 ha	0 ha	3.6
20%	6,632 ha	3,231 ha	939 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.9
30%	4,177 ha	1,325 ha	127 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.5
40%	2,778 ha	533 ha	22 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.4
50%	1,573 ha	239 ha	4 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.2
60%	953 ha	115 ha	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.0
70%	587 ha	52 ha	1 ha	0 ha	0 ha	0 ha	0 ha	0 ha	1.0
80%	282 ha	23 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.9
90%	130 ha	6 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0.9

6.3. Sedimentation

The process of consolidation is not considered in the simulations. Therefore, the resulting sedimentation is calculated afterwards for three different densities given below. Results in Table 5.3:

- **180 kg/ m³** freshly sedimented mud with high water content
- **300 kg/ m³** deposited mud after some months
- **1650 kg/m³** consolidated material

The higher the density, the more consolidated the sediment is and as a result the lower the sedimentation heights become.

6.3.1. Sedimentation heights

Results regarding sedimentation cover:

- the maximum sedimentation height (Figure 6.10)
- sedimentation heights anticipated at the end of the construction work (Figure 6.11)
- sedimentation heights anticipated 1 month after the end of the construction work (Figure 6.12)

and provide the following insights:

Limited spatial expansion: The largest sedimentation occurs as expected in the close vicinity of the cables with a maximum height of 178 mm (based on 180 kg/m³, Table 6.7). In the shallow areas, sedimentation is limited to the close vicinity of the cables (the source). In areas with deeper water depth, the sediment is deposited North-west of the cables following the prevailing current direction towards Northwest. Based on the distribution of the sediment, the Northwest direction can be recognized as the dominant direction where a net sediment transport is observed.

Important resuspension in deeper waters: Not only the spatial extent, but also the observed sediment heights differ significantly between the end of the activity and one month later. Most of the sediment is deposited near the cables at the end of the dredging period. During the following months, the sediment is resuspended in areas with larger water depths, where the current speeds are high enough to cause resuspension and transport following the prevailing current direction, see Figure 6.6). The resuspended sediment is primarily transported to the north-west, where it is deposited. This means that the sediment is spread over a larger area one month after the end of the activity. Because of the strong currents, resuspension and transport is to be expected primarily to take place along the main channel.

Table 6.7: Area (ha) experiencing sedimentation between 1 and 250 mm. For info: 100 ha = 1 km². The brightness of the cell colour indicates the magnitude of the area (dark colour = large area).

		Sedimentation [mm]								
		1	2	5	10	25	50	100	250	Maximum [mm]
180 kg/m³	End of spill	249 ha	160 ha	77 ha	50 ha	24 ha	13 ha	4 ha	0 ha	178.0
	1 month after spill	297 ha	199 ha	99 ha	50 ha	23 ha	12 ha	4 ha	0 ha	178.0
	Maximum	401 ha	252 ha	122 ha	64 ha	29 ha	15 ha	4 ha	0 ha	178.0
300 kg/m³	End of spill	181 ha	107 ha	54 ha	35 ha	17 ha	6 ha	1 ha	0 ha	106.8
	1 month after spill	217 ha	142 ha	58 ha	32 ha	14 ha	5 ha	1 ha	0 ha	106.8
	Maximum	282 ha	173 ha	74 ha	42 ha	17 ha	6 ha	1 ha	0 ha	106.8
1650 kg/m³	End of spill	53 ha	31 ha	14 ha	4 ha	0 ha	0 ha	0 ha	0 ha	19.4
	1 month after spill	54 ha	30 ha	13 ha	4 ha	0 ha	0 ha	0 ha	0 ha	19.4
	Maximum	69 ha	38 ha	16 ha	5 ha	0 ha	0 ha	0 ha	0 ha	19.4

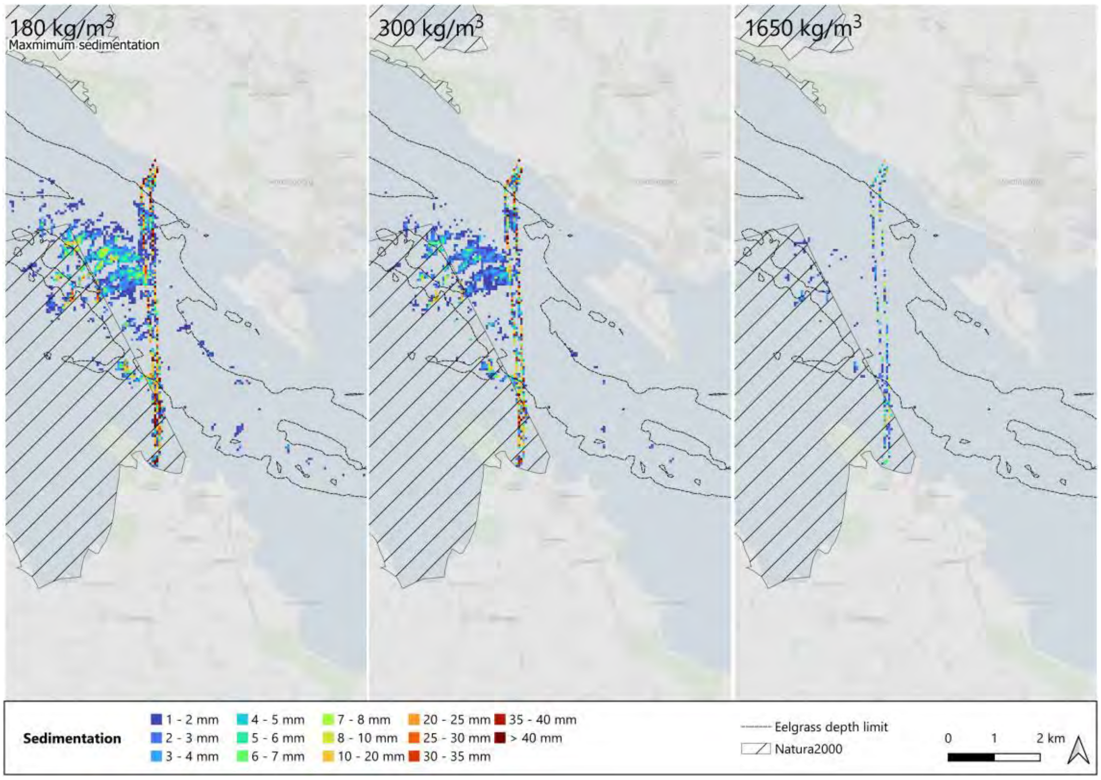

Figure 6.10: Maximum sedimentation heights (for different sediment densities). It should be noted that the maximum sedimentation heights shown occur spatially at different times. The eelgrass limit depth shown varies for the individual water bodies (see delimitation in Appendix 4).

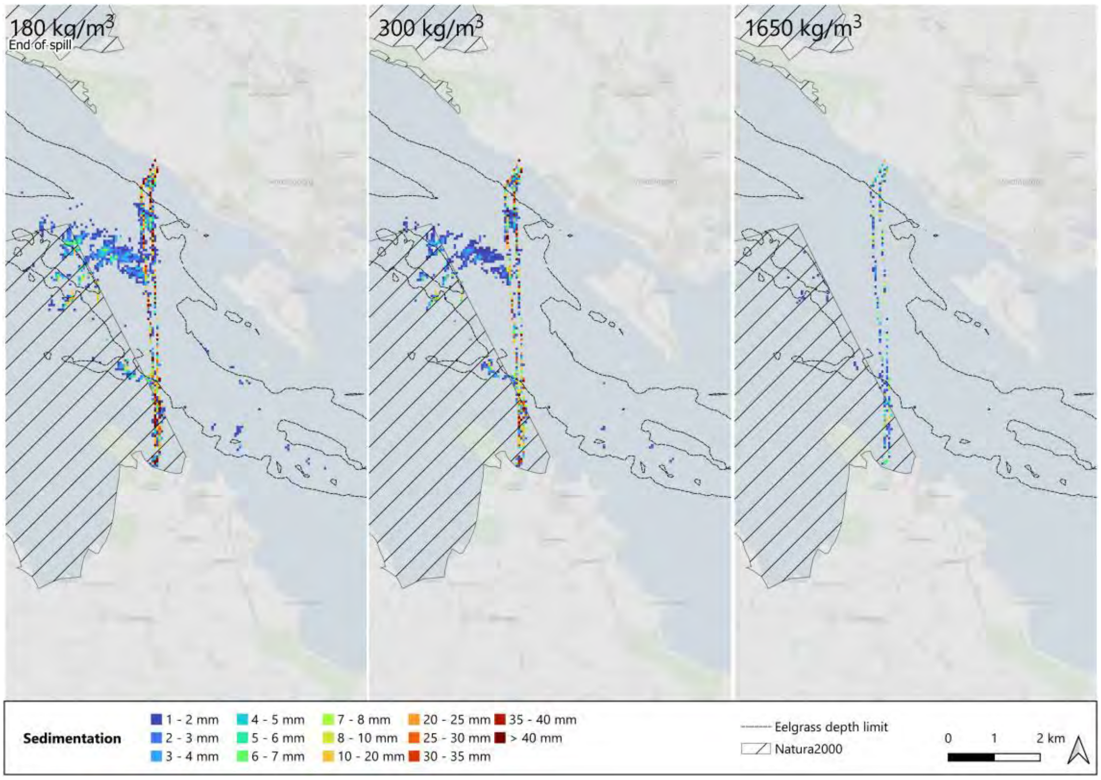

Figure 6.11: Sedimentation heights (for different sediment densities) at the end of the construction phase. The eelgrass limit depth shown varies for the individual water bodies (see delimitation in Appendix 4).

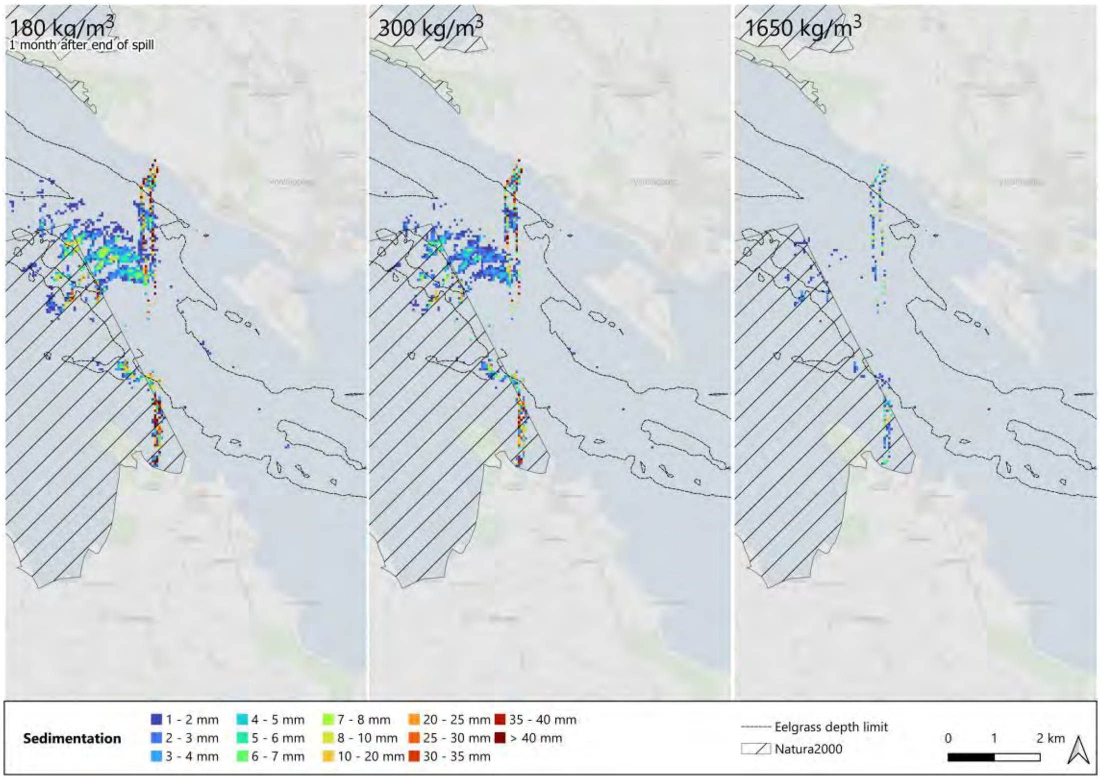

Figure 6.12: Sedimentation heights (for different sediment densities) one month after the end of the construction phase. The eelgrass limit depth shown varies for the individual water bodies (see delimitation in Appendix 4).

6.3.2. Exceedance durations of sedimentation

Aligned with the sedimentation, the exceedance durations are presented.

- for the cumulative period (Figure 6.13, Table 6.8, and Appendix 11)
- for the longest consecutive period (Figure 6.14, Table 6.9 and Appendix 12)

in which the selected sedimentation height is reached or exceeded. In contrast to the sediment concentrations, the difference between cumulative and the longest consecutive durations is smaller. Regarding a duration of 10 days, almost no difference is recognizable. The longer the duration considered, the more pronounced the differences.

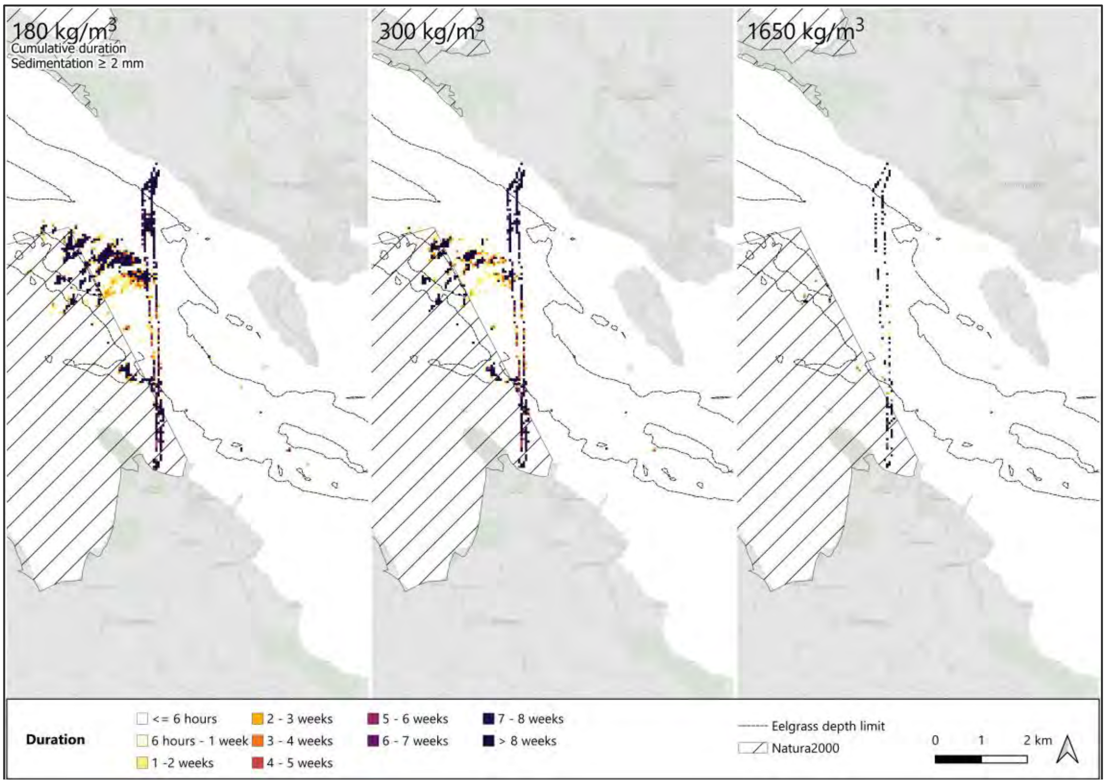

Figure 6.13: Cumulative duration, during which a sedimentation of 2 mm is reached or exceeded given different densities (the black 7m line indicates the maximum depth distribution of eelgrass).

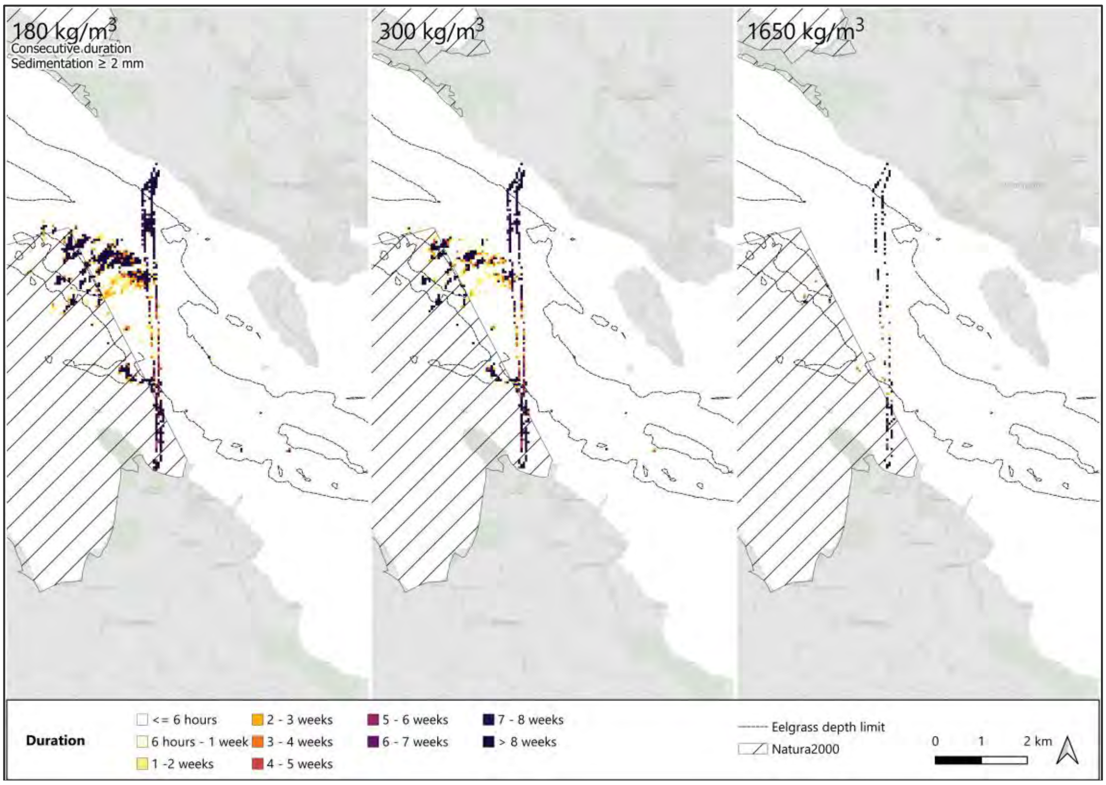

Figure 6.14: Longest consecutive duration, during which a sedimentation of 2 mm is reached or exceeded, given different densities (the black 7 m line indicates the maximum depth distribution of eelgrass)

Table 6.8: Area (ha) experiencing sedimentation between 1 and 50 mm for cumulative durations. For info: 100 ha = 1 km². The brightness of the cell colour indicates the magnitude of the area (dark colour = large area).

		Consecutive Duration									
	Sedimentation	6 h	12 h	24 h	2 d	7 d	2 weeks	4 weeks	6 weeks	8 weeks	9 weeks
180 kg/m³	2 mm	257 ha	253 ha	246 ha	244 ha	231 ha	195 ha	167 ha	154 ha	142 ha	135 ha
	5 mm	124 ha	118 ha	114 ha	114 ha	109 ha	90 ha	78 ha	71 ha	59 ha	56 ha
	10 mm	63 ha	62 ha	60 ha	60 ha	59 ha	53 ha	49 ha	44 ha	38 ha	36 ha
	50 mm	15 ha	15 ha	15 ha	15 ha	14 ha	14 ha	13 ha	11 ha	7 ha	6 ha
300 kg/m³	2 mm	176 ha	173 ha	166 ha	165 ha	159 ha	130 ha	111 ha	101 ha	88 ha	83 ha
	5 mm	75 ha	74 ha	72 ha	71 ha	68 ha	59 ha	53 ha	49 ha	41 ha	40 ha
	10 mm	42 ha	42 ha	42 ha	42 ha	41 ha	37 ha	35 ha	31 ha	25 ha	23 ha
	50 mm	6 ha	6 ha	6 ha	6 ha	6 ha	6 ha	6 ha	5 ha	4 ha	3 ha
1650 kg/m³	2 mm	39 ha	38 ha	37 ha	37 ha	36 ha	33 ha	31 ha	28 ha	23 ha	21 ha
	5 mm	16 ha	16 ha	16 ha	16 ha	16 ha	15 ha	14 ha	12 ha	8 ha	7 ha
	10 mm	5 ha	5 ha	5 ha	4 ha	4 ha	4 ha	4 ha	4 ha	3 ha	2 ha
	50 mm	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha

Table 6.9: Area (ha) experiencing sedimentation between 1 and 50 mm for different longest consecutive durations. For info: 100 ha = 1 km². The brightness of the cell colour indicates the magnitude of the area (dark colour = large area).

		Consecutive Duration									
	Sedimentation	6 h	12 h	24 h	2 d	7 d	2 weeks	4 weeks	6 weeks	8 weeks	9 weeks
180 kg/m³	2 mm	257 ha	253 ha	246 ha	244 ha	231 ha	191 ha	161 ha	149 ha	135 ha	127 ha
	5 mm	124 ha	118 ha	114 ha	114 ha	109 ha	89 ha	76 ha	68 ha	56 ha	54 ha
	10 mm	63 ha	62 ha	60 ha	60 ha	59 ha	52 ha	49 ha	43 ha	35 ha	33 ha
	50 mm	15 ha	15 ha	15 ha	15 ha	14 ha	14 ha	13 ha	10 ha	7 ha	6 ha
300 kg/m³	2 mm	176 ha	173 ha	166 ha	165 ha	159 ha	128 ha	107 ha	97 ha	83 ha	78 ha
	5 mm	75 ha	73 ha	72 ha	71 ha	68 ha	58 ha	53 ha	48 ha	39 ha	37 ha
	10 mm	42 ha	42 ha	42 ha	42 ha	41 ha	37 ha	34 ha	30 ha	23 ha	21 ha
	50 mm	6 ha	6 ha	6 ha	6 ha	6 ha	6 ha	6 ha	5 ha	4 ha	3 ha
1650 kg/m³	2 mm	39 ha	38 ha	37 ha	37 ha	36 ha	33 ha	31 ha	26 ha	21 ha	19 ha
	5 mm	16 ha	16 ha	16 ha	16 ha	16 ha	15 ha	14 ha	12 ha	7 ha	7 ha
	10 mm	5 ha	5 ha	5 ha	4 ha	4 ha	4 ha	4 ha	4 ha	3 ha	2 ha
	50 mm	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha	0 ha

7. Discussion

In the following section, the effects of the above given assumptions are analysed. Finally, an overall assessment of the impact of the sediment spill based on the modelling results is presented.

Assumption 1: The natural background concentration of suspended sediment has an impact on the local habitats. The effects of excluding the background concentration in the model are therefore not easy to predict, but since the background concentration is generally deemed to be very low this is not considered to have an impact. However, any given background concentration of sediment will increase the total suspended solids concentration, and thereby may increase the ability of particles to flocculate. The background concentration can increase the settling rate of the sediment and thus reduce the concentration of suspended sediment, and the light attenuation respectively. In general, assessing the effects of sediment spill from dredging operations without knowing the natural background concentration may overlook some environmental impacts related to the biology in the area. For the present project, the effect of flocculation and settling on concentration and light reduction is not modelled but implicitly taken into account in the settling velocity values.

Assumption 2: When sediment is deposited on the seabed, a consolidation process starts gradually allowing the sediment to become more consolidated and thus more resistant to erosion and resuspension. This process is not included in the model, which in some cases can lead:

- to an overestimation of resuspended sediment and thus the concentration of sediment in the water column.
- To an overestimation of the light attenuation at the seabed as it depends on the concentration of suspended sediment.

Assumption 3: On the seabed, a number of biological processes take place that may affect the sediment both in suspension and deposited on the seabed. For example, seaweed and eelgrass usually increase sediment settling rates as the local flow conditions around the seaweed/eelgrass change. Similarly, filter feeders such as mussels and worms will trap sediment along the seabed. Since these biological processes are not taken into account in the model simulations, the amount of suspended sediment in the system may be overestimated in the model simulations. In the long term, this may lead to an overestimation of light attenuation along the seabed. At the same time, the assumption may cause sedimentation rates to be slightly underestimated.

Overall assessment: In the present sediment spill study, the effect of the dredging works on suspended sediment concentrations and sedimentation is analyzed during the installation period of the two power cables between Ore and Orehoved. The interpretation of the results is based on the assumptions provided above. The used model gives conservative estimates for light attenuation on the seabed, the dispersion of suspended sediment, and the distribution of deposited material. Therefore, it is deemed a conservative estimate.

Comparison to natural variations: As discussed in chapter 4.6, during the period of activity (May to September), the background concentration is expected to be low (1 -2 mg/l). Generally, in the nearshore the background concentration will be higher than in offshore conditions and exhibit more pronounced temporal variations caused by resuspension from the waves. The impact of waves is not considered in the assessment, since the natural background concentrations nearshore are occasionally very high and the sediment resuspension events are frequent and thus the effect of spilled material will be small both in terms of light dampening and in terms of deposition as the local habitats are used to frequent elevated sediment concentrations. Consequently, based on the simulation results, the highest excess concentrations are to be expected in deeper water, close to the seabed with 50 mg/l being exceeded over an area of 1 ha for 0.6 days (Figure 6.4). The vertical distribution and order of magnitude align with observations from the Fehmarnbelt Fixed Link projects [10], where background concentrations of 30–50 mg/l have been reported under offshore conditions, with the highest levels observed near the seabed. Thus, the modelled excess concentrations occurring over half a day will be in the same order of magnitude as the background concentrations. However, high excess concentrations and background concentrations are not expected to coincide, as elevated background levels typically occur in autumn, after the activity has ended.

8. References

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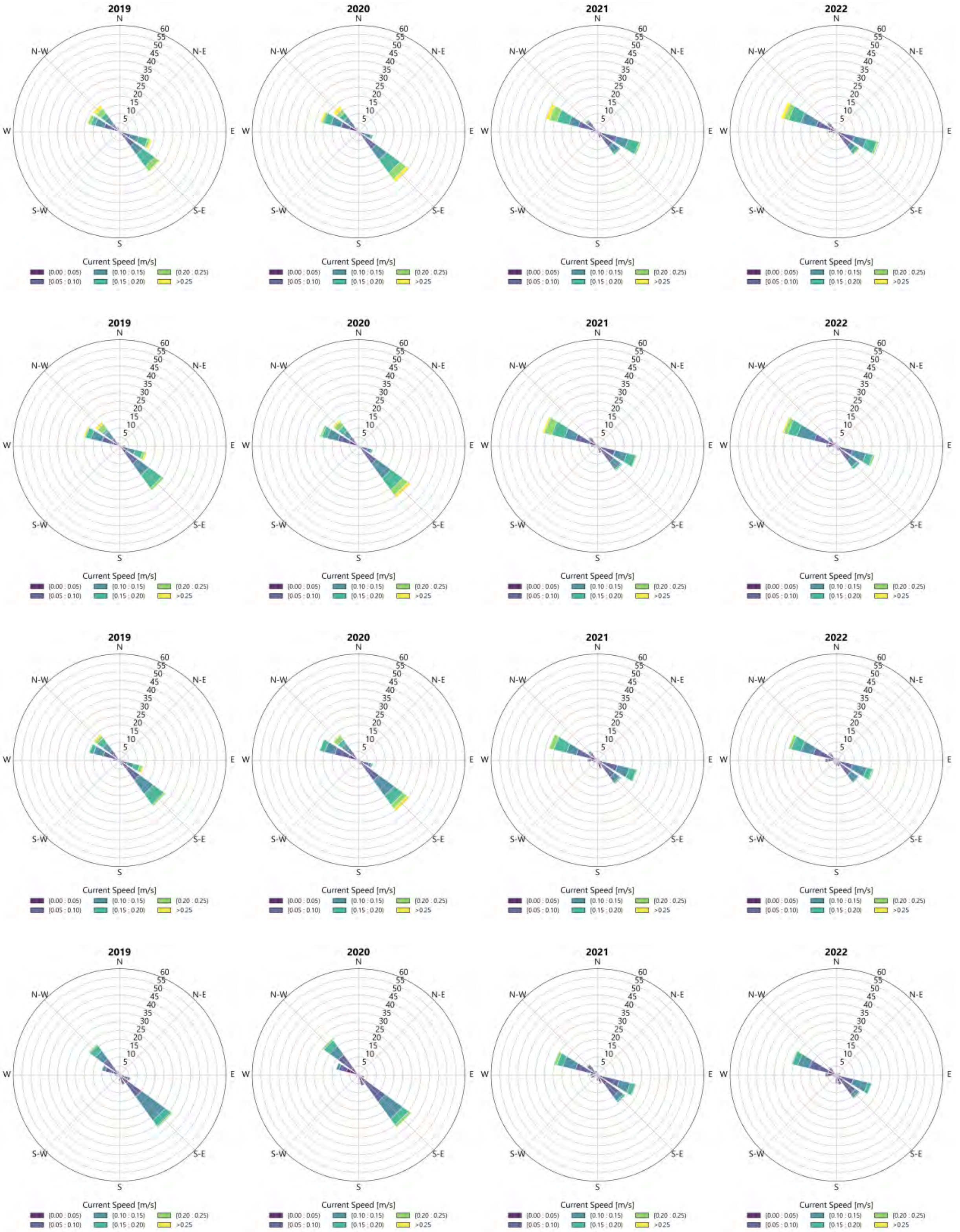
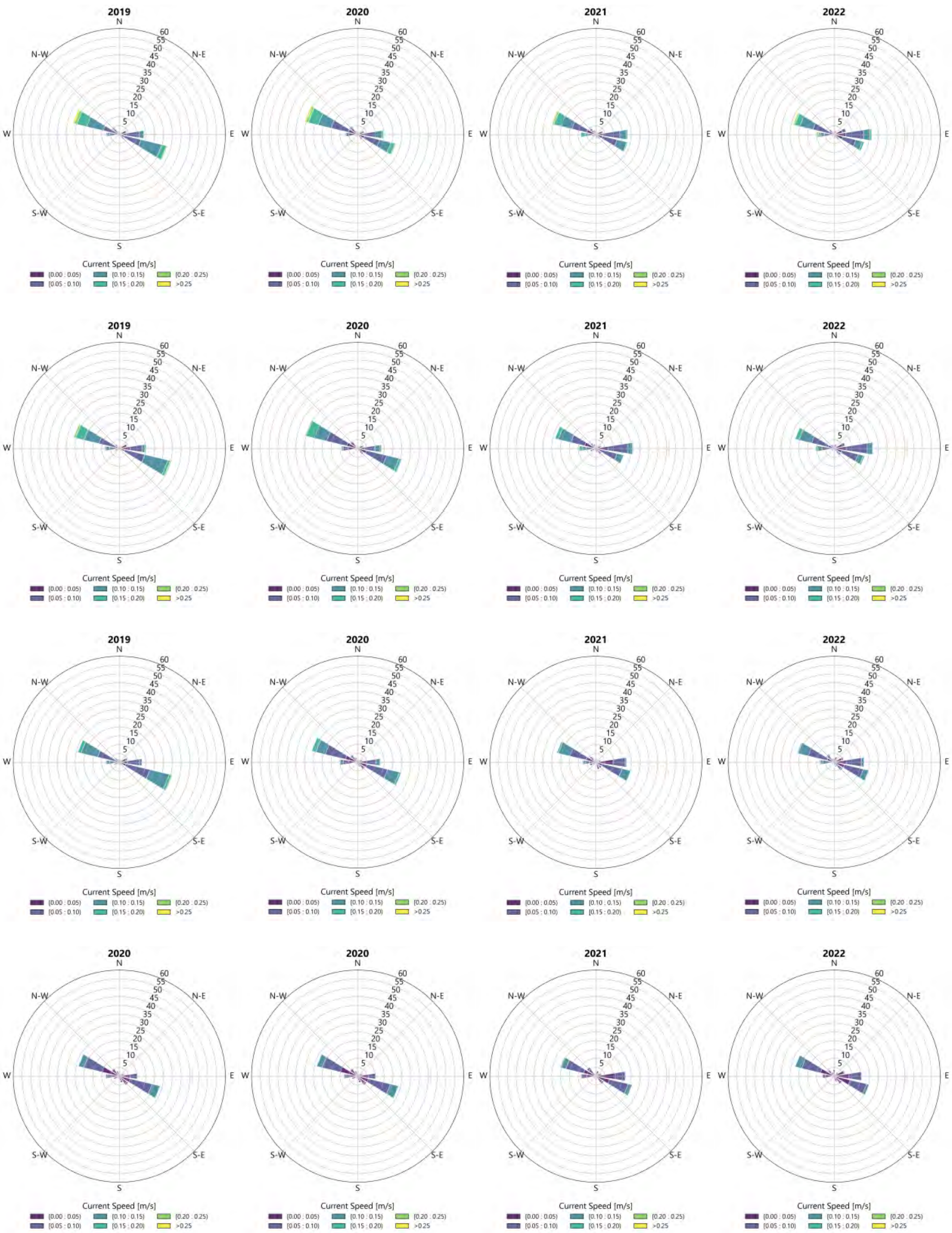
Appendix 1 SMHI- Data

Figure 30: Locations of points where current roses, salinity and temperature profiles are extracted

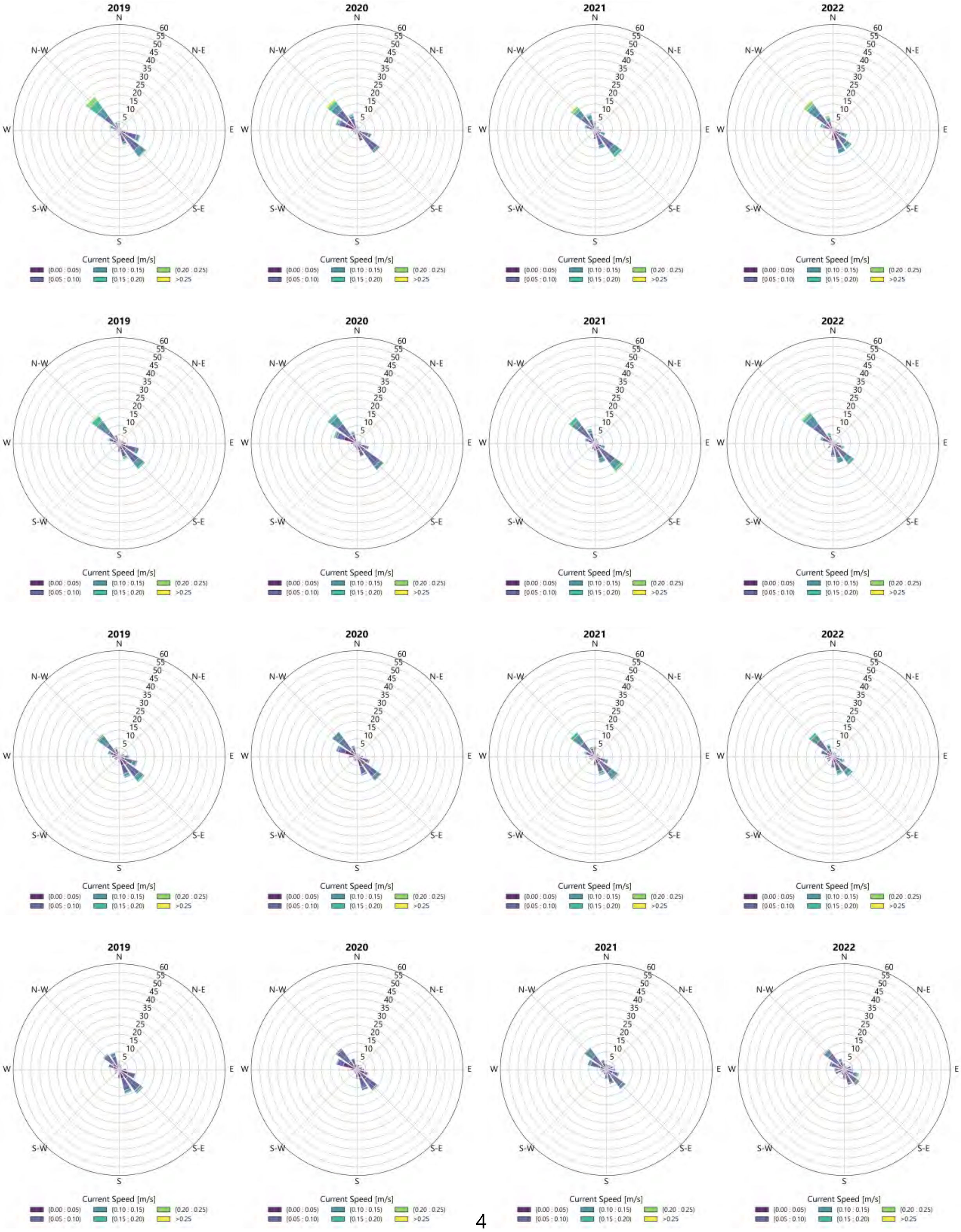
Current Roses



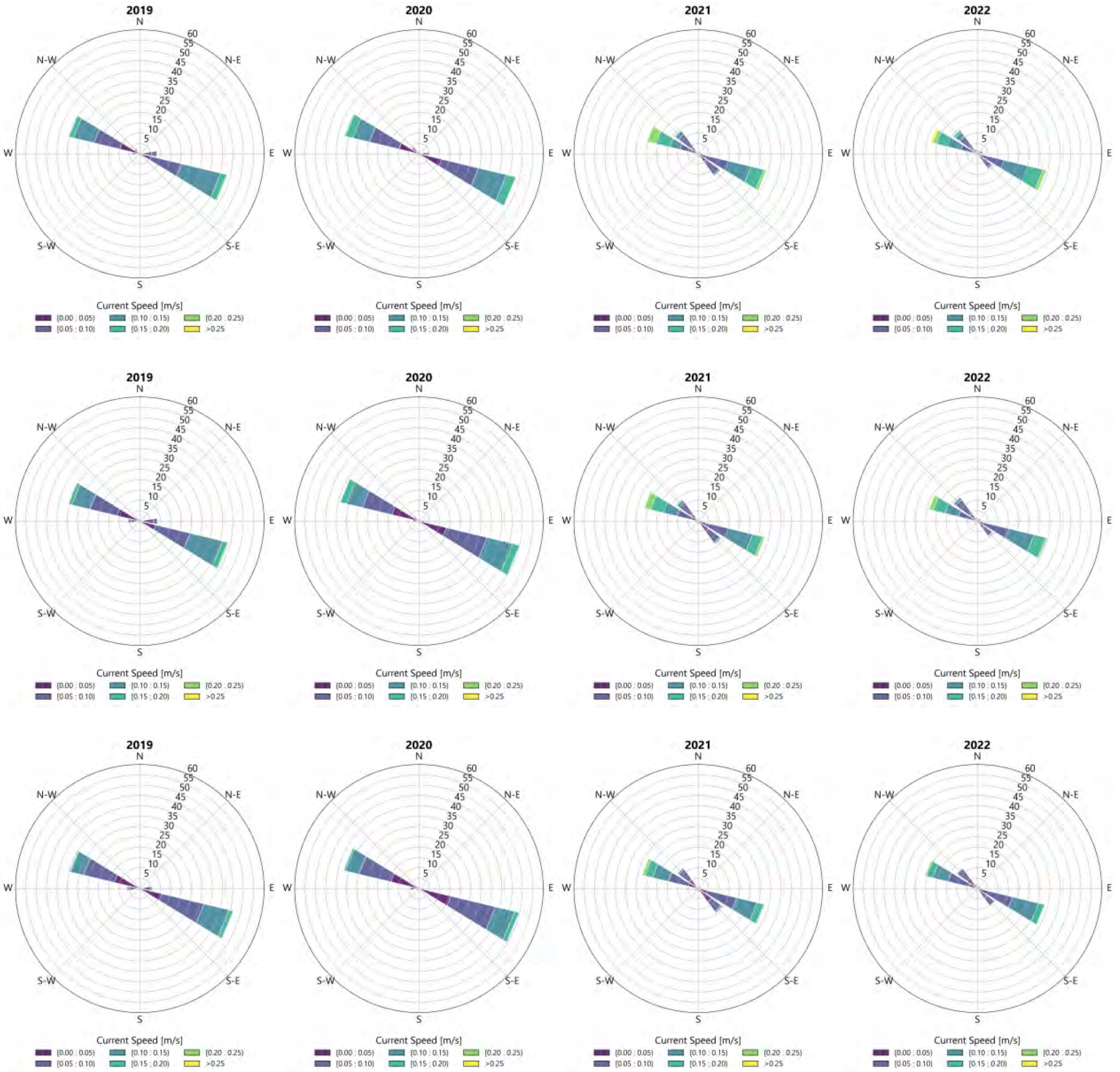
Annual Current roses extracted from SMHI-Data at Point 1 (see Figure 30) for four distinct years and at different depths: -1m (top row), -2m (second row), -3m (third row) and -4m (bottom row).



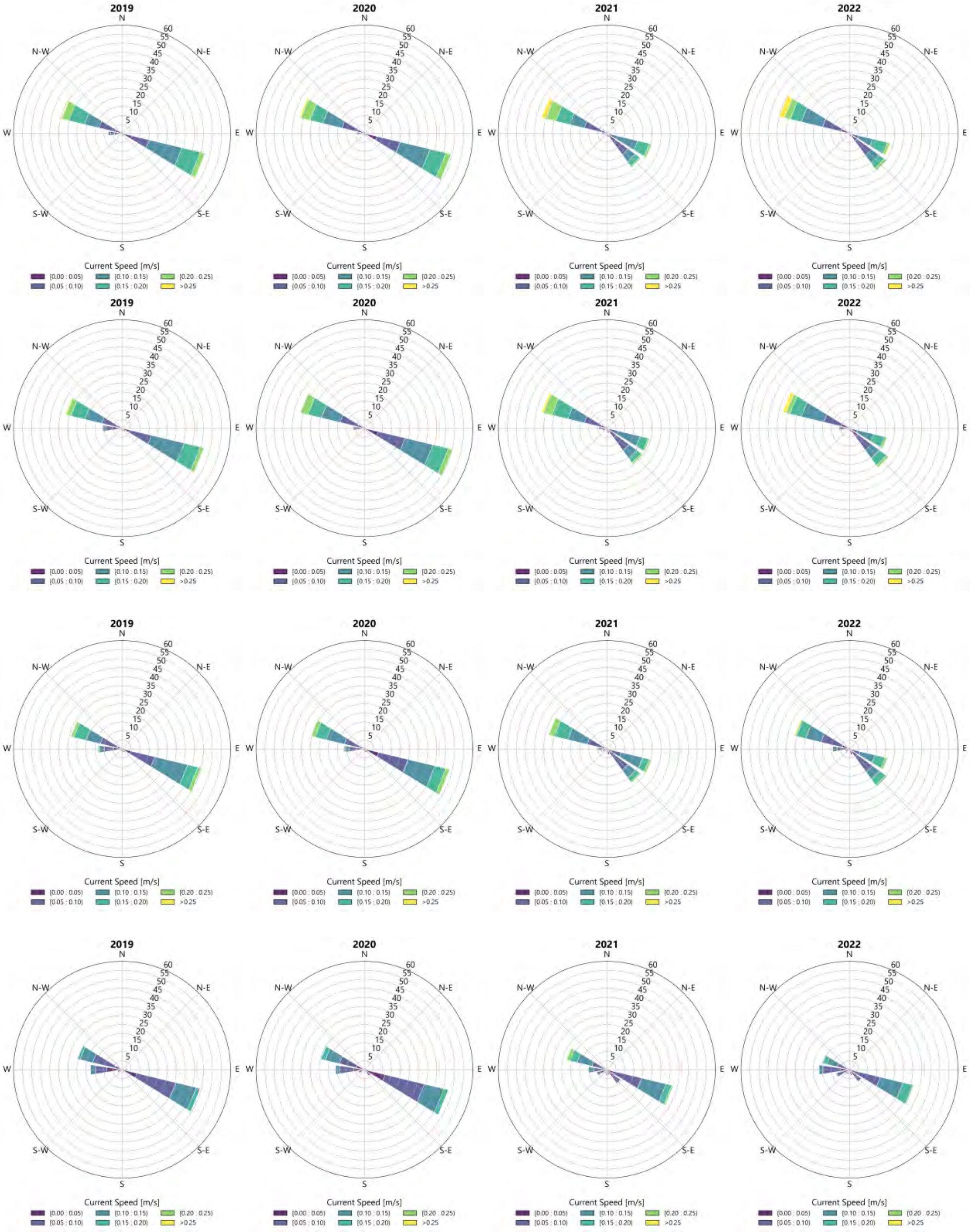
Annual Current roses extracted from SMHI-Data at Point 2 (see Figure 30) *for four distinct years and at different depths: -2m (top row), -3m (second row), -4m (third row) and -5m (bottom row).*



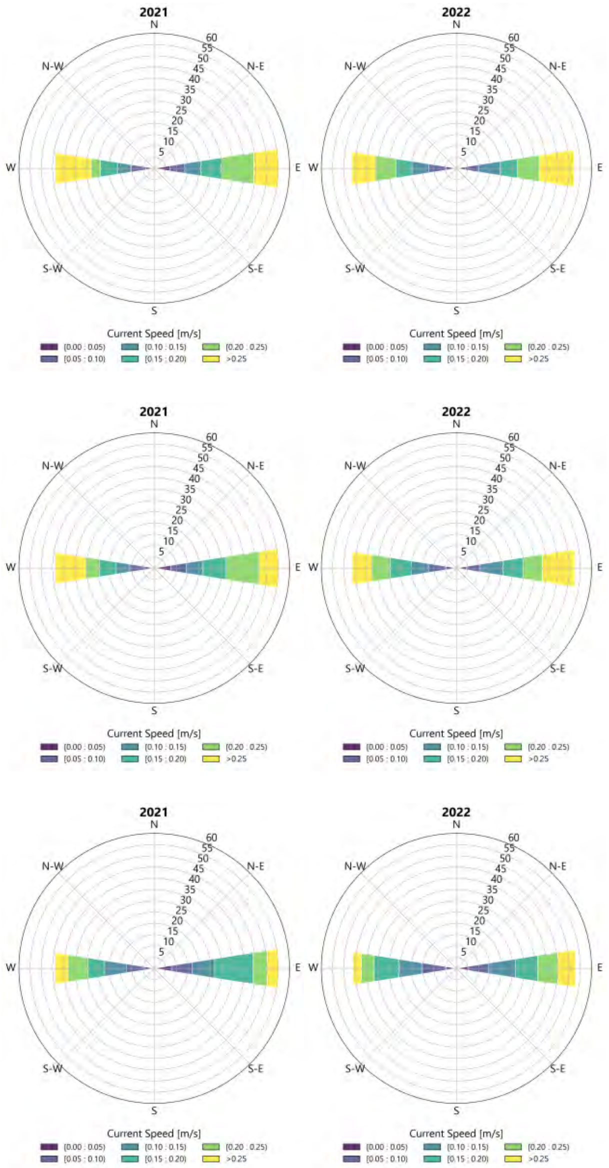
Annual Current roses extracted from SMHI-Data at Point 3 (see Figure 30) for four distinct years and at different depths: -2m (top row), -4m (second row), -6m (third row) and -8m (bottom row).



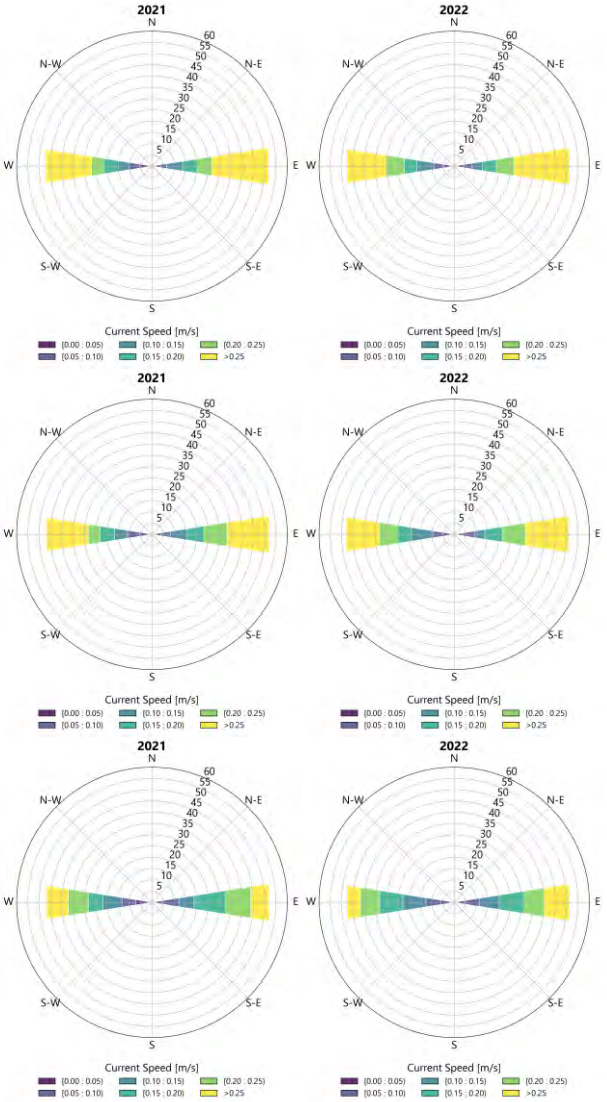
Annual Current roses extracted from SMHI-Data at Point -1 (see Figure 30*) for four distinct years and at different depths: -1m (top row), -2m (middle row) and -3m (bottom row).*



Annual Current roses extracted from SMHI-Data at Point -2 (see Figure 30) for four distinct years and at different depths: -1m (top row), -2m (second row), -3m (third row) and -4m (bottom row).

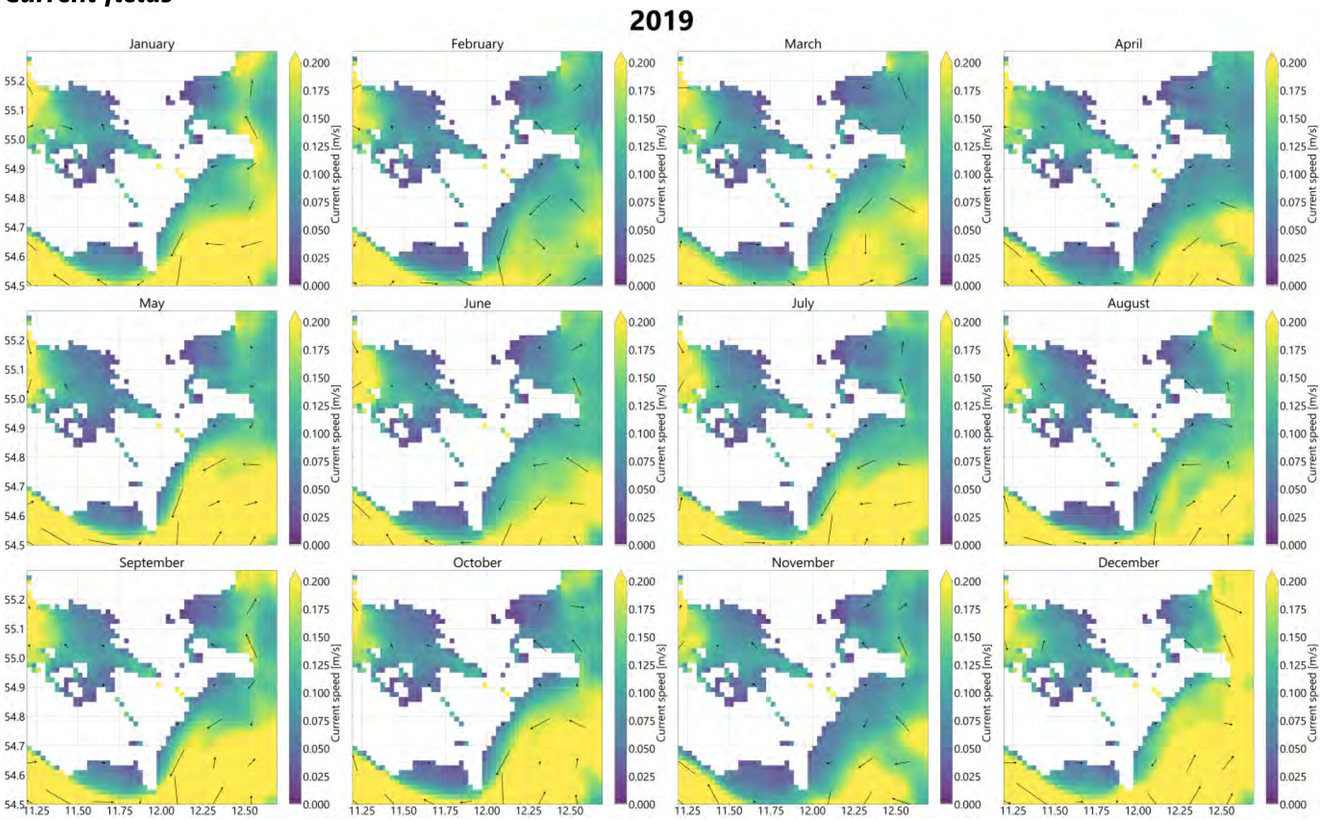


Annual Current roses extracted from SMHI-Data at Point -3 (see Figure 30*) for 2021 and 2022 (other years are not available) and at different depths: at the surface (top row), -1m (middle row) and -2m (bottom row) .*

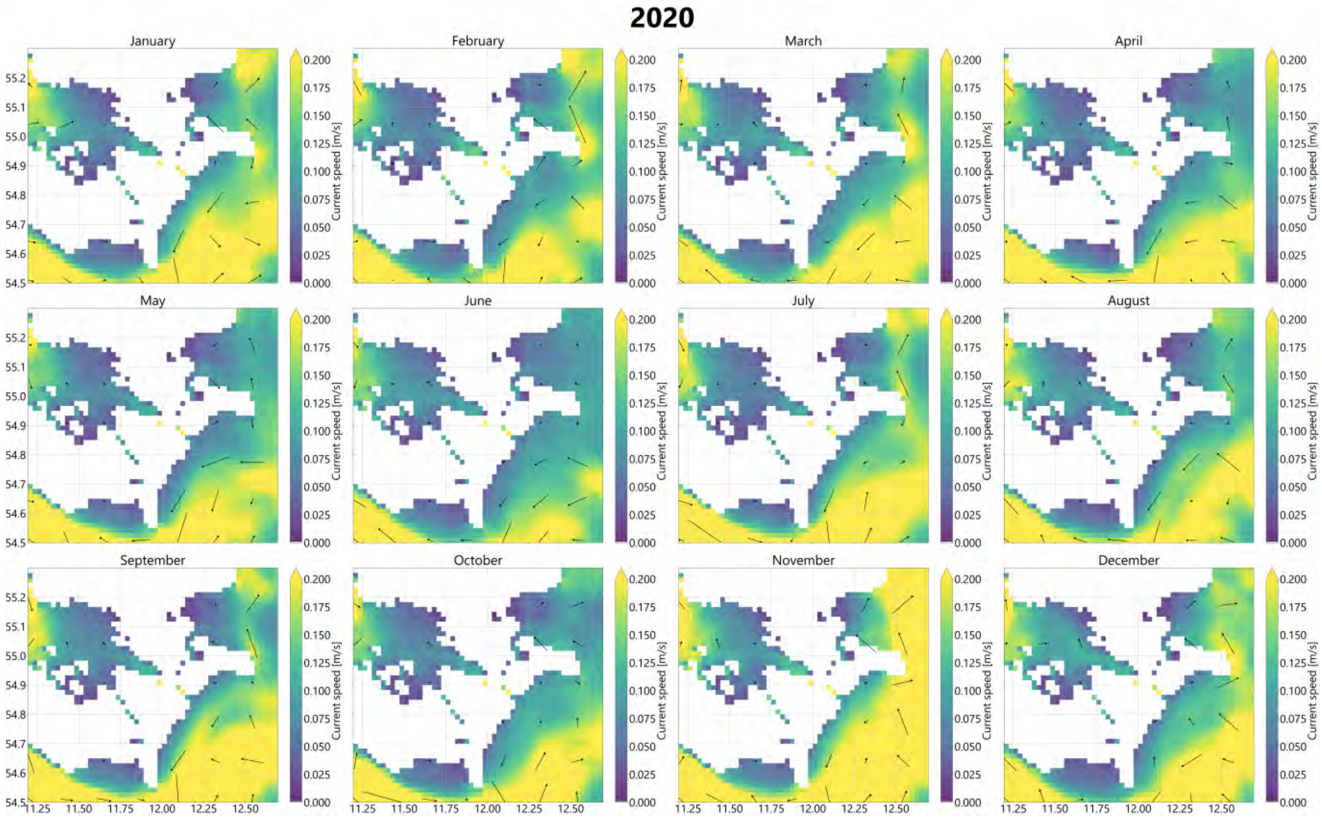


Annual Current roses extracted from SMHI-Data at Point -4 (see Figure 30) for for 2021 and 2022 (other years are not available) and at different depths: at the surface (top row), -1m (second row), -2m (third row) and -3m (bottom row).

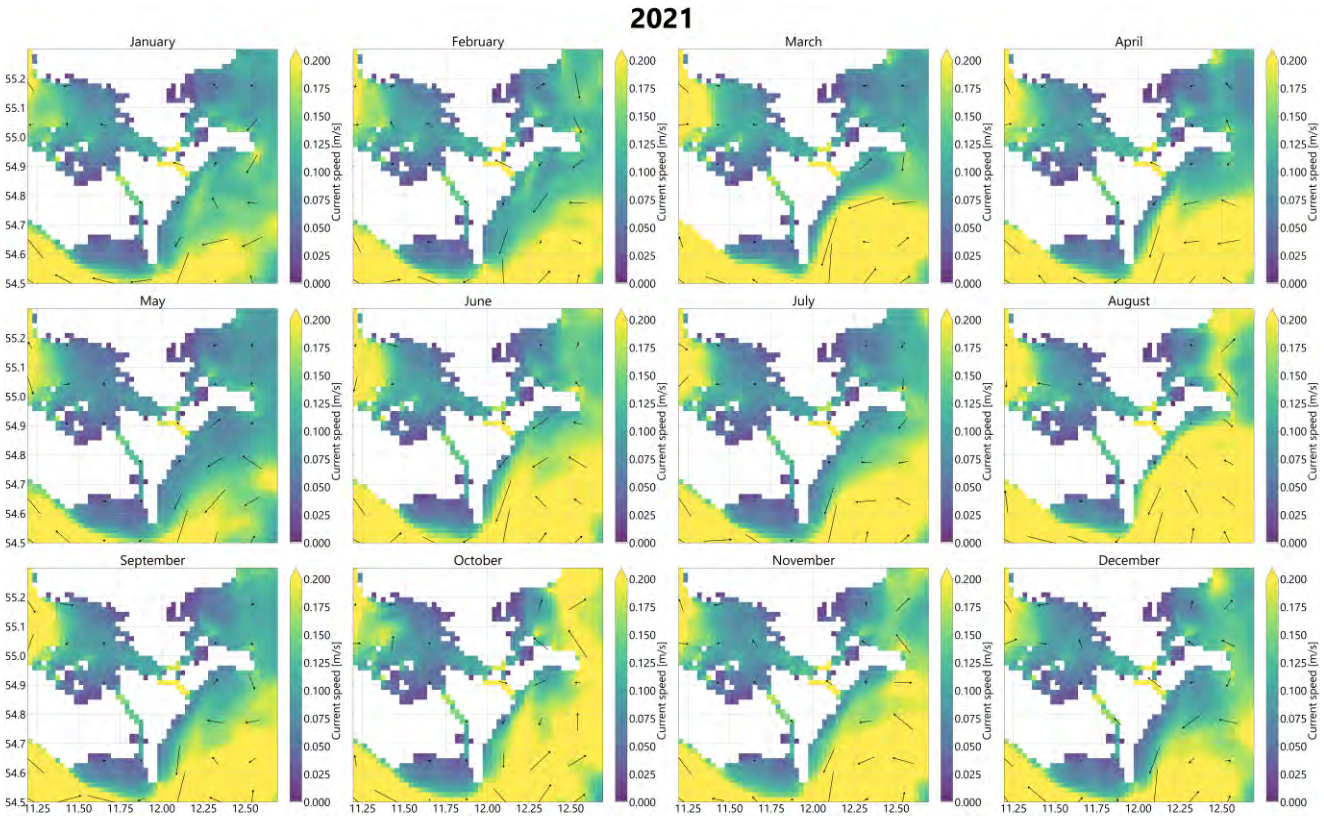
Current fields



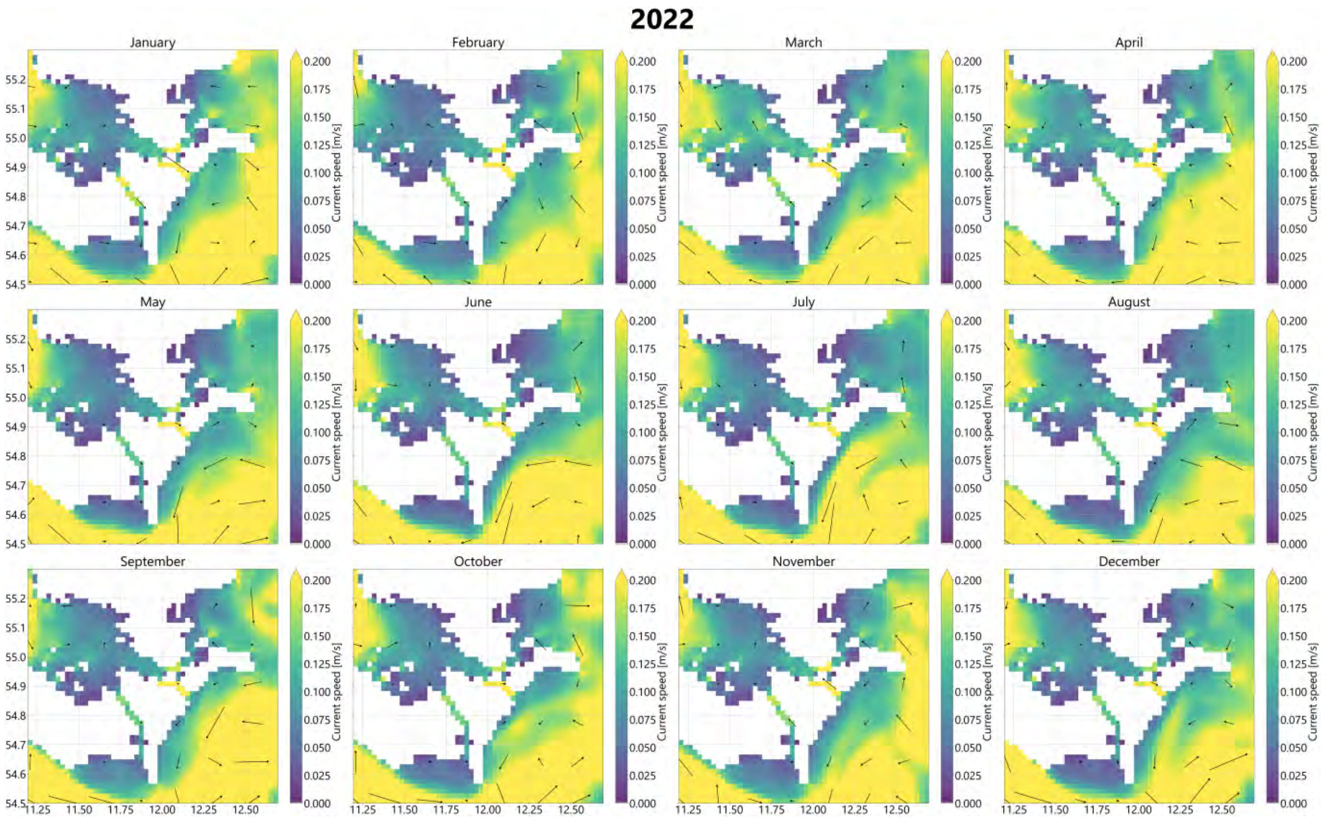
Monthly field of surface current in 2019 extracted from SMHI-Data



Monthly field of surface current in 2020 extracted from SMHI-Data

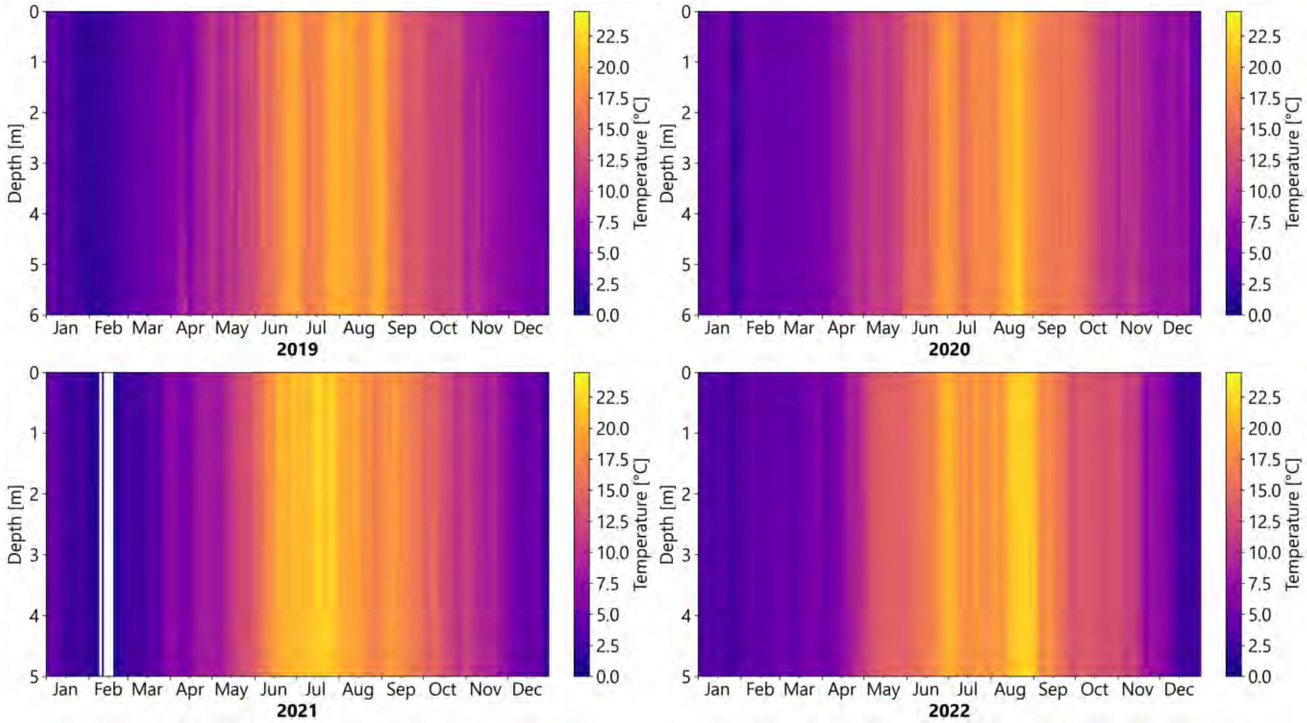


Monthly field of surface current in 2021 extracted from SMHI-Data

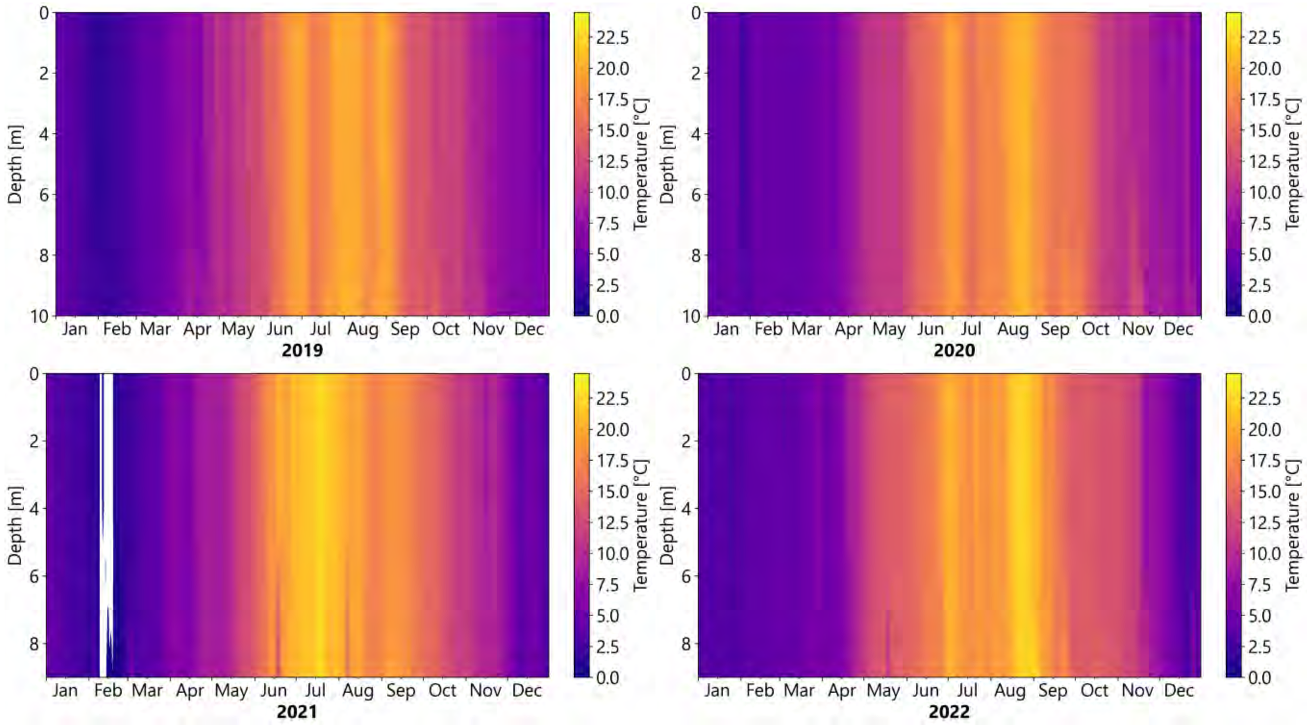


Monthly field of surface current in 2022 extracted from SMHI-Data

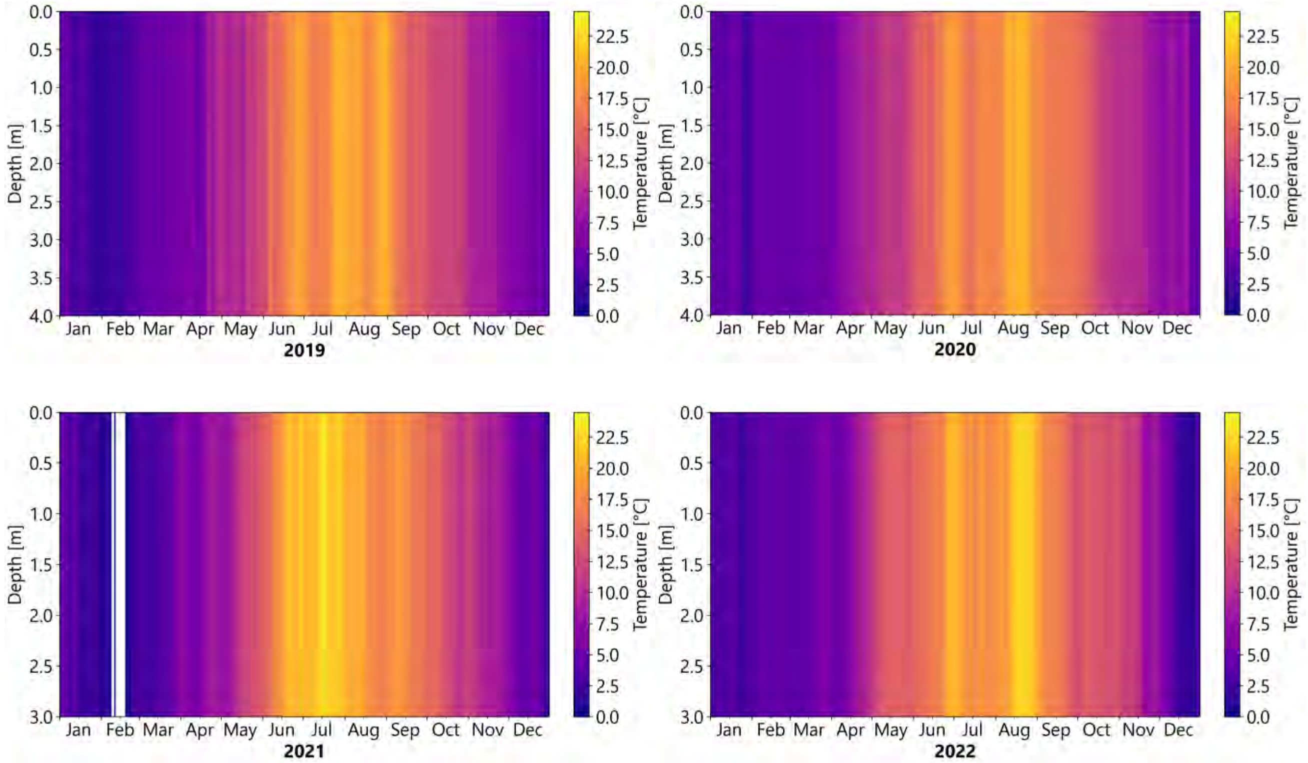
Temperature Profiles



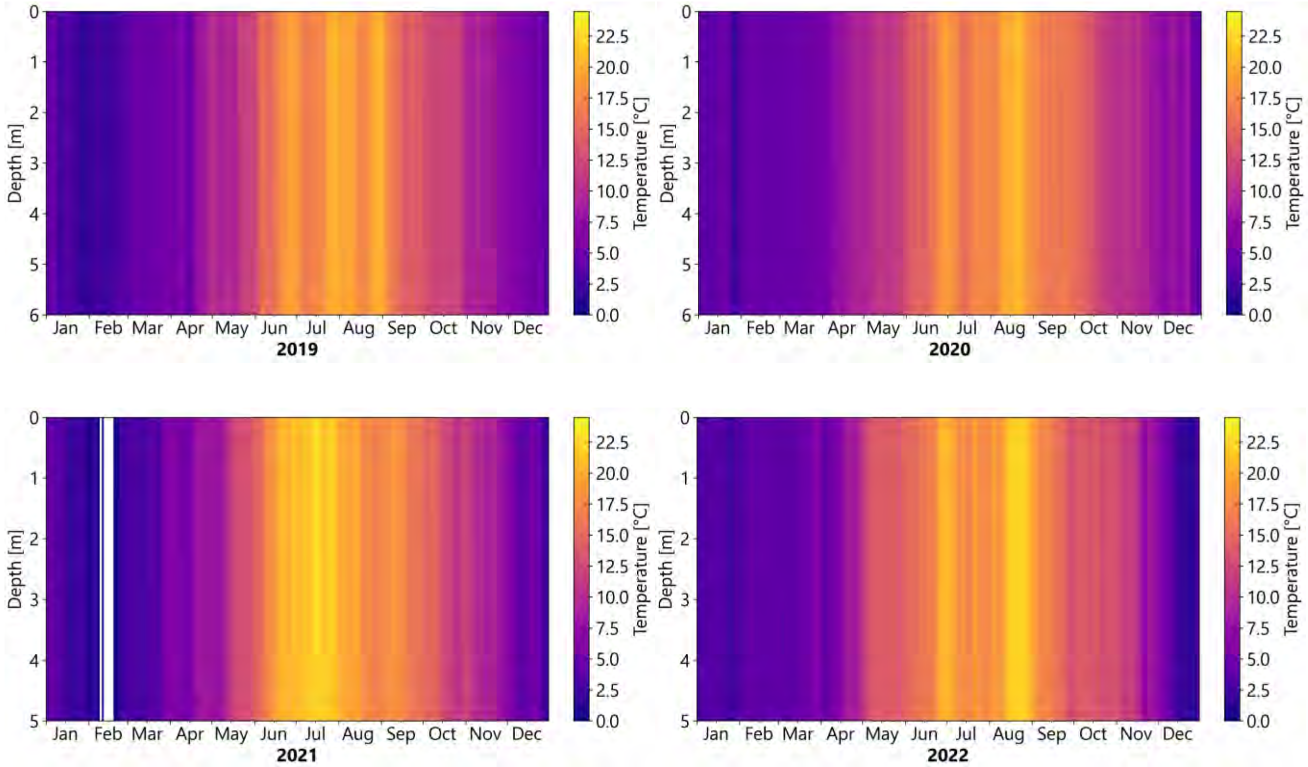
Temperature profiles extracted from SMHI-Data at Point 2 (see Figure 30 in Appendix 1)



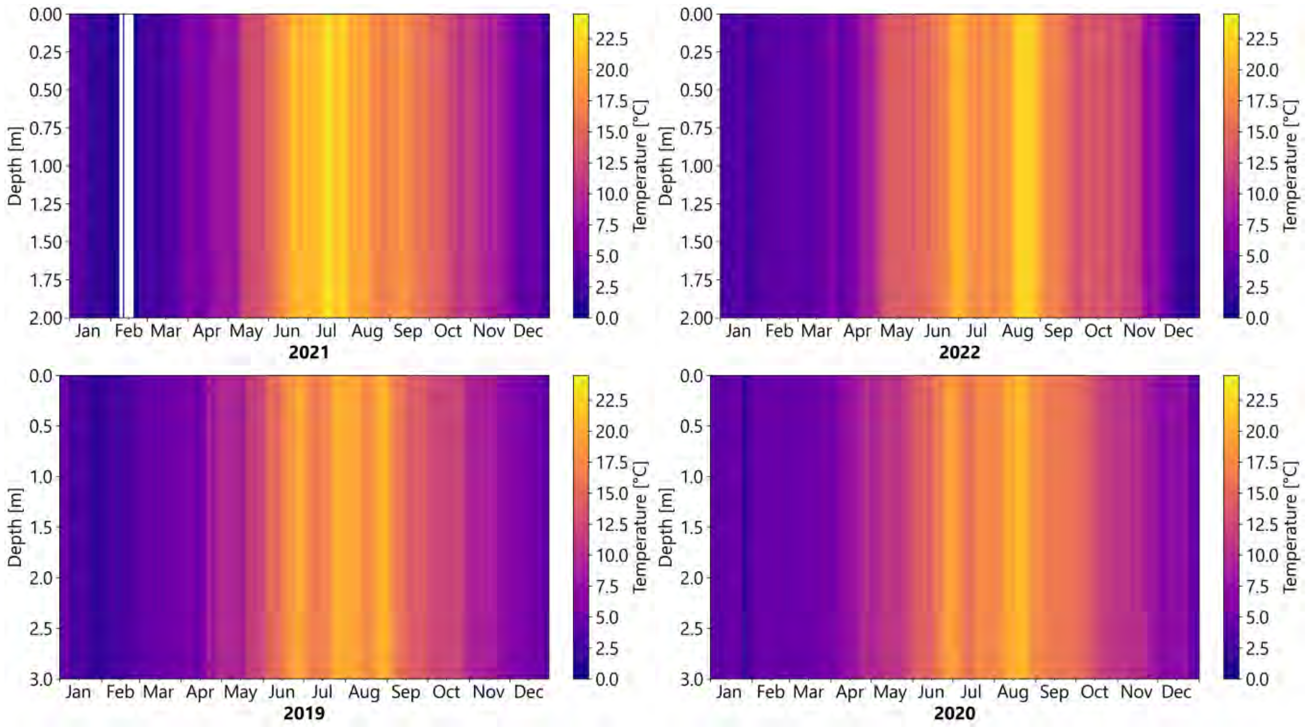
Temperature profiles extracted from SMHI-Data at Point 3 (see Figure 30 in Appendix 1)



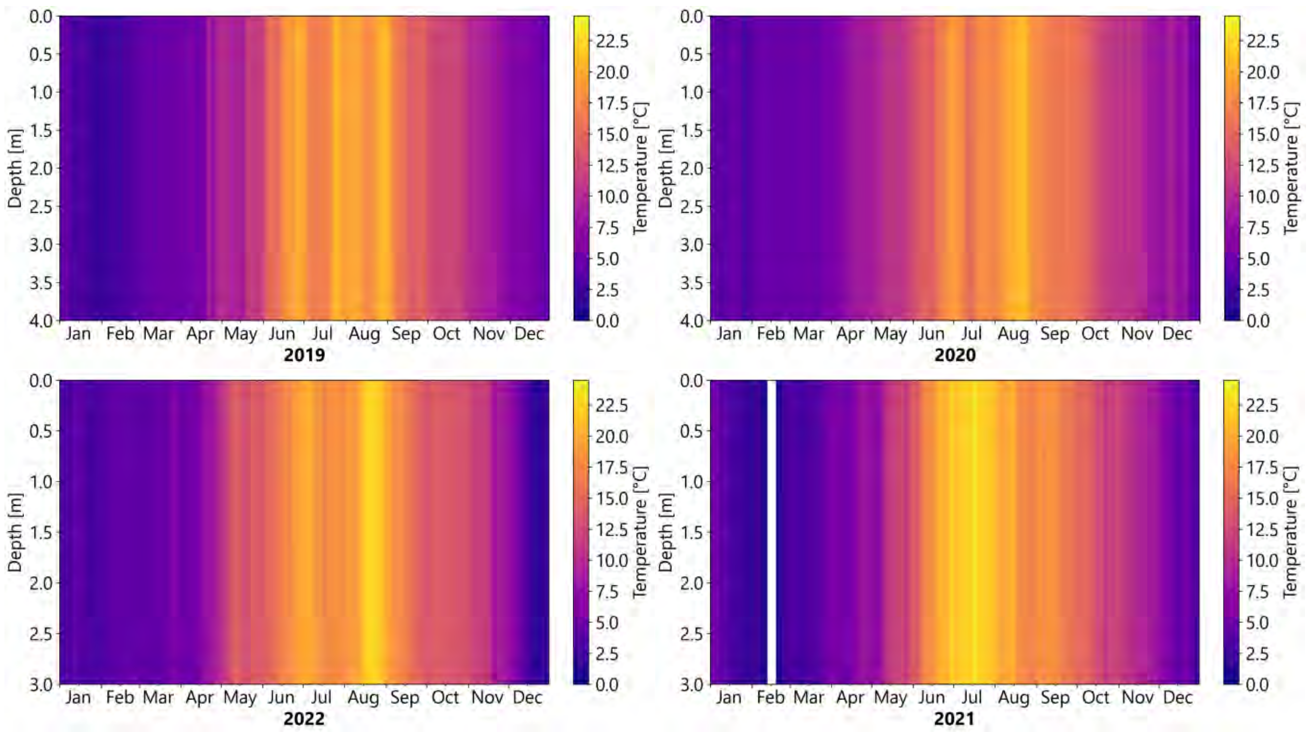
Temperature profiles extracted from SMHI-Data at Point -1 (see Figure 30 *in Appendix 1)*



Temperature profiles extracted from SMHI-Data at Point -2 (see Figure 30 *in Appendix 1)*

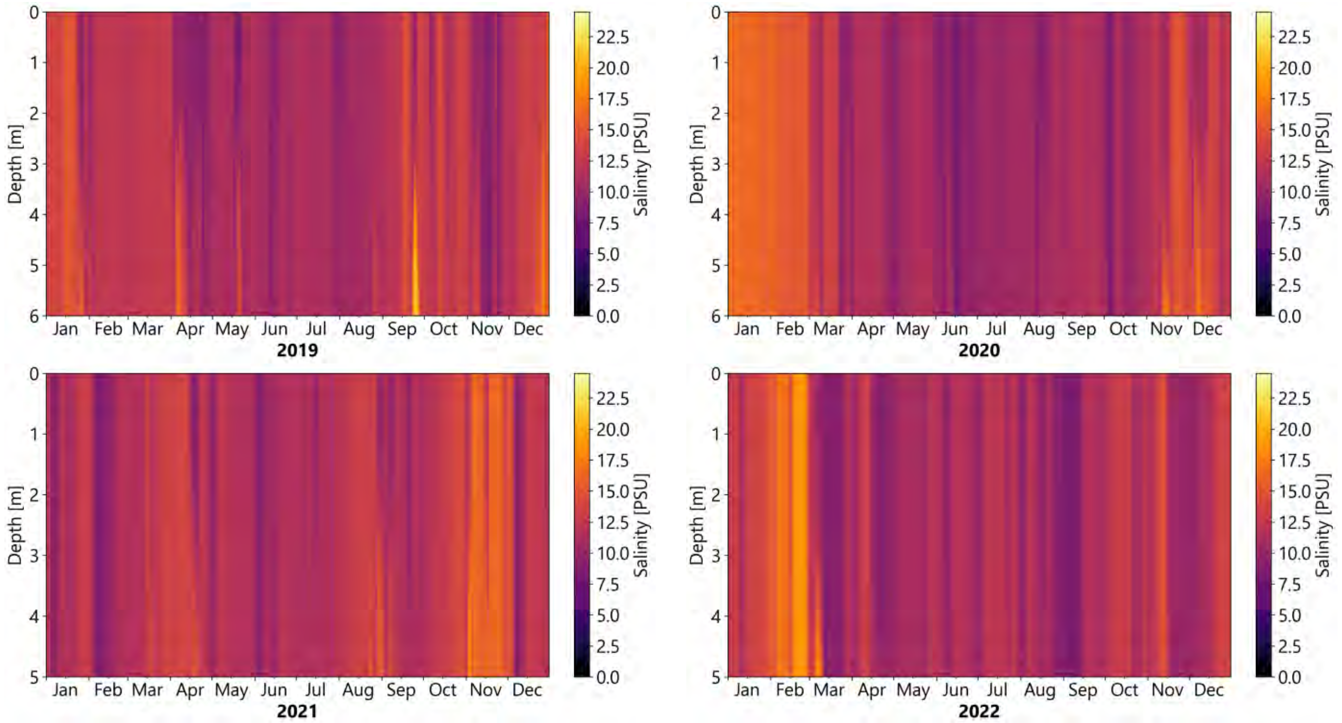


Temperature profiles extracted from SMHI-Data at Point -3 (see Figure 30 in Appendix 1)

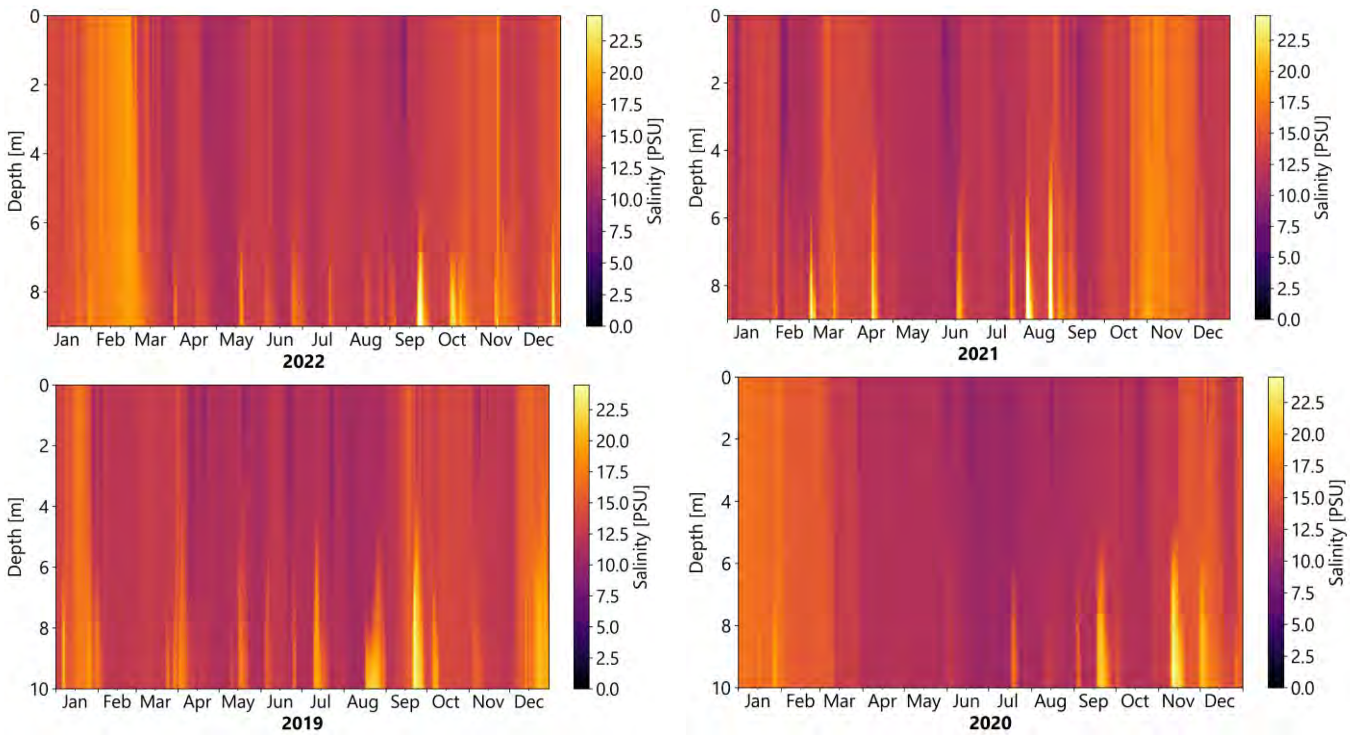


Temperature profiles extracted from SMHI-Data at Point -4 (see Figure 30 in Appendix 1)

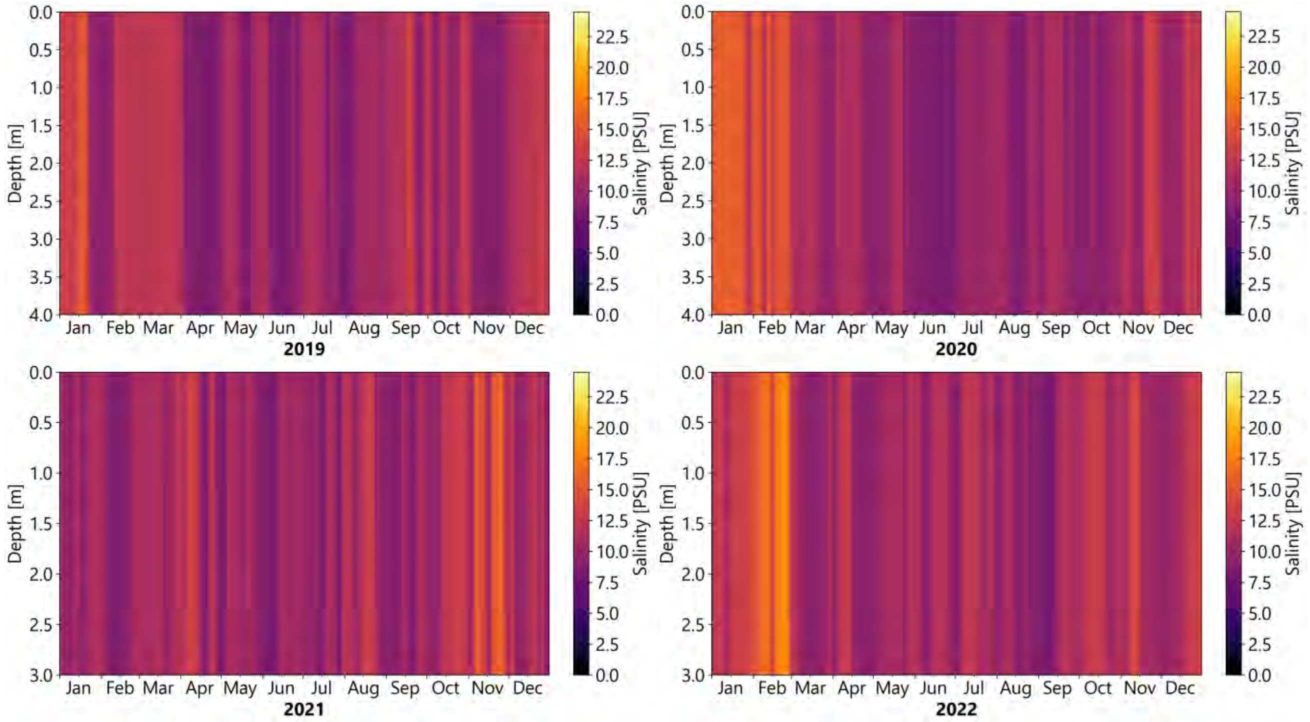
Salinity Profiles



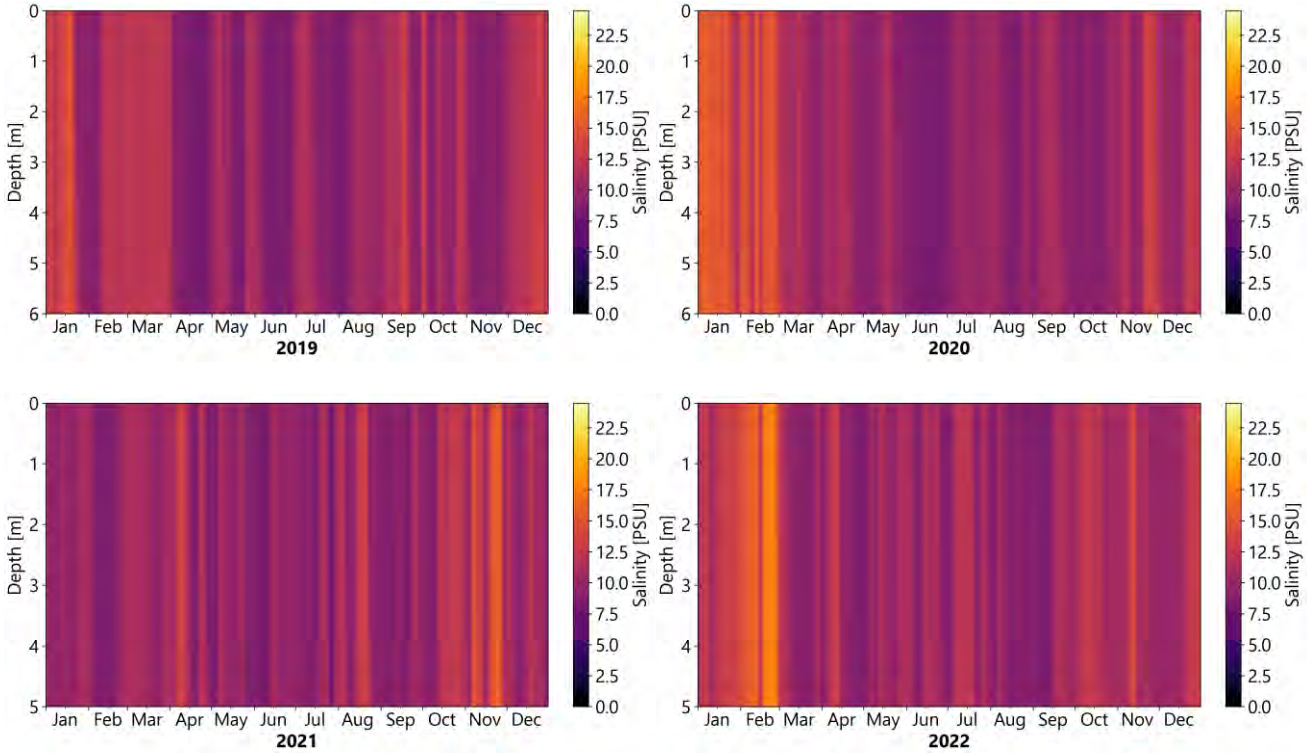
Salinity profiles extracted from SMHI-Data at Point 2 (see Figure 30 *in Appendix 1)*



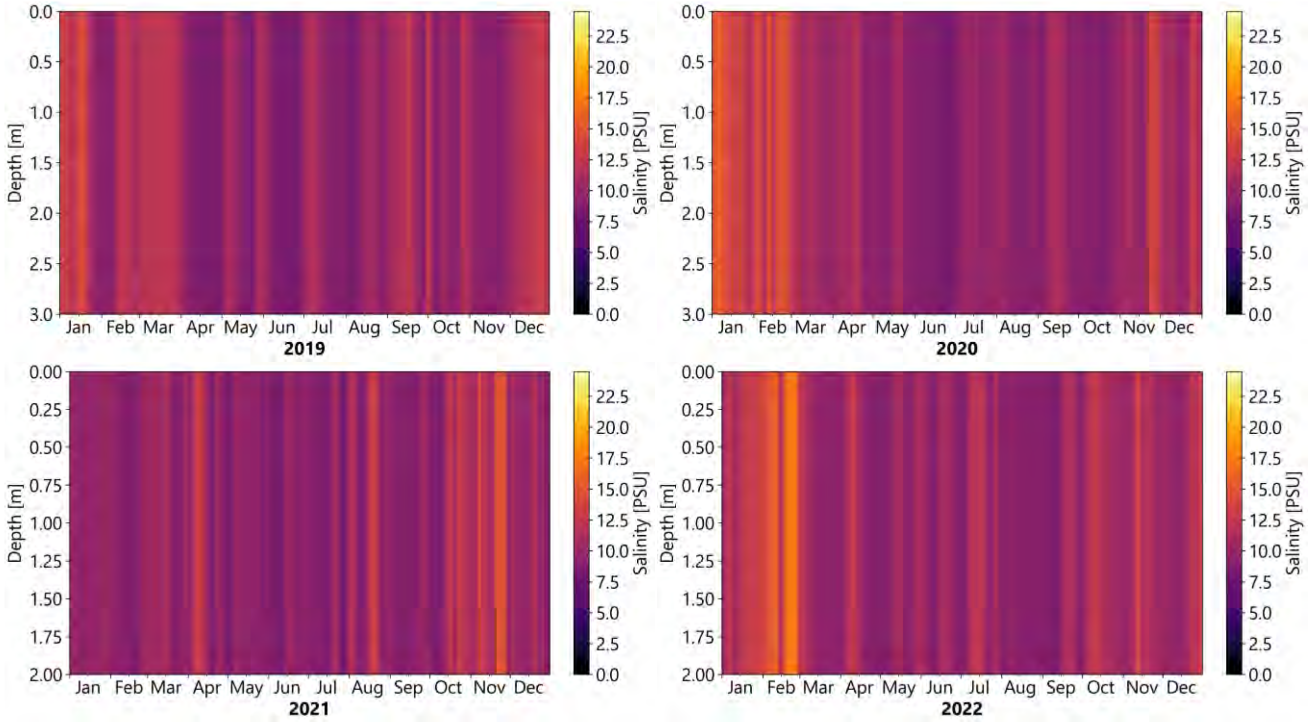
Salinity profiles extracted from SMHI-Data at Point 3 (see Figure 30 *in Appendix 1)*



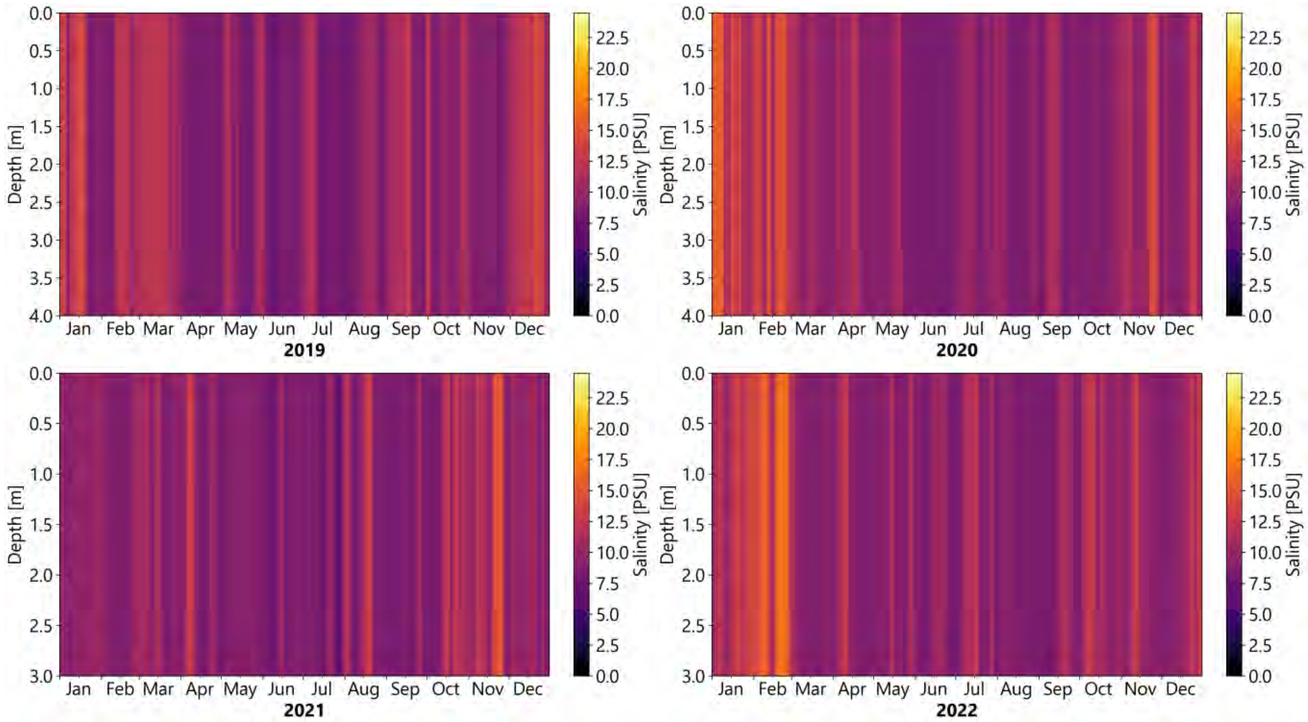
Salinity profiles extracted from SMHI-Data at Point -1 (see Figure 30 *in Appendix 1)*



Salinity profiles extracted from SMHI-Data at Point -2 (see Figure 30 *in Appendix 1)*

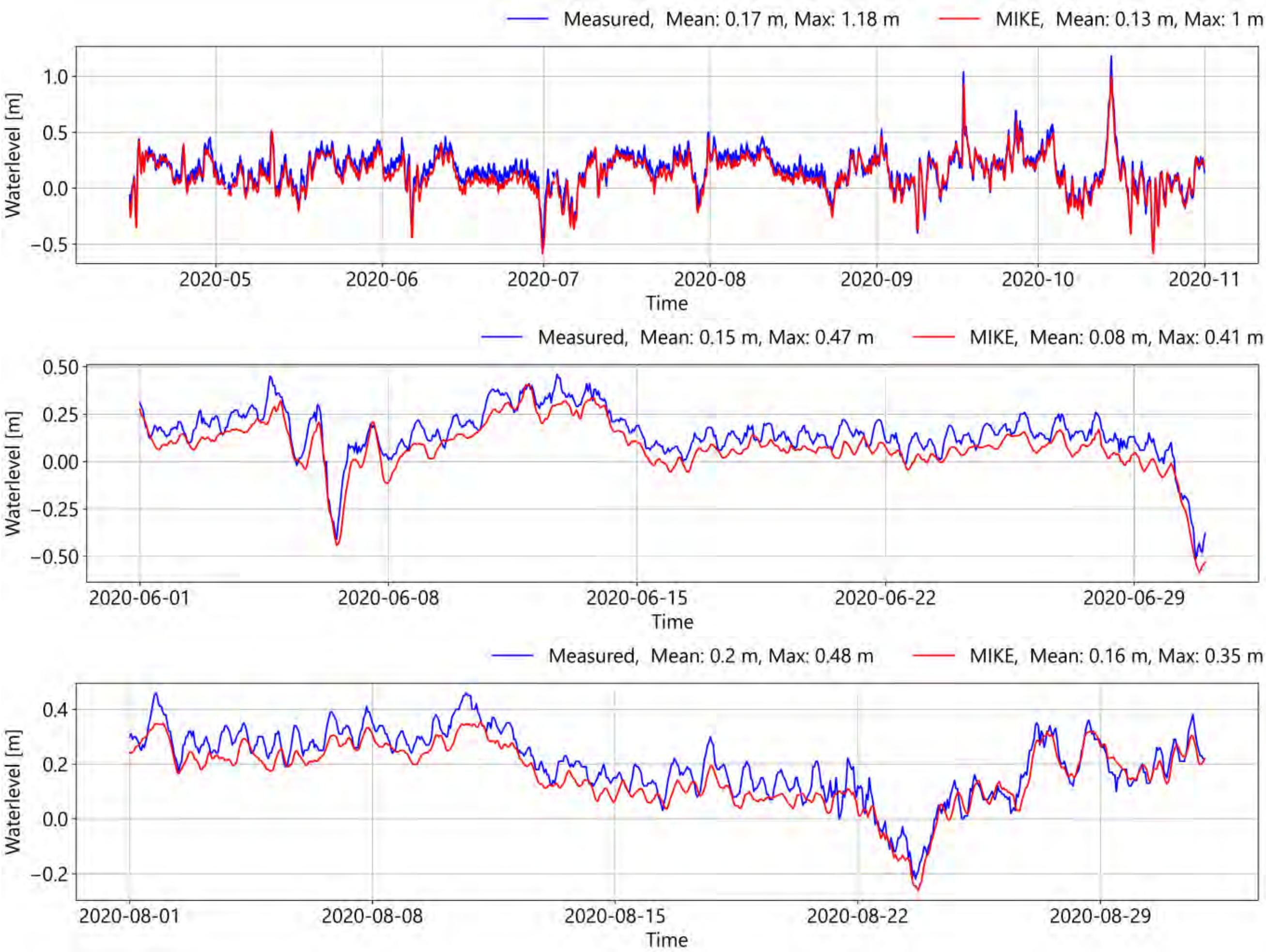


Salinity profiles extracted from SMHI-Data at Point -3 (see Figure 30 in Appendix 1)

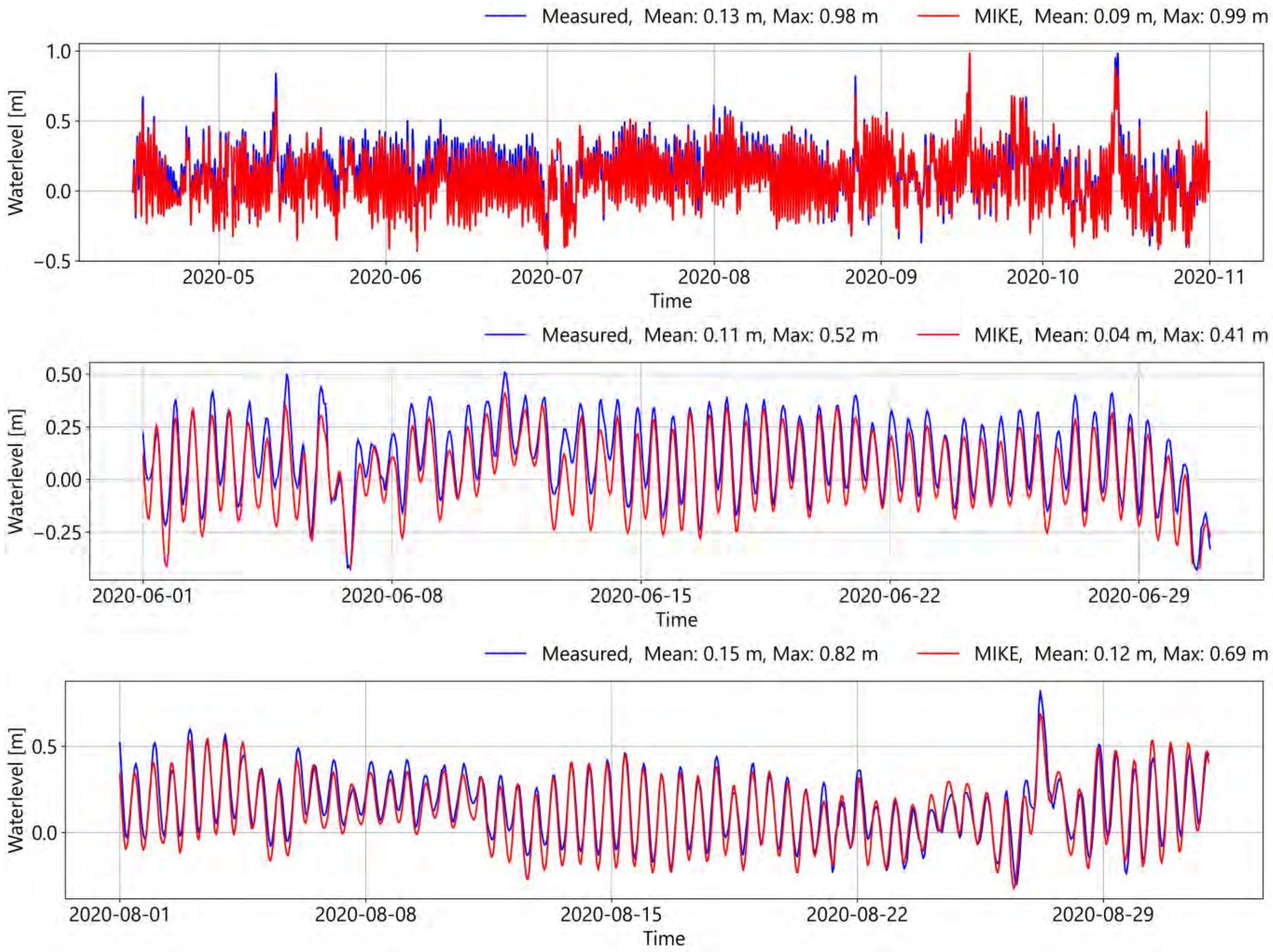


Salinity profiles extracted from SMHI-Data at Point -4 (see Figure 38 in Appendix 1)

Appendix 2 HD-model: Calibration



Comparison between modelled and measured water level time series at station 9030301. Top: entire simulation period. Middle and bottom: extracted months respectively June and August.



Comparison between modelled and measured water level time series at station 9030501. Top: entire simulation period. Middle and bottom: extracted months respectively June and August.

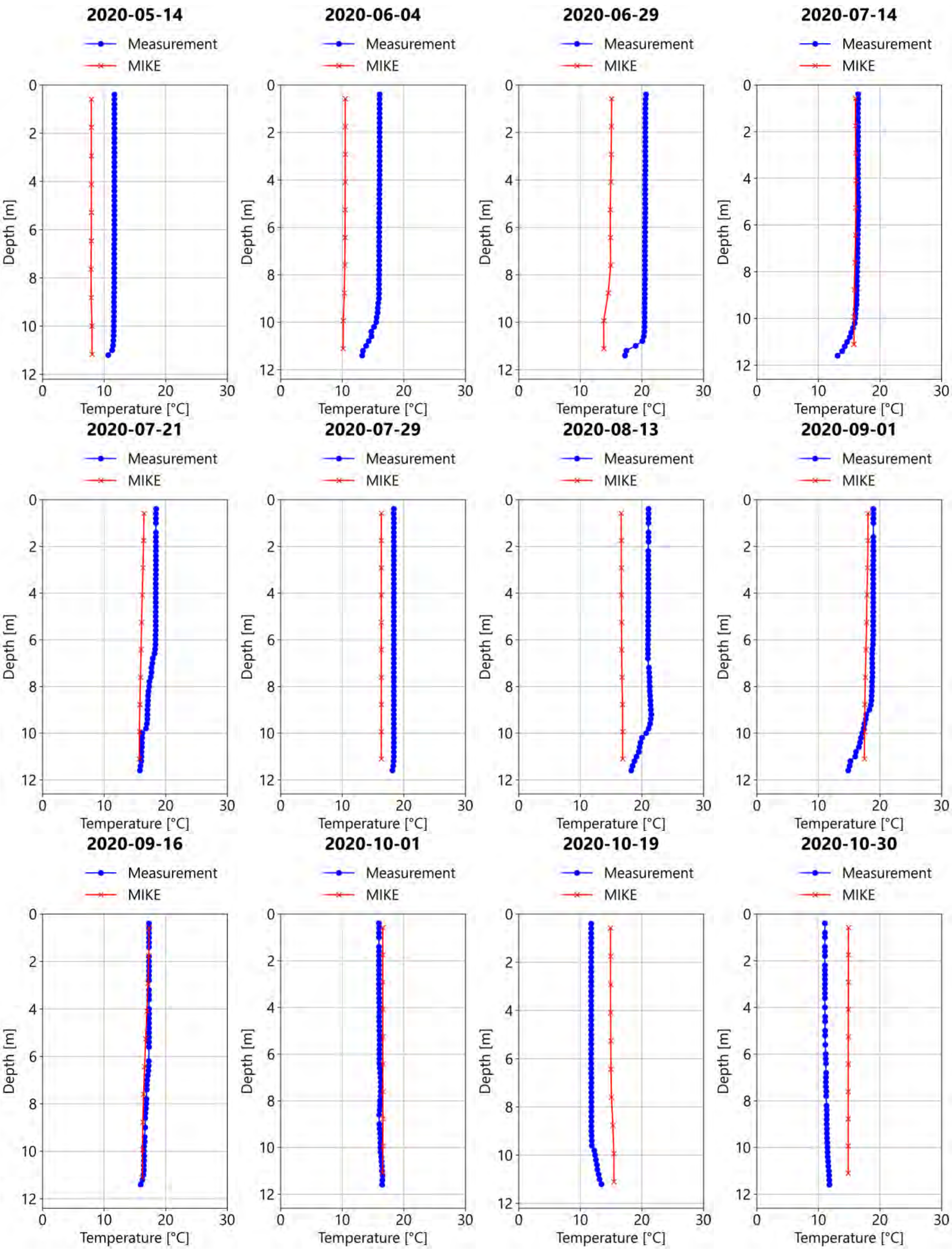
Performance Metrics of the HD-Model in respect to the Water levels (June 2020)

Station-ID	ME [m]	MAE [m]	RMSE [m]	Std. of Residuals [m]	Correlation Coefficients [-]
9030501	-0.08	0.08	0.09	0.05	0.96
9030301	-0.07	0.07	0.08	0.04	0.95
9030201	-0.04	0.05	0.06	0.04	0.91

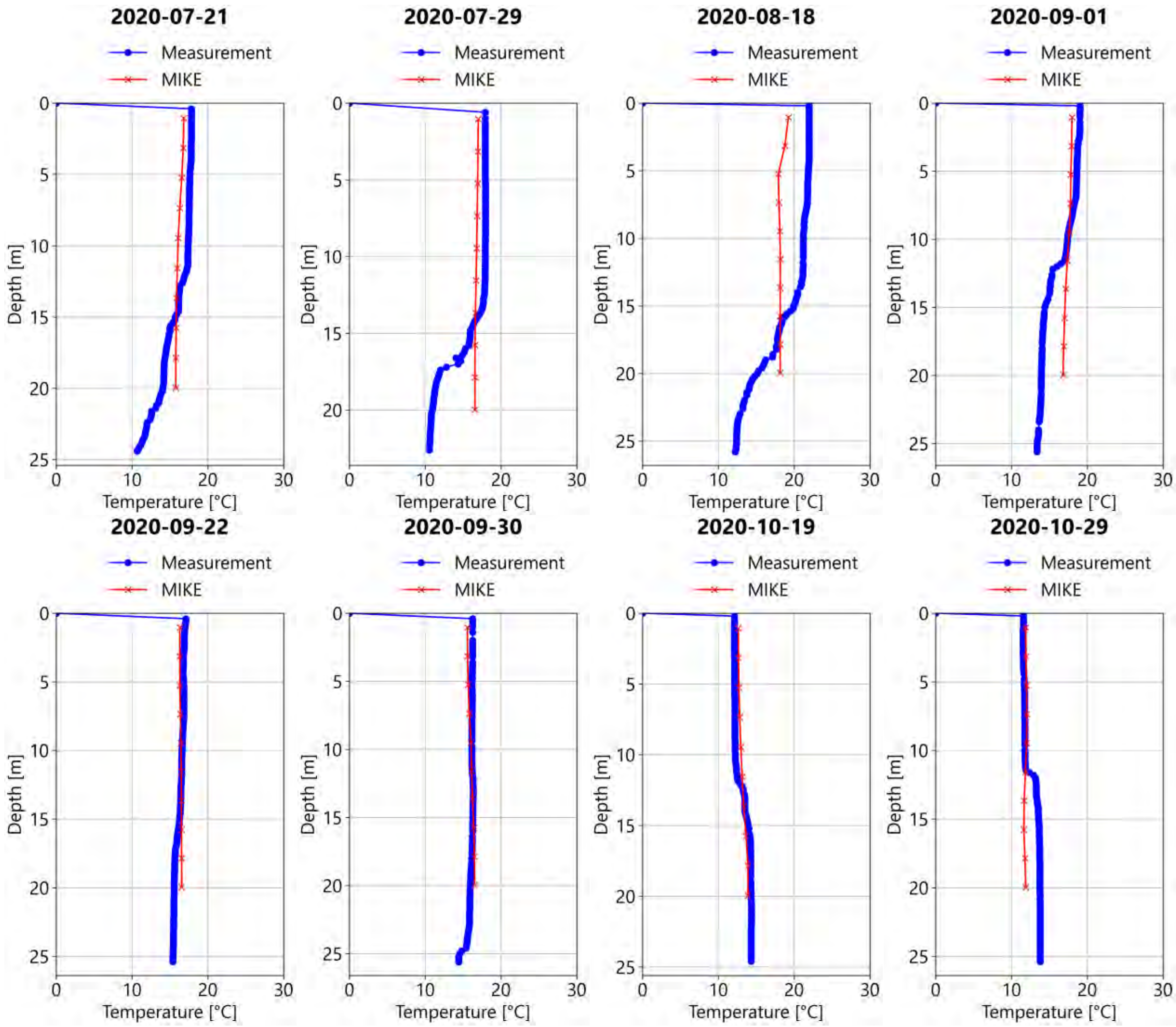
Performance Metrics of the HD-Model in respect to the Water levels (August 2020)

Station-ID	ME [m]	MAE [m]	RMSE [m]	Std. of Residuals [m]	Correlation Coefficients [-]
9030501	-0.04	0.06	0.08	0.07	0.94
9030301	-0.04	0.05	0.06	0.05	0.96
9030201	-0.01	0.04	0.06	0.06	0.92

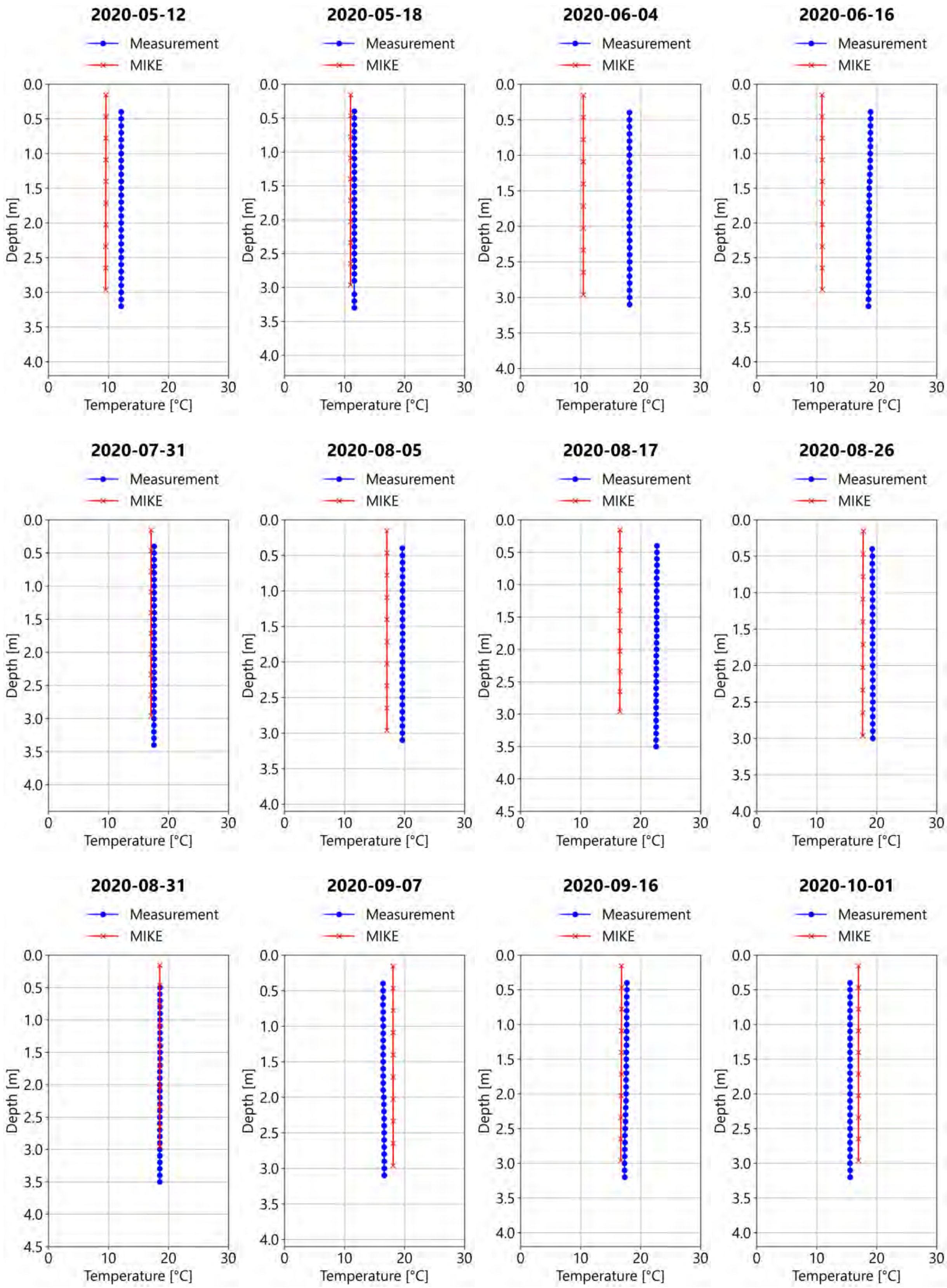
Station STO-0101015: Temperature



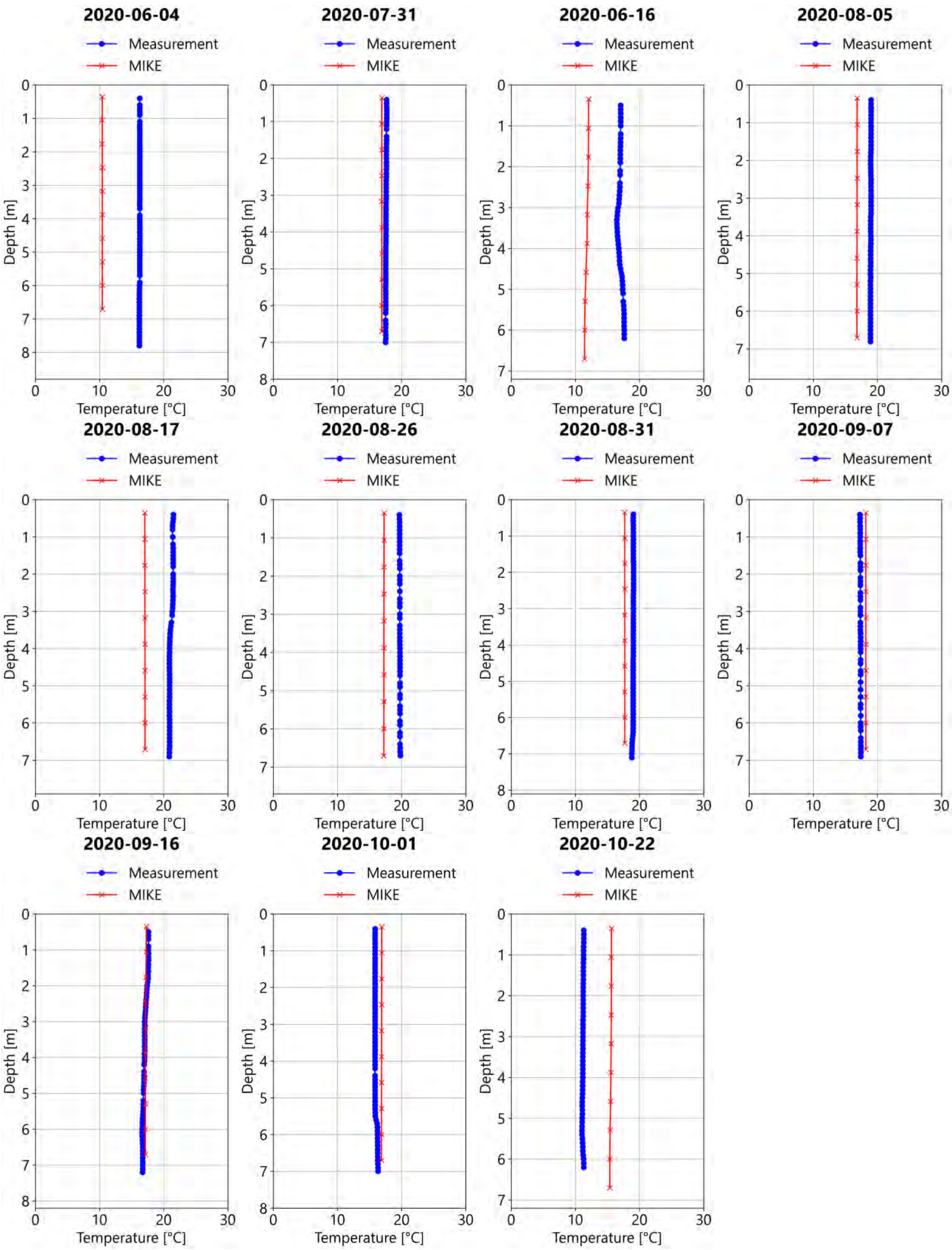
Station STO-0101023: Temperature



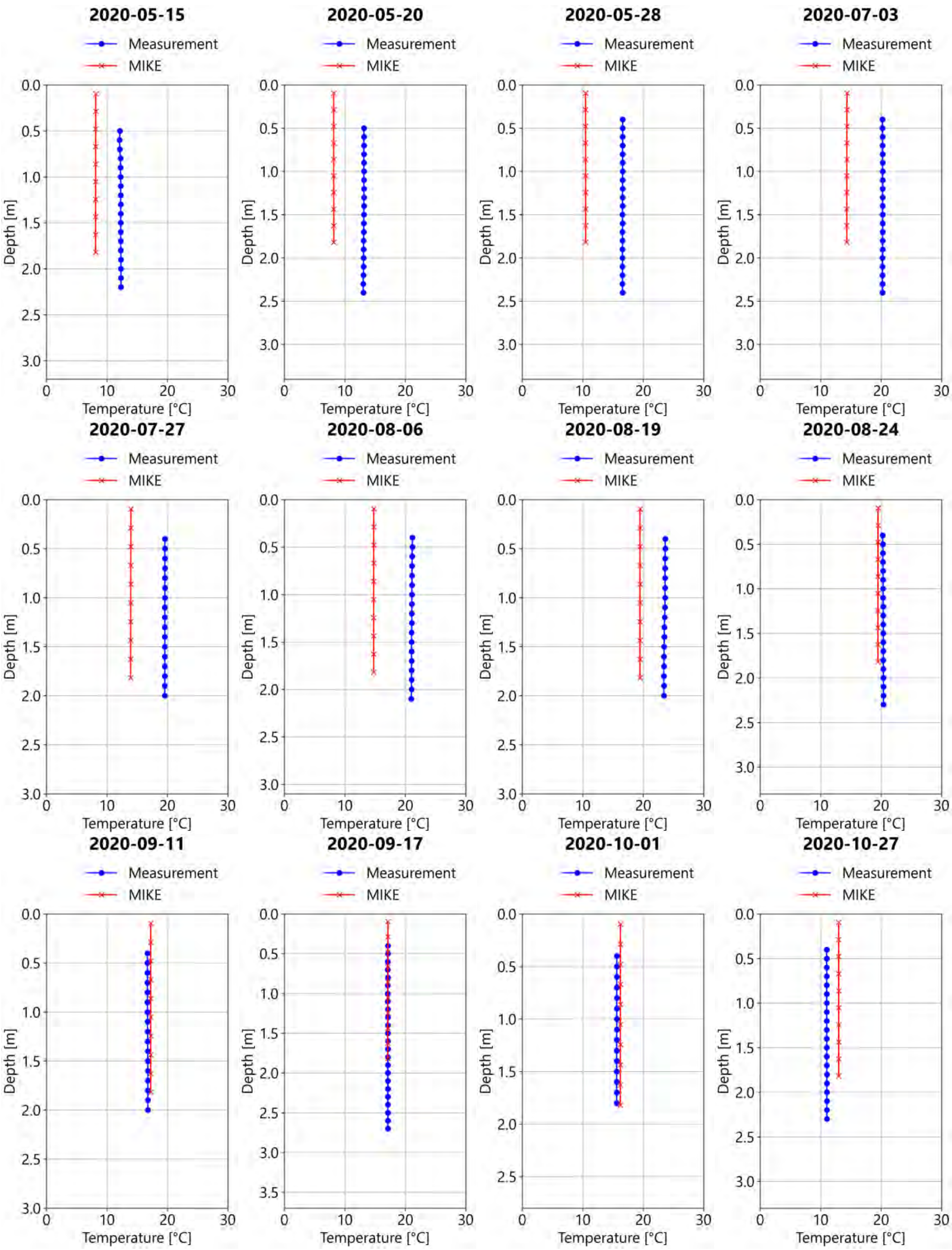
Station STO-0101061: Temperature



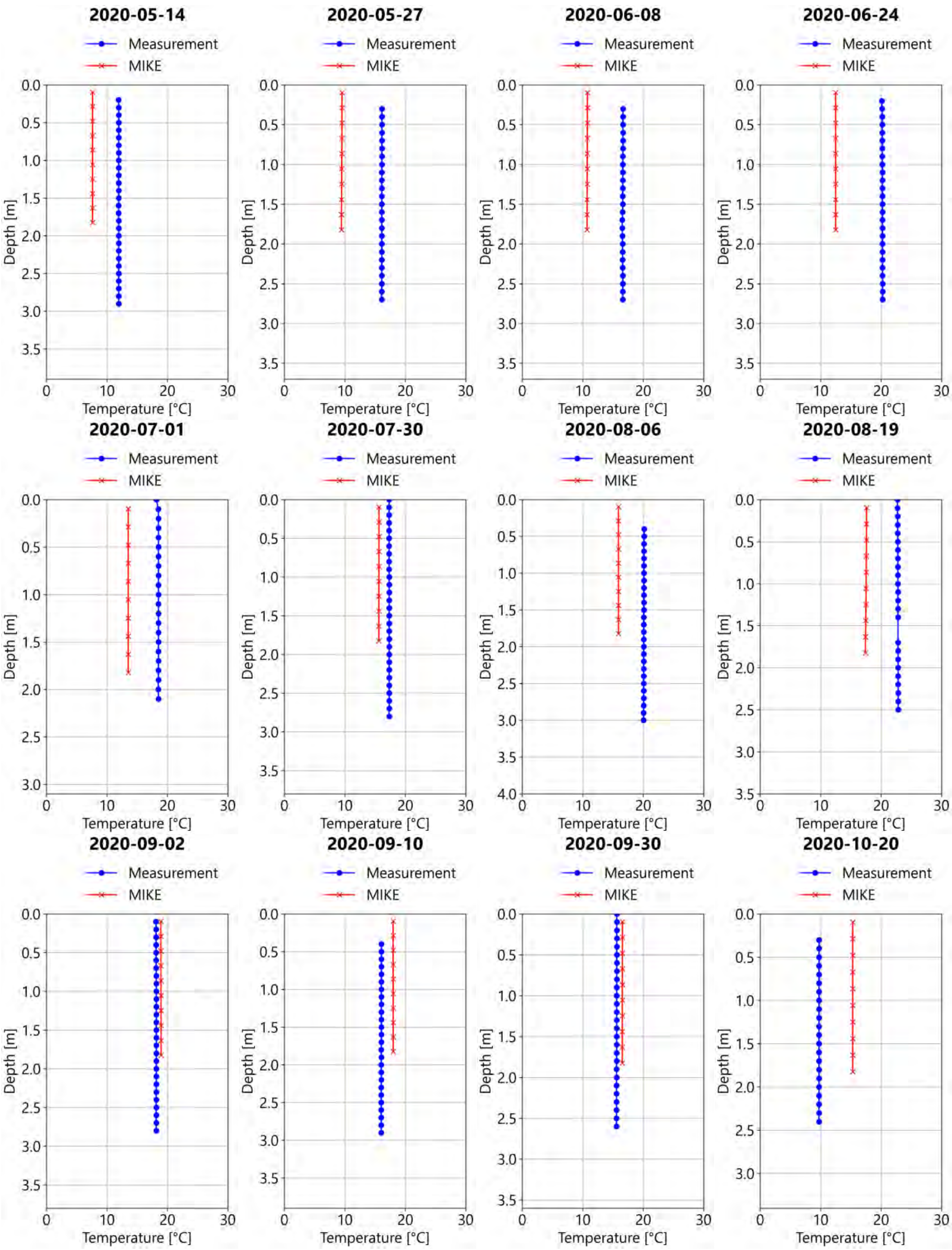
Station STO-0101076: Temperature



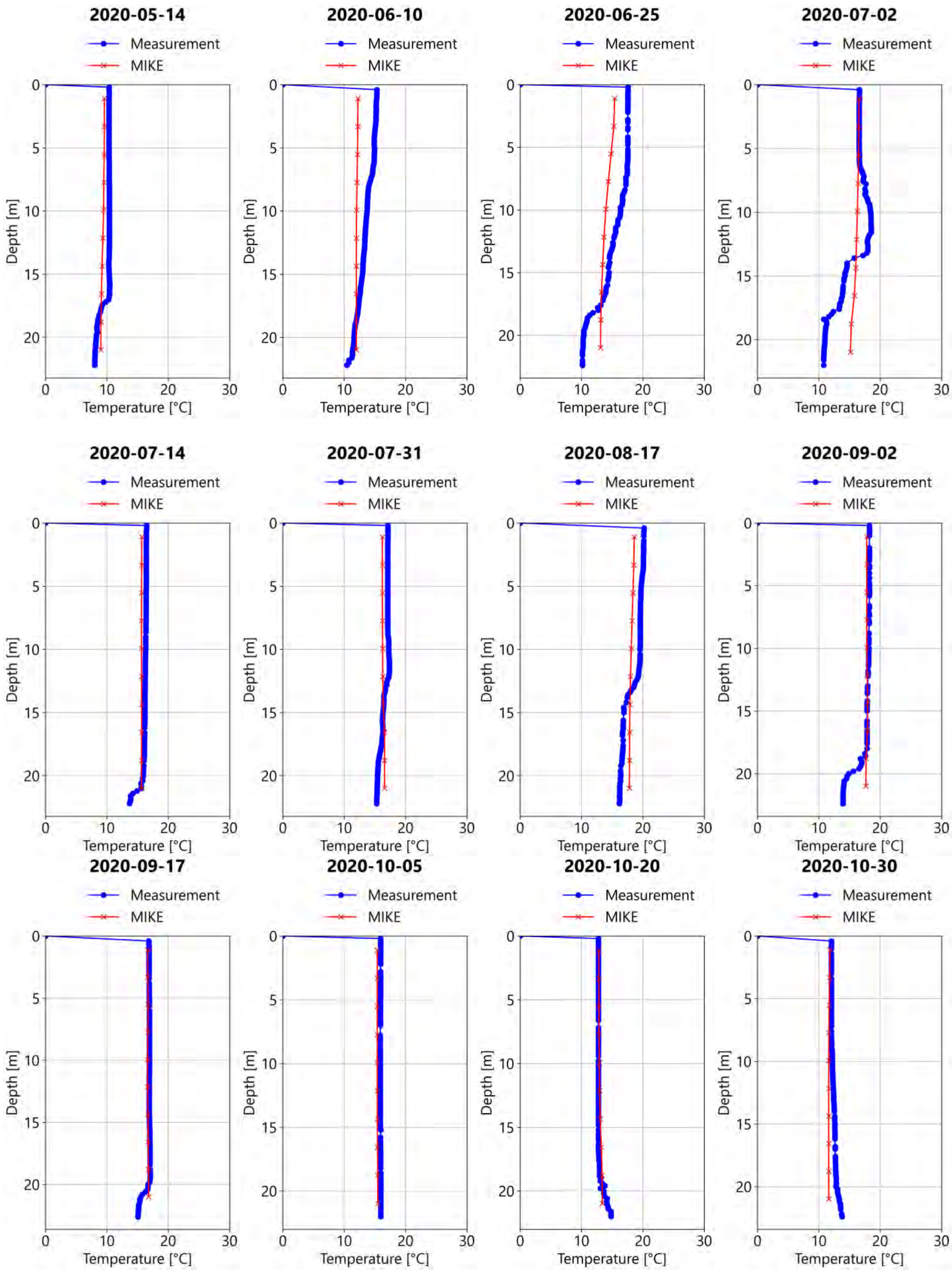
Station STO-0101056: Temperature



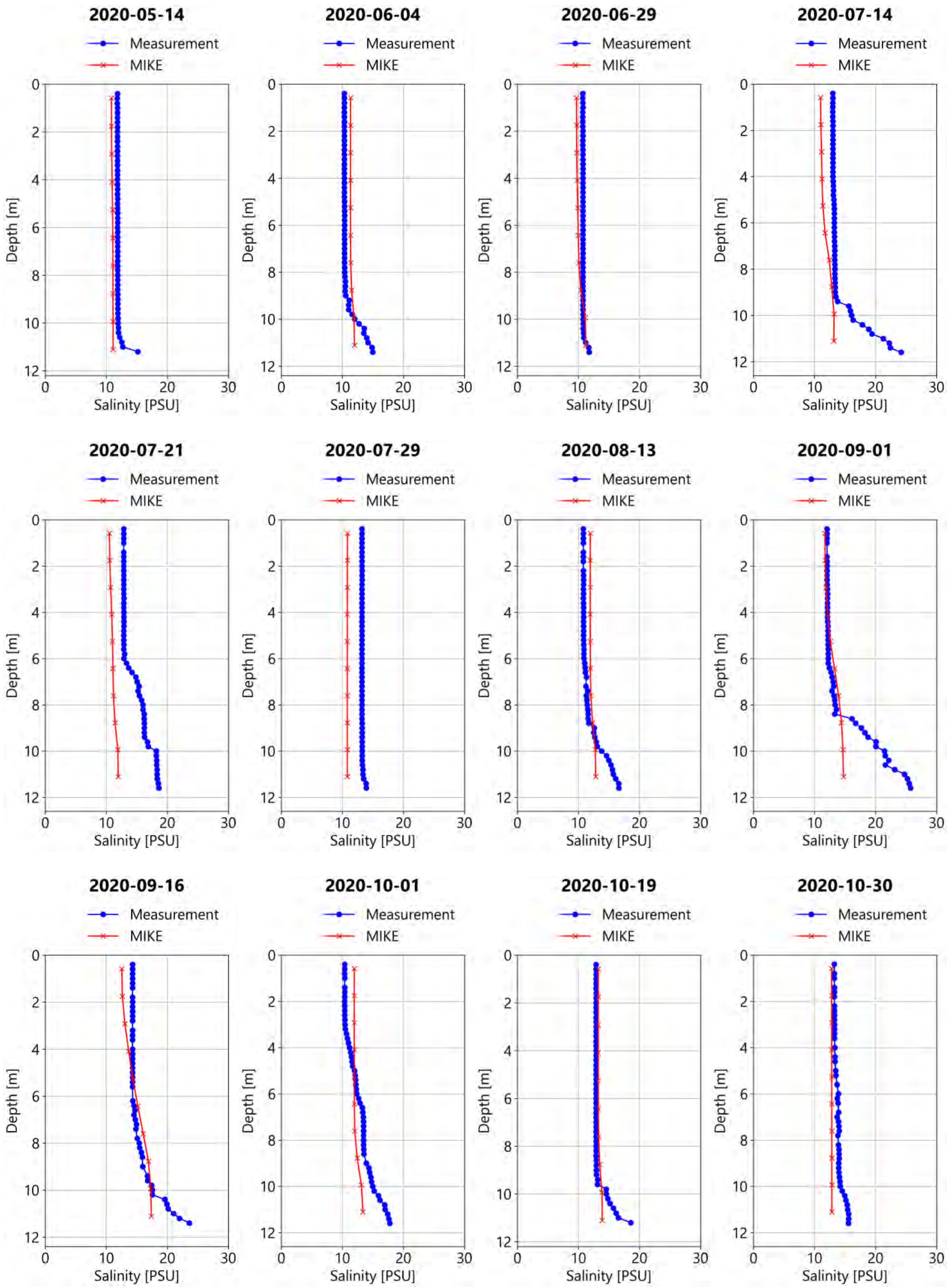
Station STO-0104010: Temperature



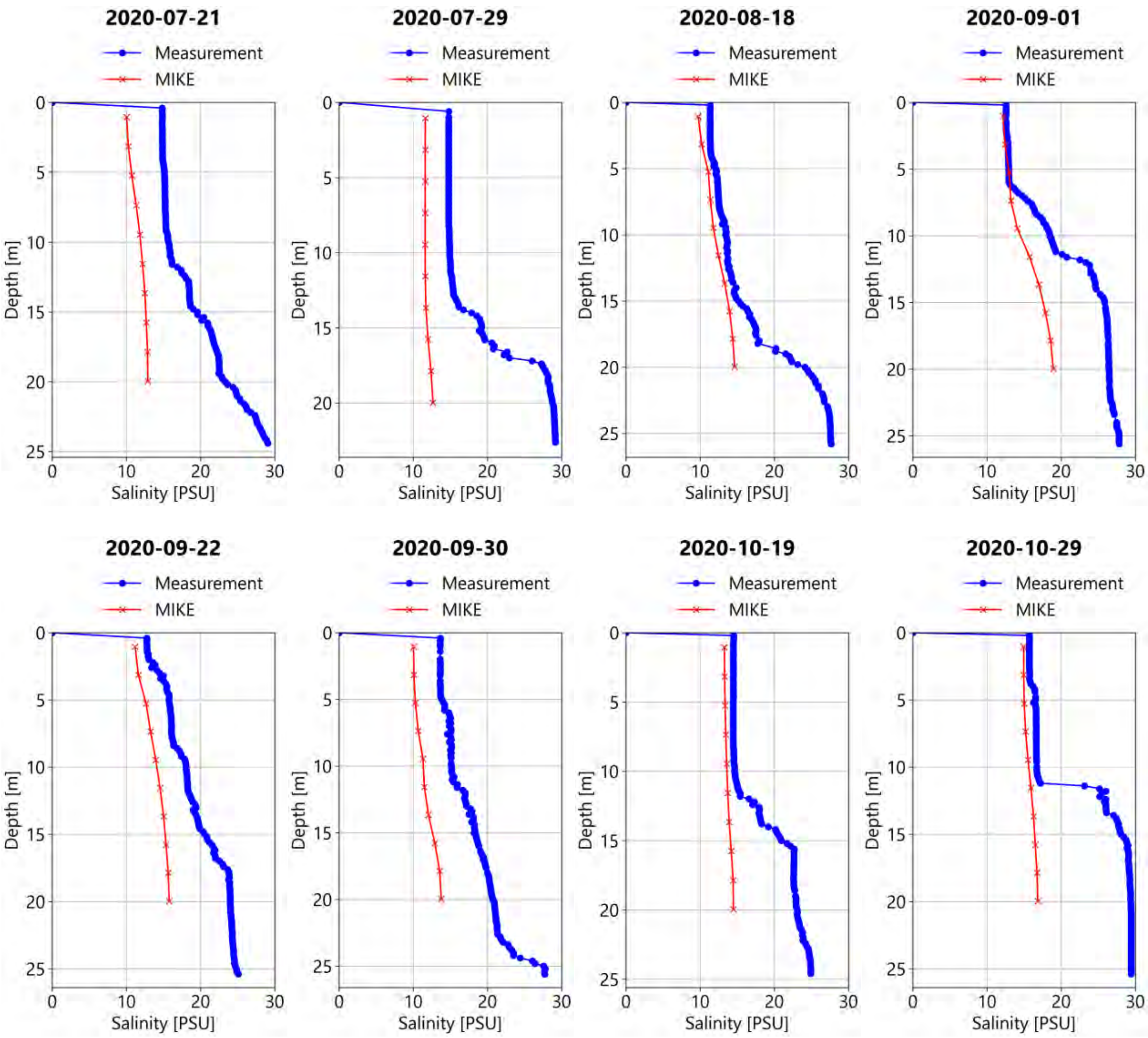
Station STO-0101016: Temperature



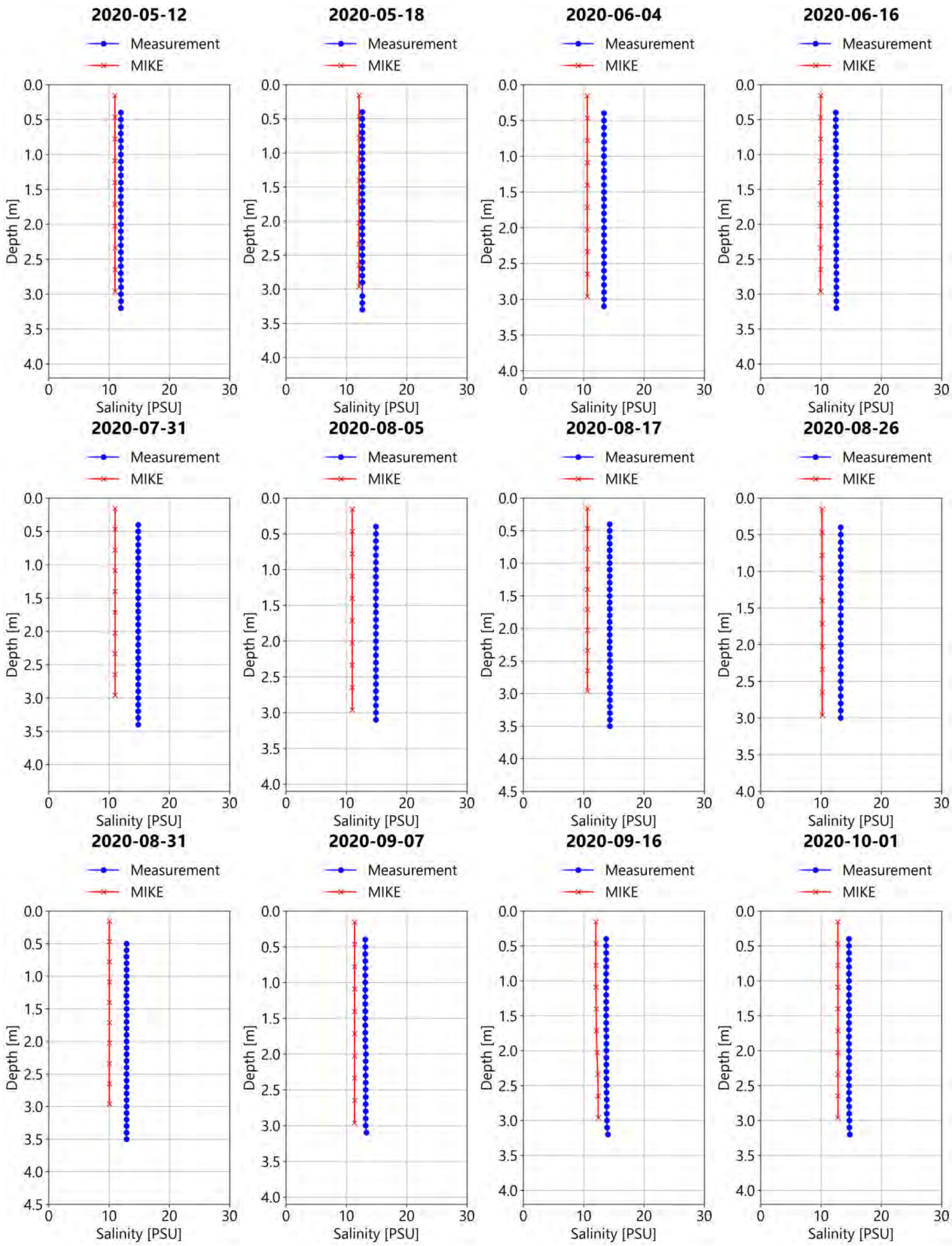
Station STO-0101015: Salinity



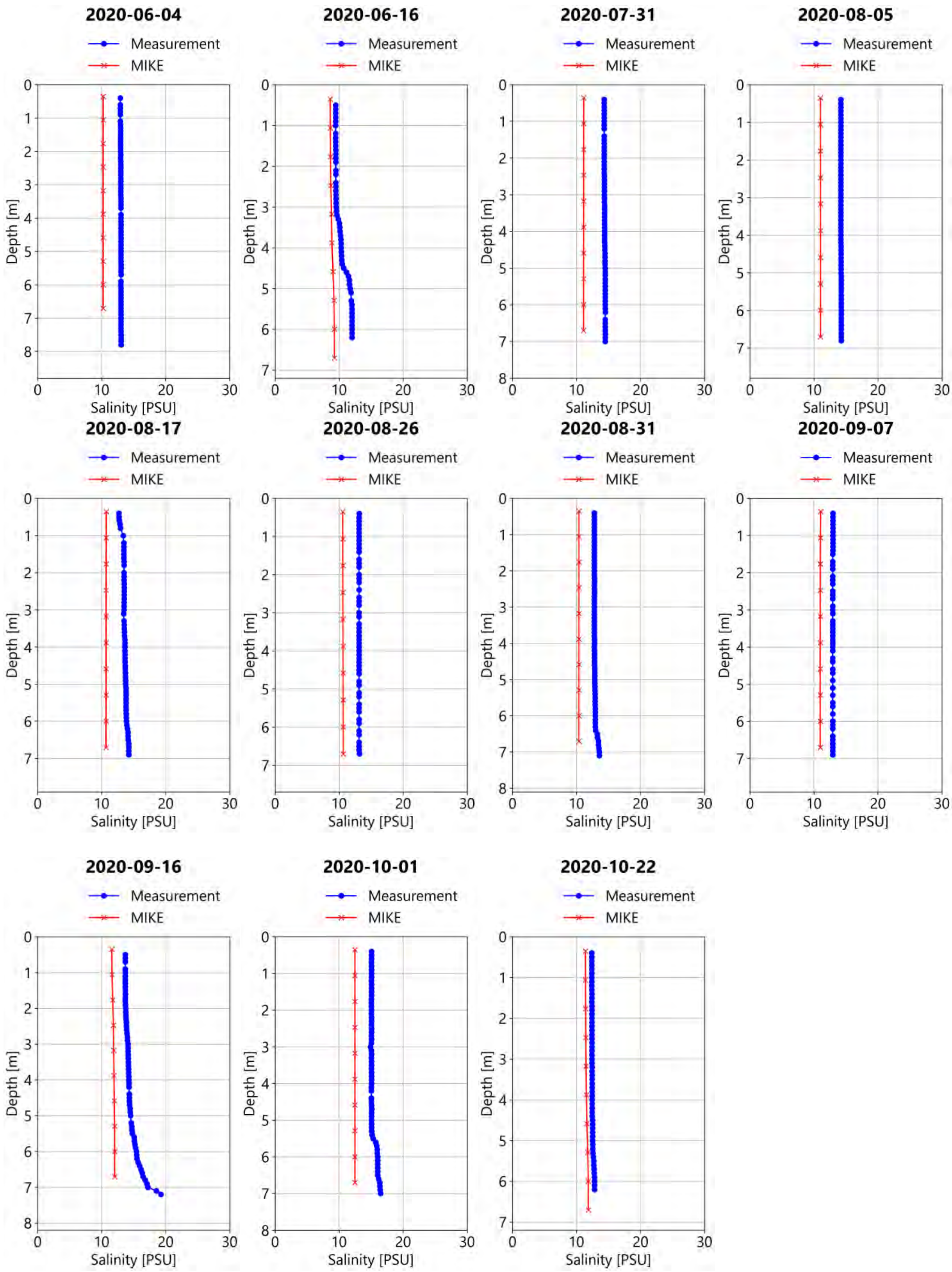
Station STO-0101023: Salinity



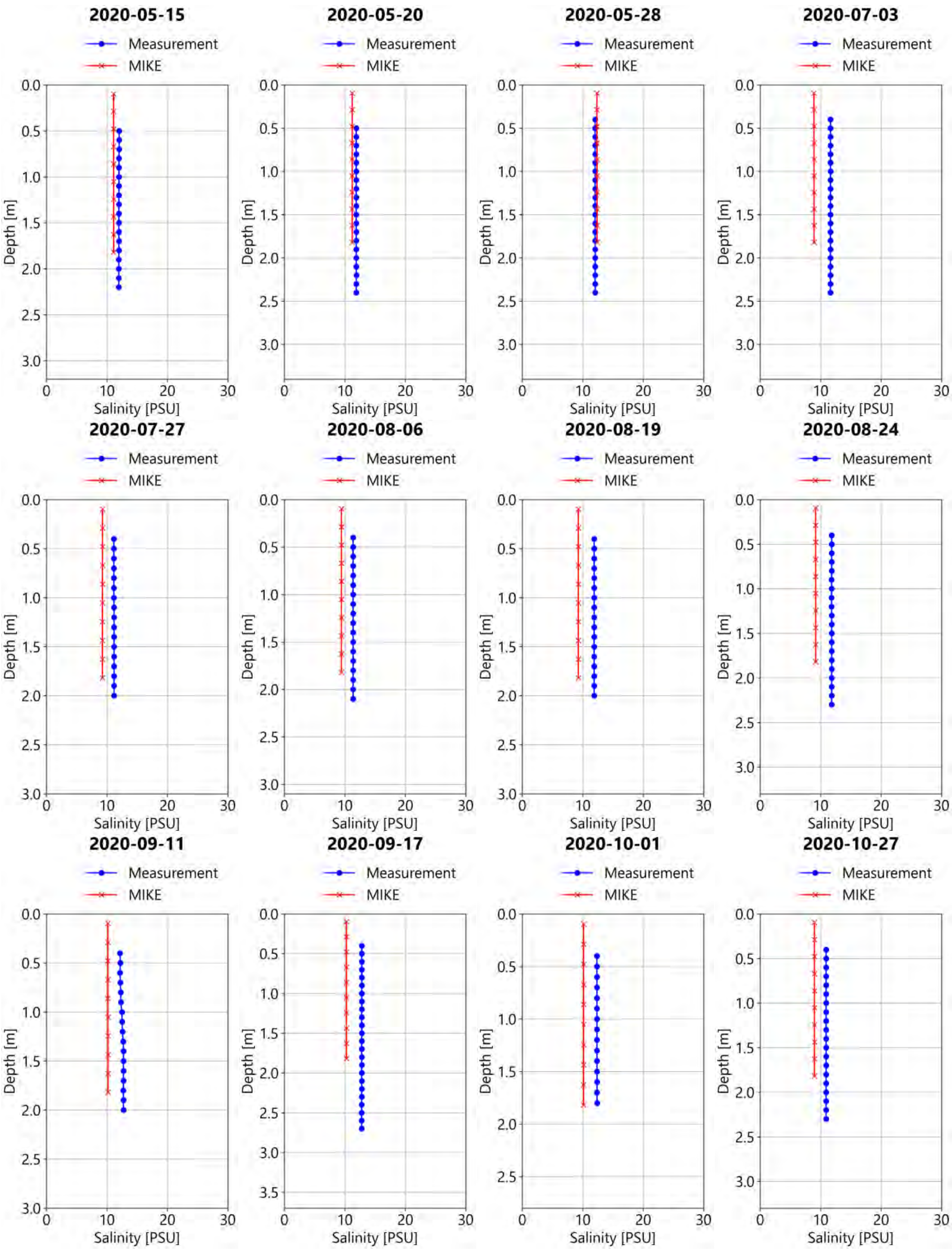
***Station STO-0101061:* Salinity**



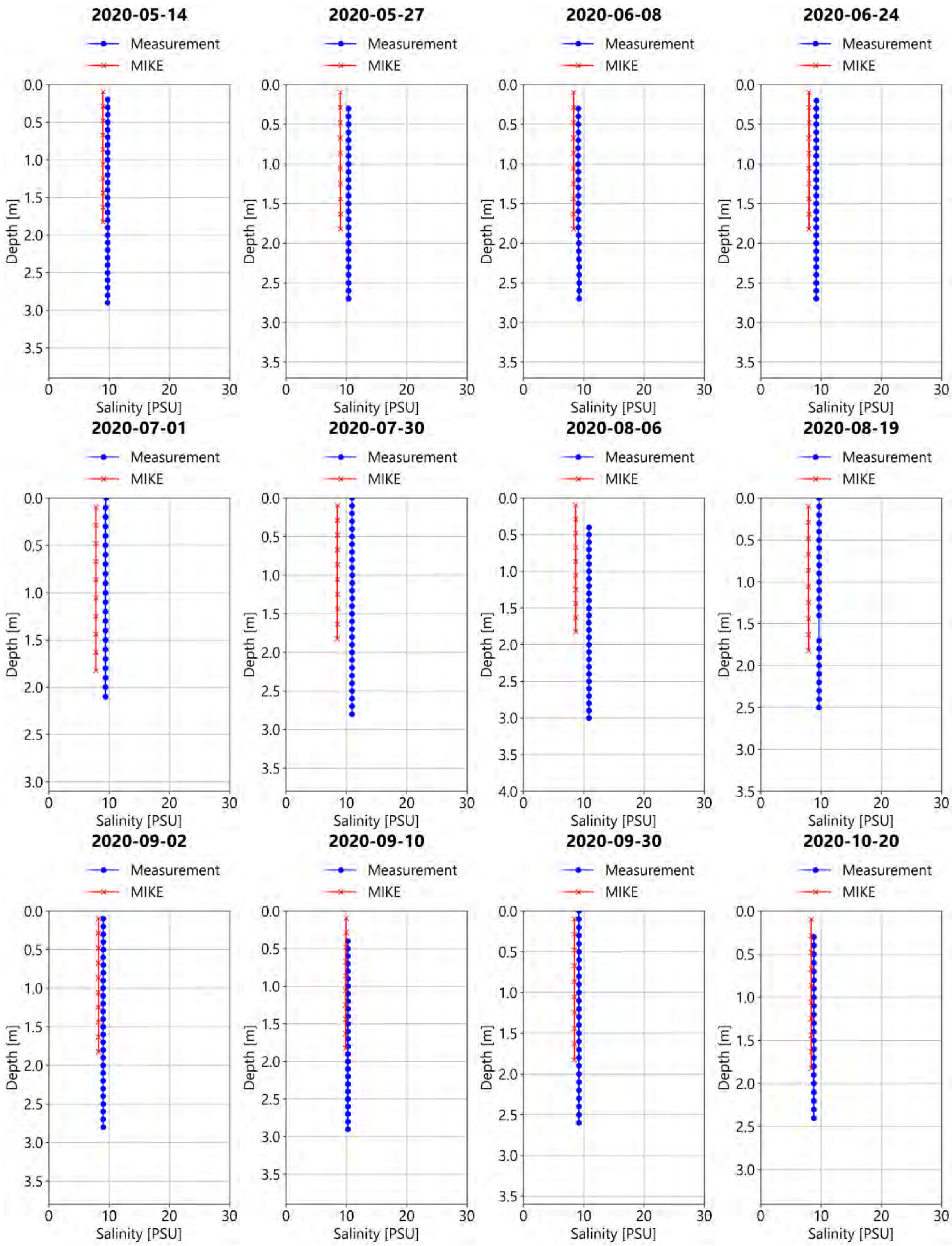
***Station STO-0101076:* Salinity**



***Station STO-0101056:* Salinity**



***Station STO-0104010:* Salinity**

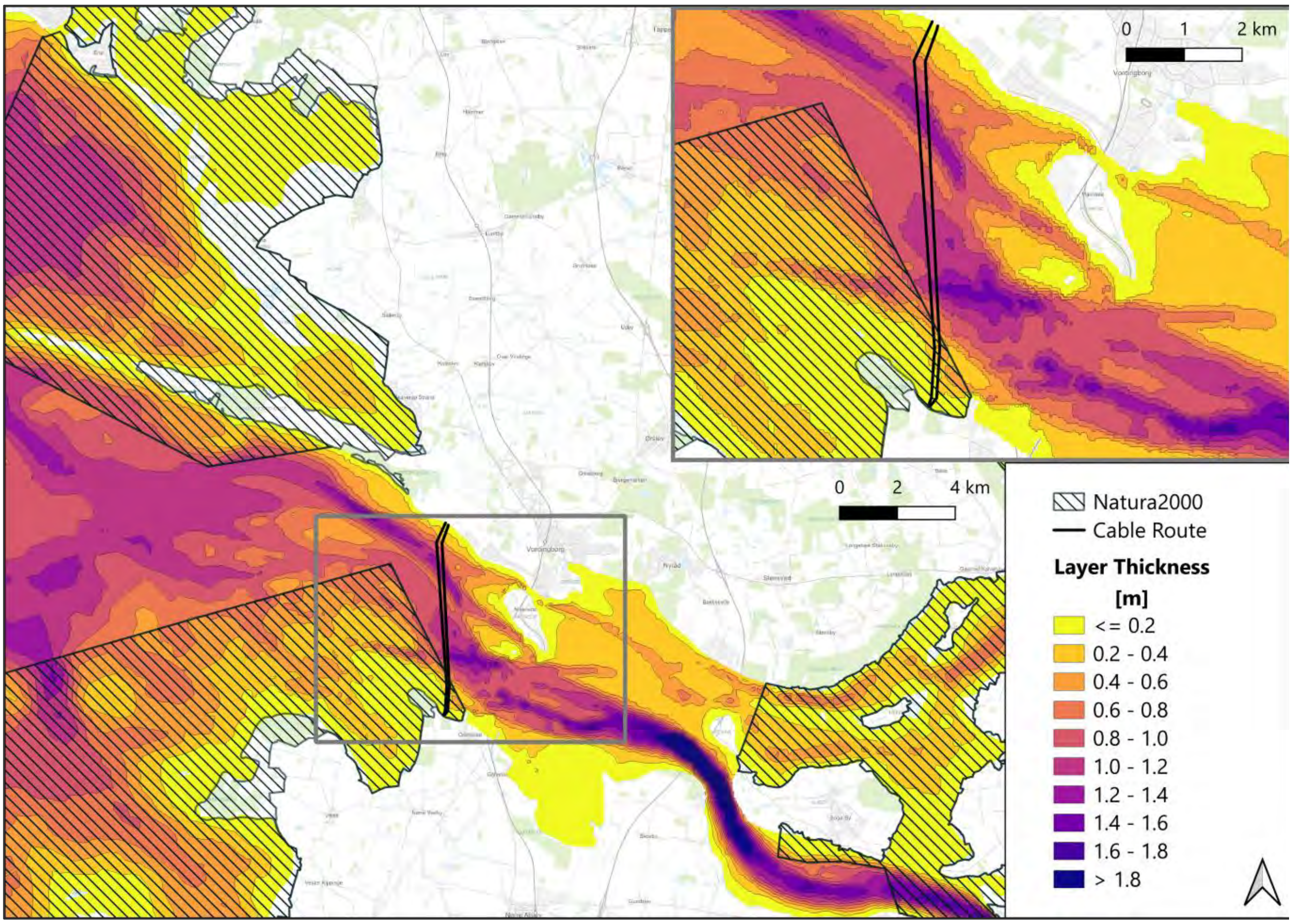


Appendix 3 Grain sieve analyses

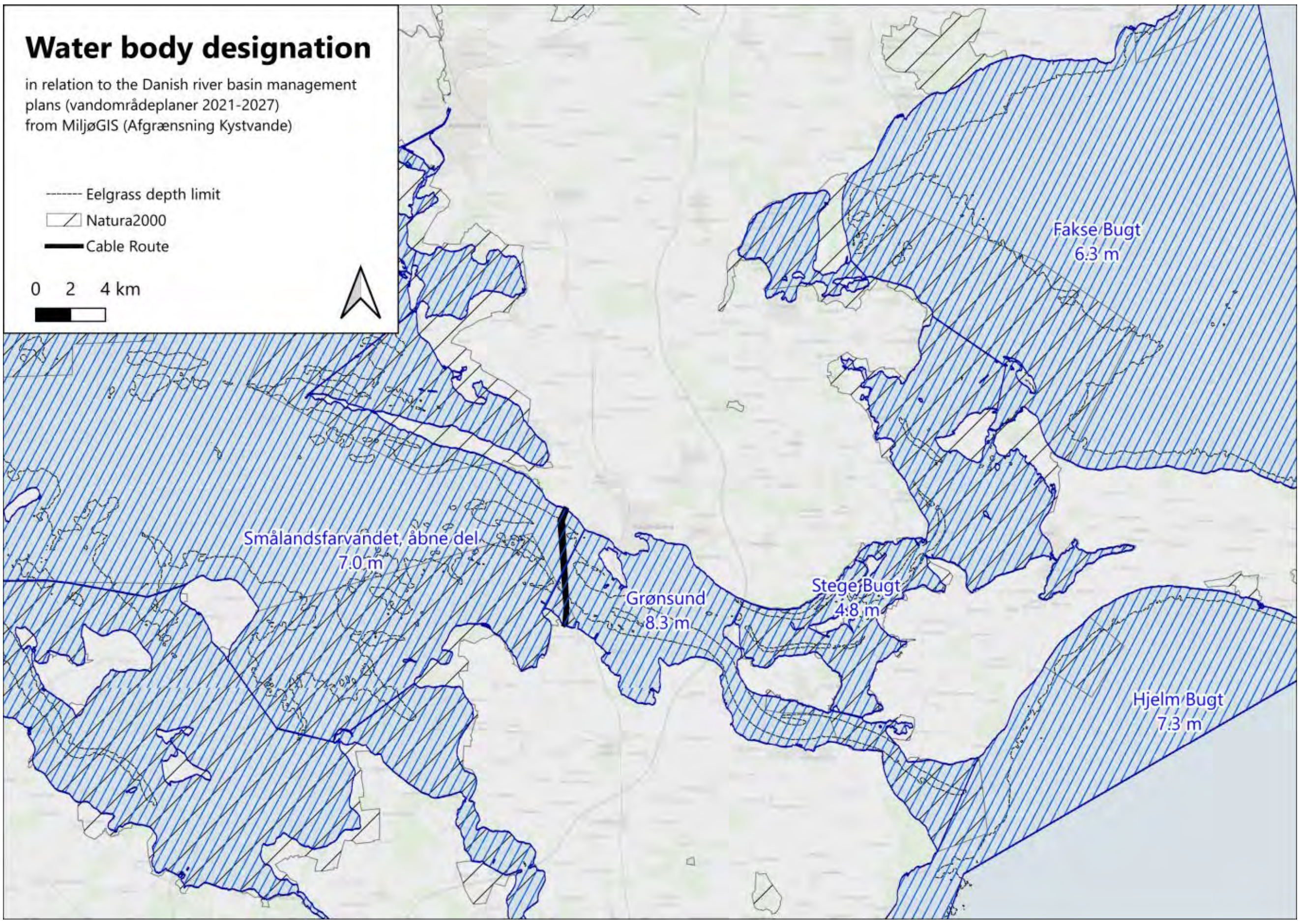
Grain size distribution for the sediment samples extracted by Ramboll [8] and equivalent settling velocities [13]. If no information was provided for the finer fractions as fine sand, the finer fractions were assumed to be evenly distributed. The effect of this assumption was checked by means of additional simulations and the difference was found to be negligible.

	coarse	fine sand	coarse silt	medium silt	fine silt	Clay
Settling velocity	-	15.0 mm/s	2.90 mm/s	0.560 mm/s	0.070 mm/s	0.030 mm/s
d, mean	-	0.1565 mm	0.0425 mm	0.0141 mm	0.0044 mm	0.0013 mm
d, minimum	-	0.0630 mm	0.0219 mm	0.0062 mm	0.0025 mm	0.0000 mm
d, maximum	-	0.2500 mm	0.0630 mm	0.0219 mm	0.0062 mm	0.0025 mm
SE1 / ENV1	17%	57.0%	12.5%	4.1%	4.3%	4.9%
SE1 / GT1	15%	56%	12.0%	5.7%	4.8%	6.4%
SE2 / GT1	32%	59%	2.1%	2.1%	2.1%	2.1%
SE4 / ENV1	2%	30%	23.7%	20.4%	11.9%	12.2%
SE4 / GT1	2%	39%	28.2%	10.5%	8.2%	12.1%
SE5 / ENV1	20%	39%	13.0%	8.0%	6.0%	14.5%
SE5 / GT1	24%	34%	8.6%	9.7%	7.0%	16.4%
SE6 / ENV1	4%	74%	6.3%	6.5%	1.5%	7.2%
SE6 / GT1	3%	72%	7.3%	8.0%	3.5%	6.5%
SE7 / ENV1	7%	91%	0.5%	0.5%	0.5%	0.5%
SE7 / GT1	9%	89%	0.5%	0.5%	0.5%	0.5%
SE8 / ENV1	1%	22%	15.1%	29.8%	7.0%	24.6%
SE8 / GT1	2%	21%	23.2%	19.3%	10.3%	23.6%
SE10 / ENV1	2%	80%	9.6%	2.6%	1.9%	3.7%
SE10 / GT1	2%	90%	1.9%	1.9%	1.9%	1.9%

Appendix 4 Additional maps



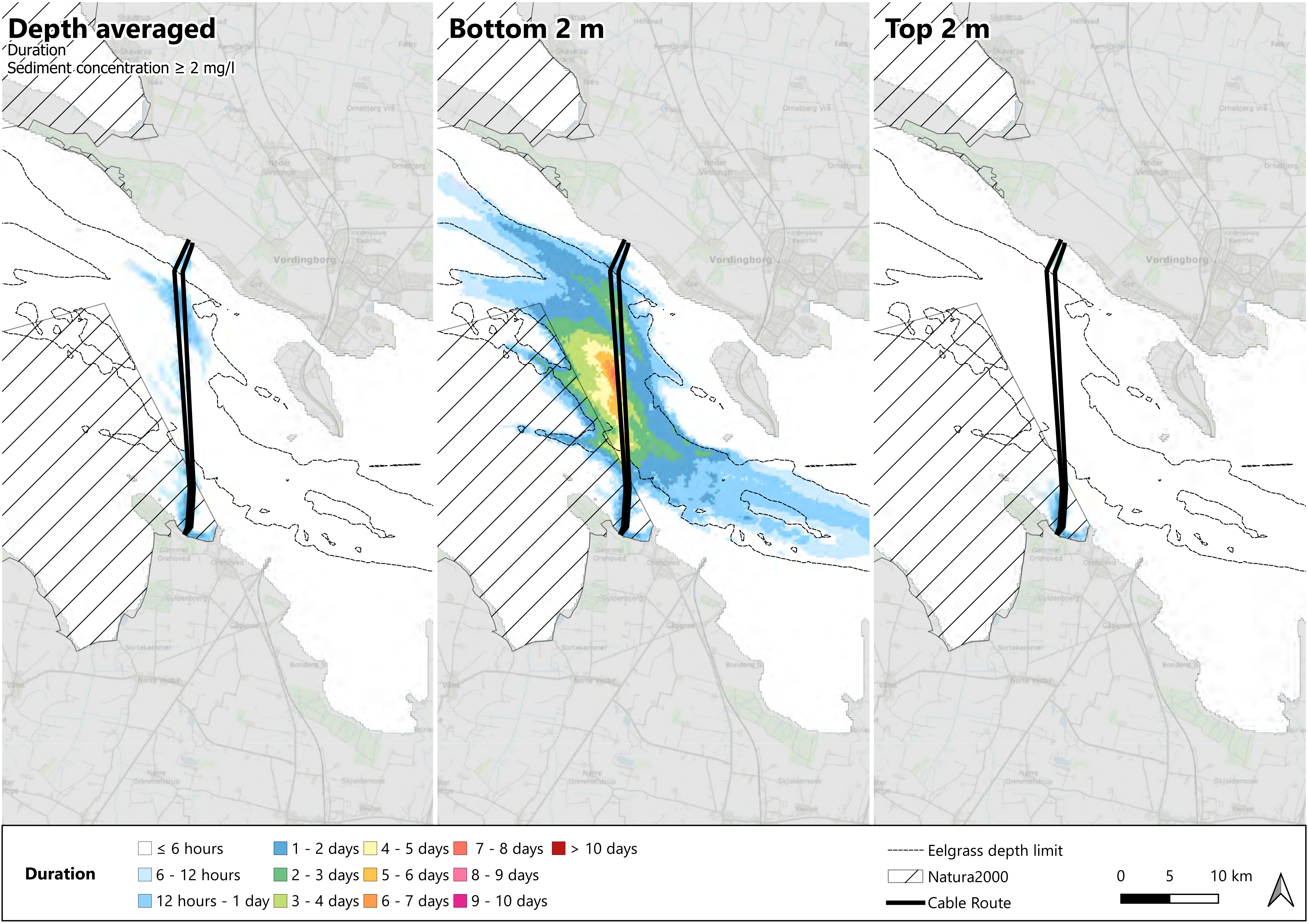
Vertical discretization of the model domain: Layer Thickness of the vertical layers of the model-domain referring to still water level (MSL) . The vertical modell domain is divided into 10 equally spaced sigma-layers, leading to smaller layer thickness in the shallow areas and larger thickness in deeper areas.



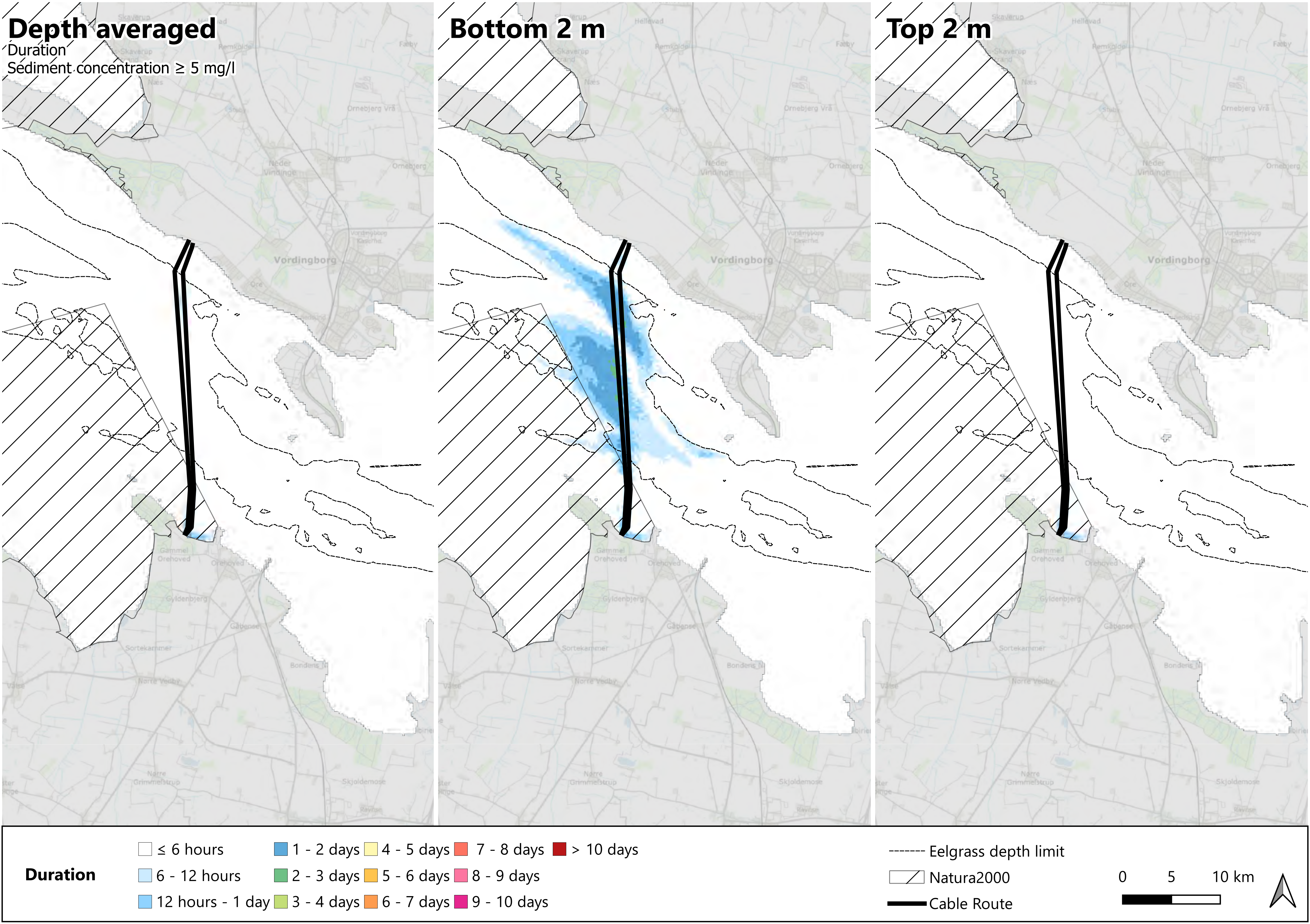
Water body designation in relation to the Danish river basin management plans (vandområdeplaner 2021-2027) from MiljøGIS (Afgrænsning Kystvande), and corresponding Eelgrass depth limits in the water bodies potentially affected by the project (source: Bekendtgørelse om overvågning, https://www.retsinformation.dk/eli/lta/2023/792)

Appendix 5 Cumulative concentration exceedance durations

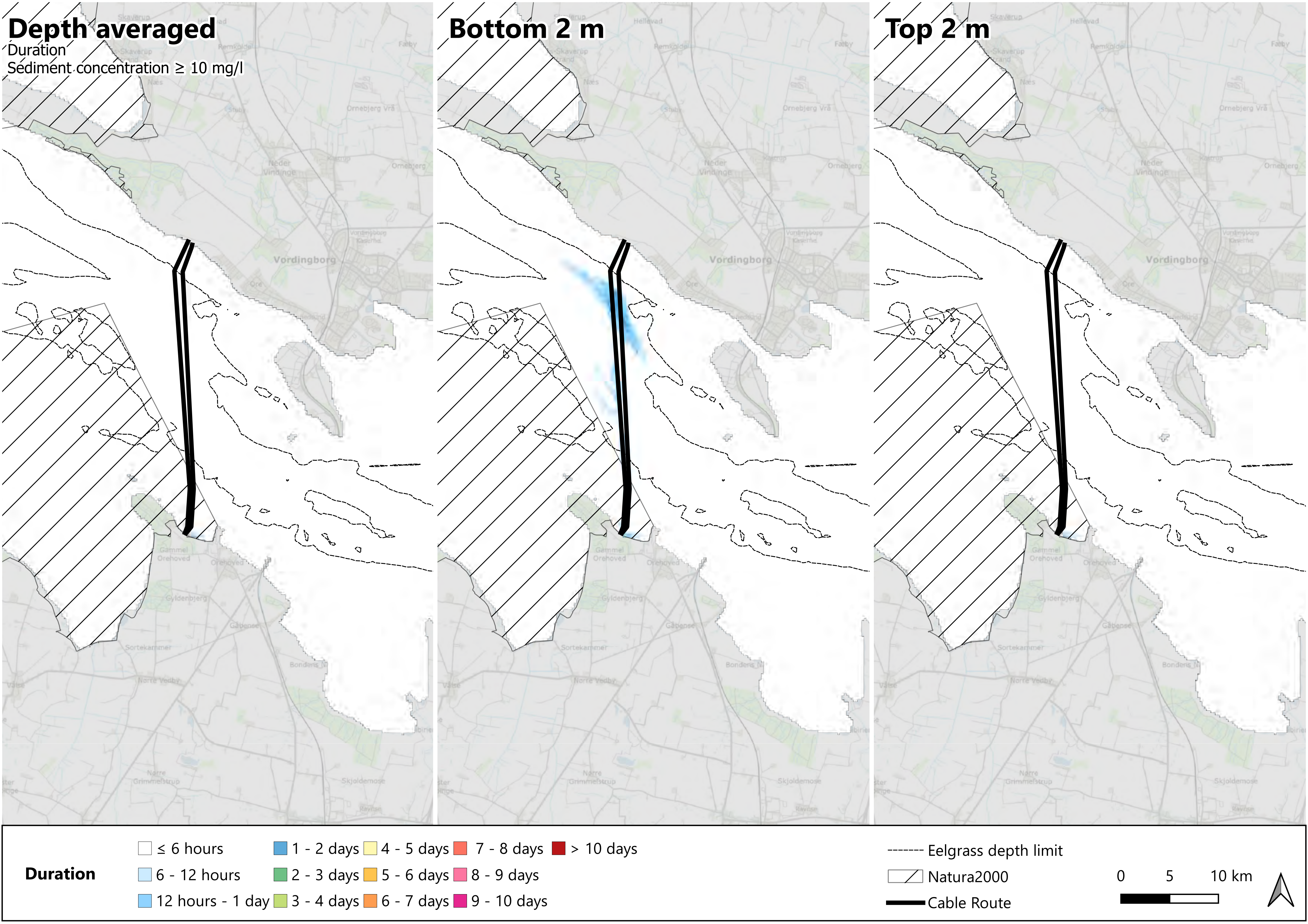
The following maps show the cumulative duration a threshold value of concentration is reached or exceeded.



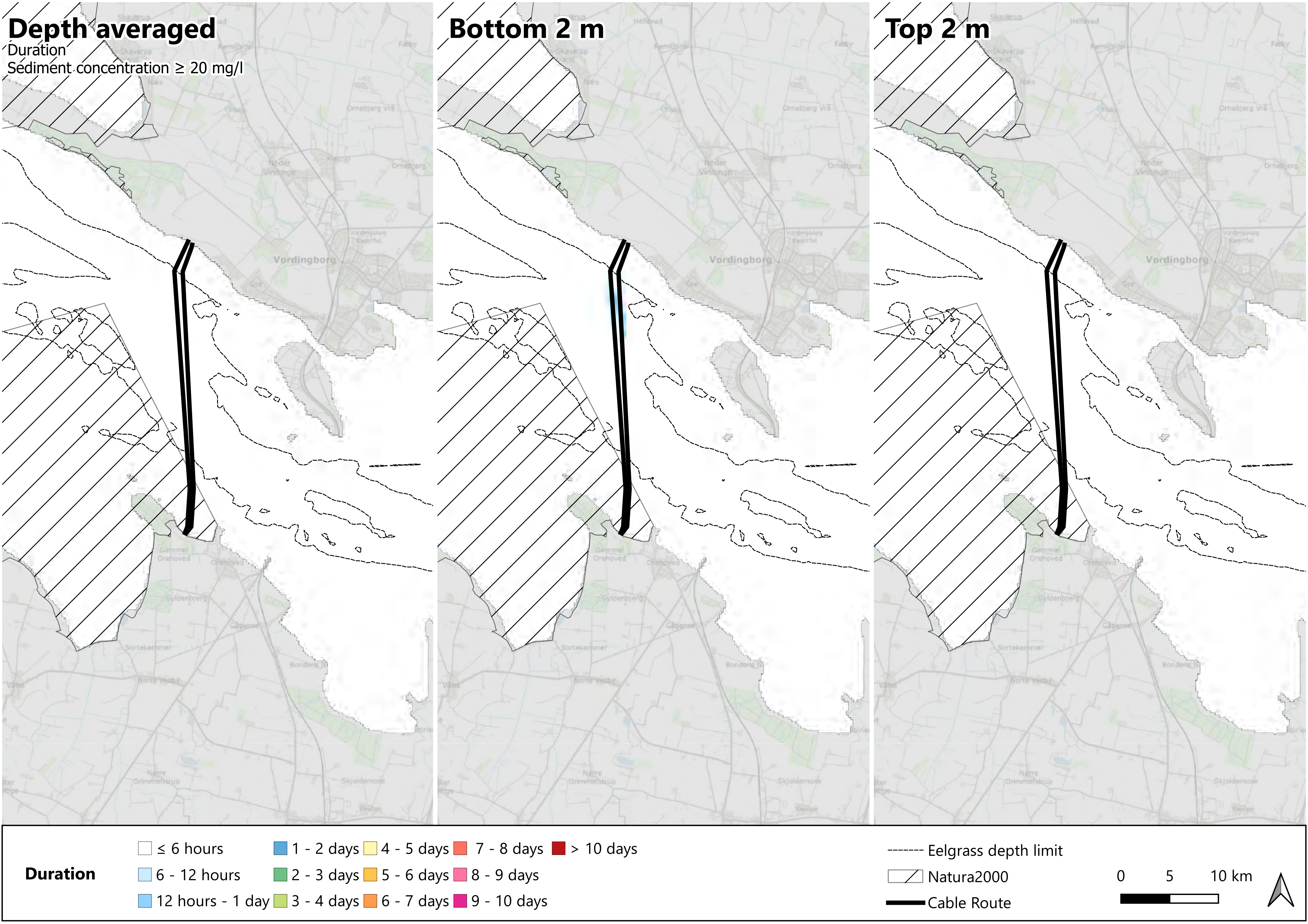
Depth averaged
Duration
Sediment concentration ≥ 2 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km



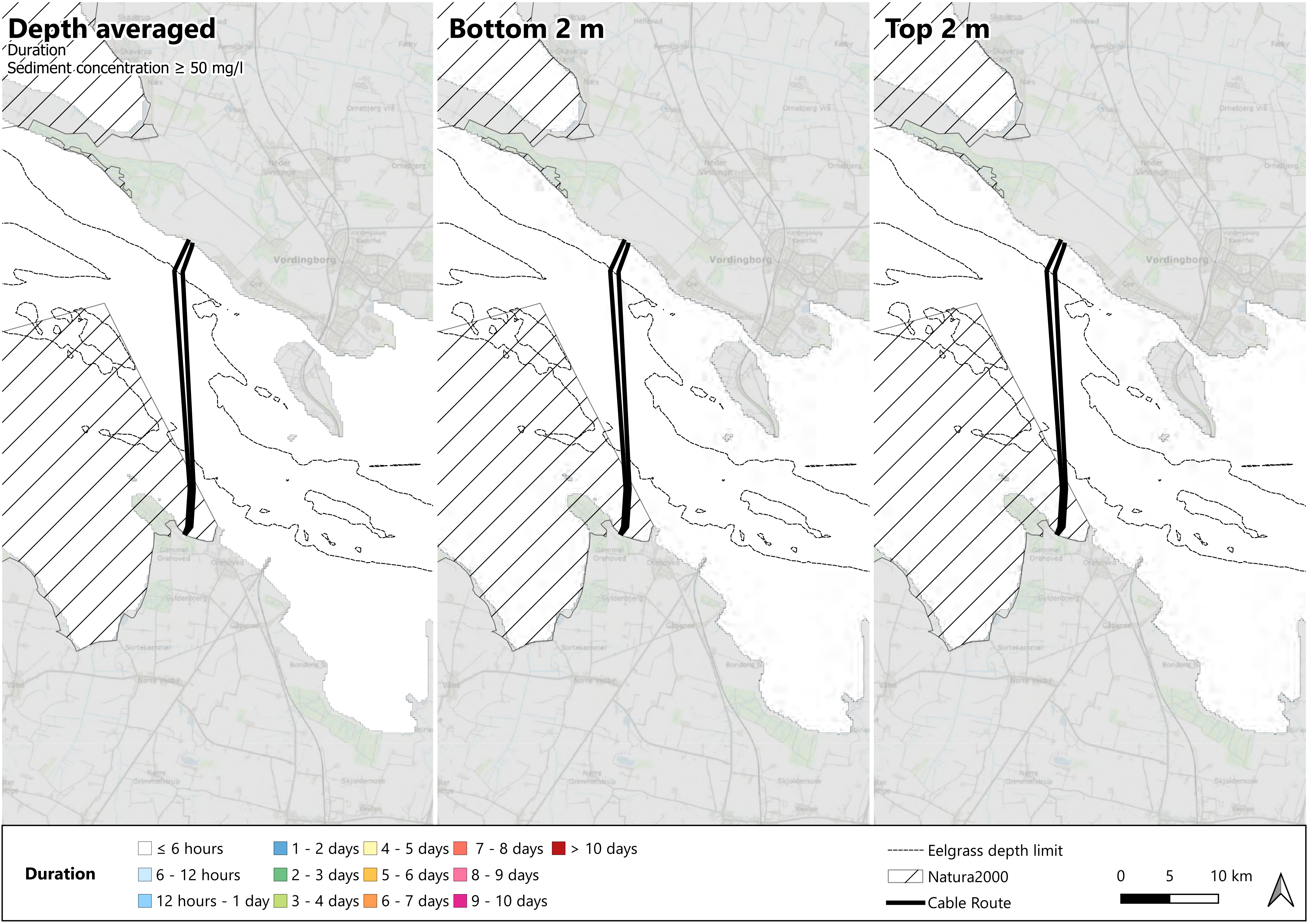
Depth averaged
Duration
Sediment concentration ≥ 5 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km



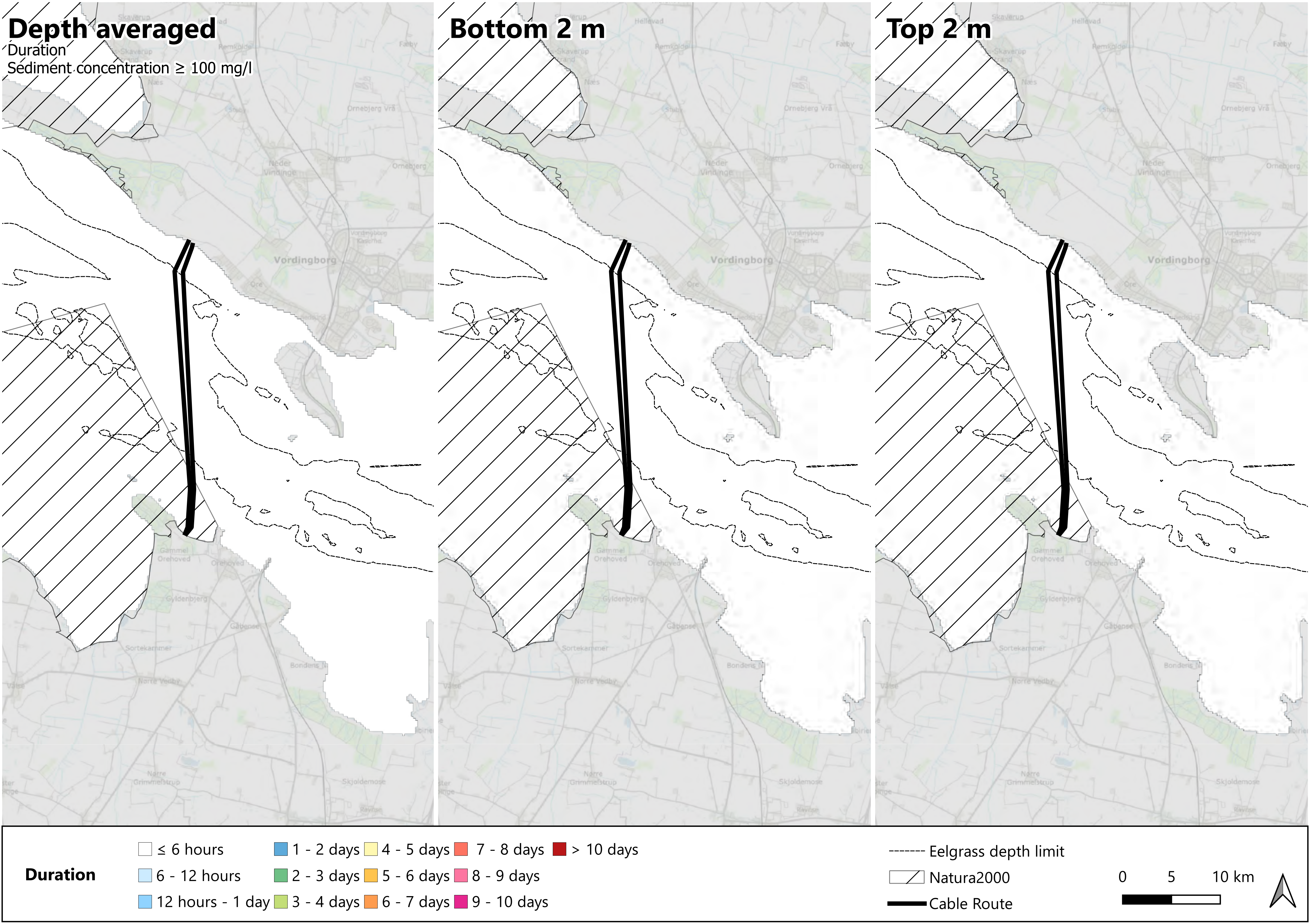
Depth averaged
Duration
Sediment concentration ≥ 10 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

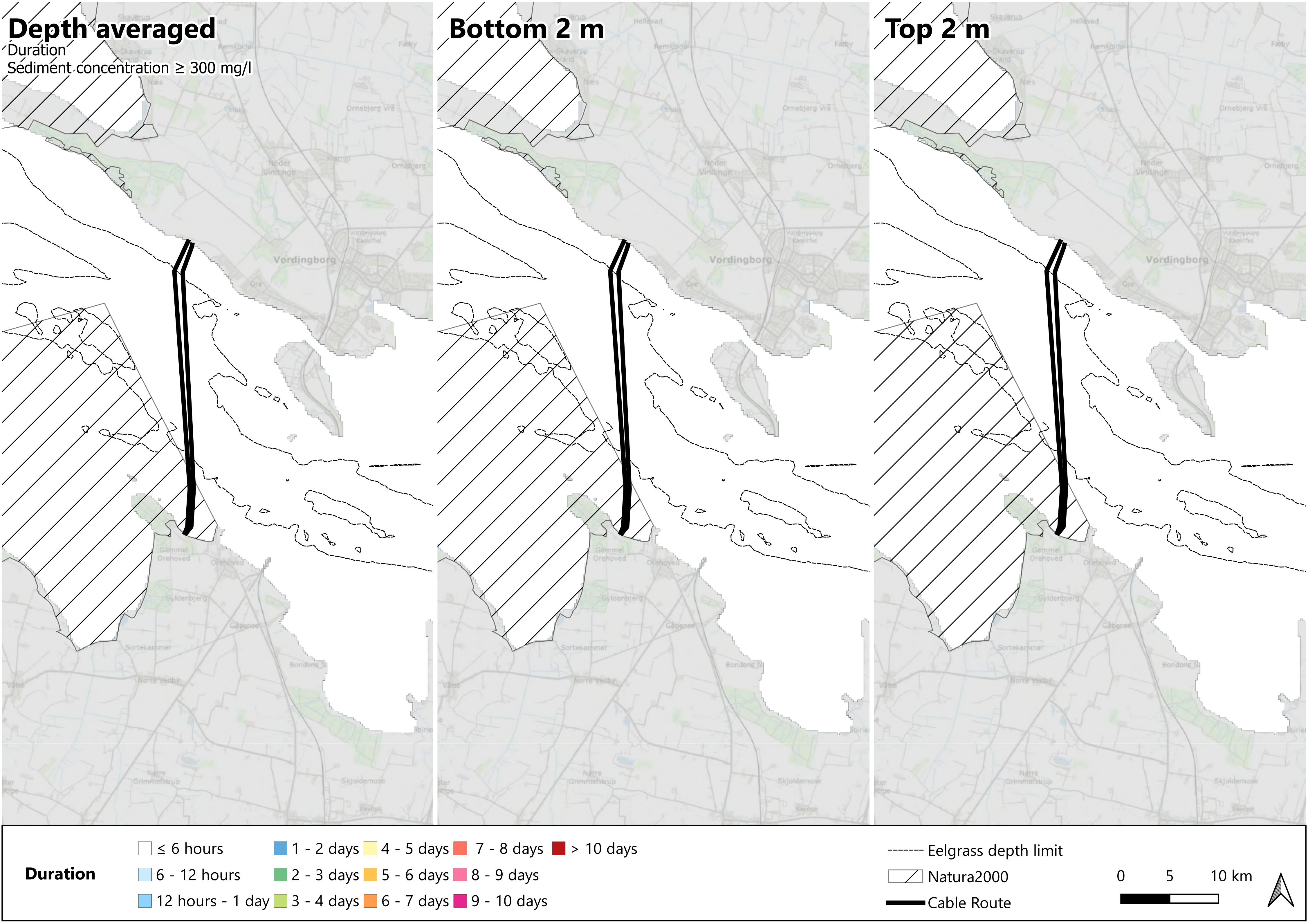


Depth averaged
Duration
Sediment concentration ≥ 20 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

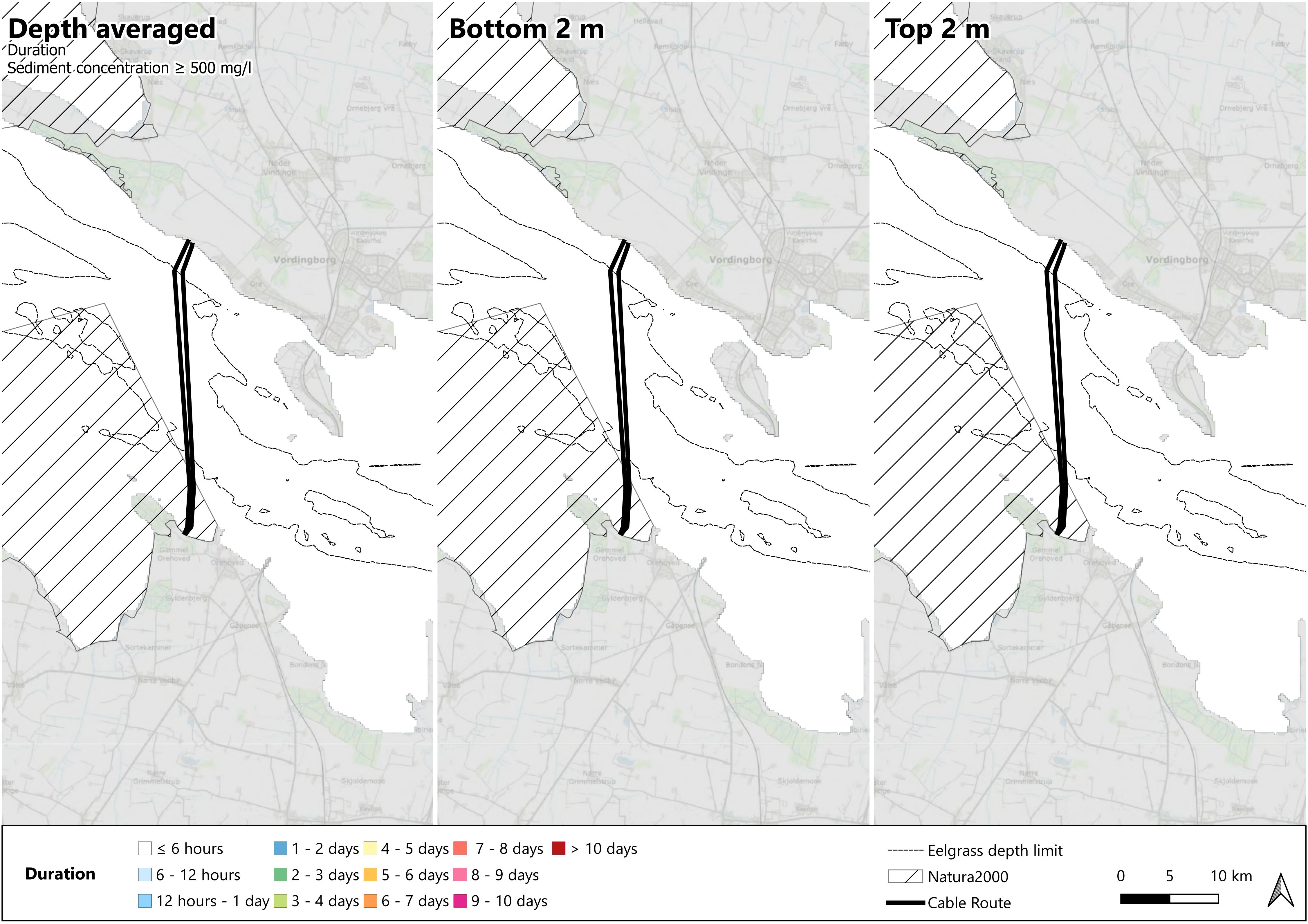


Depth averaged
Duration
Sediment concentration ≥ 50 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

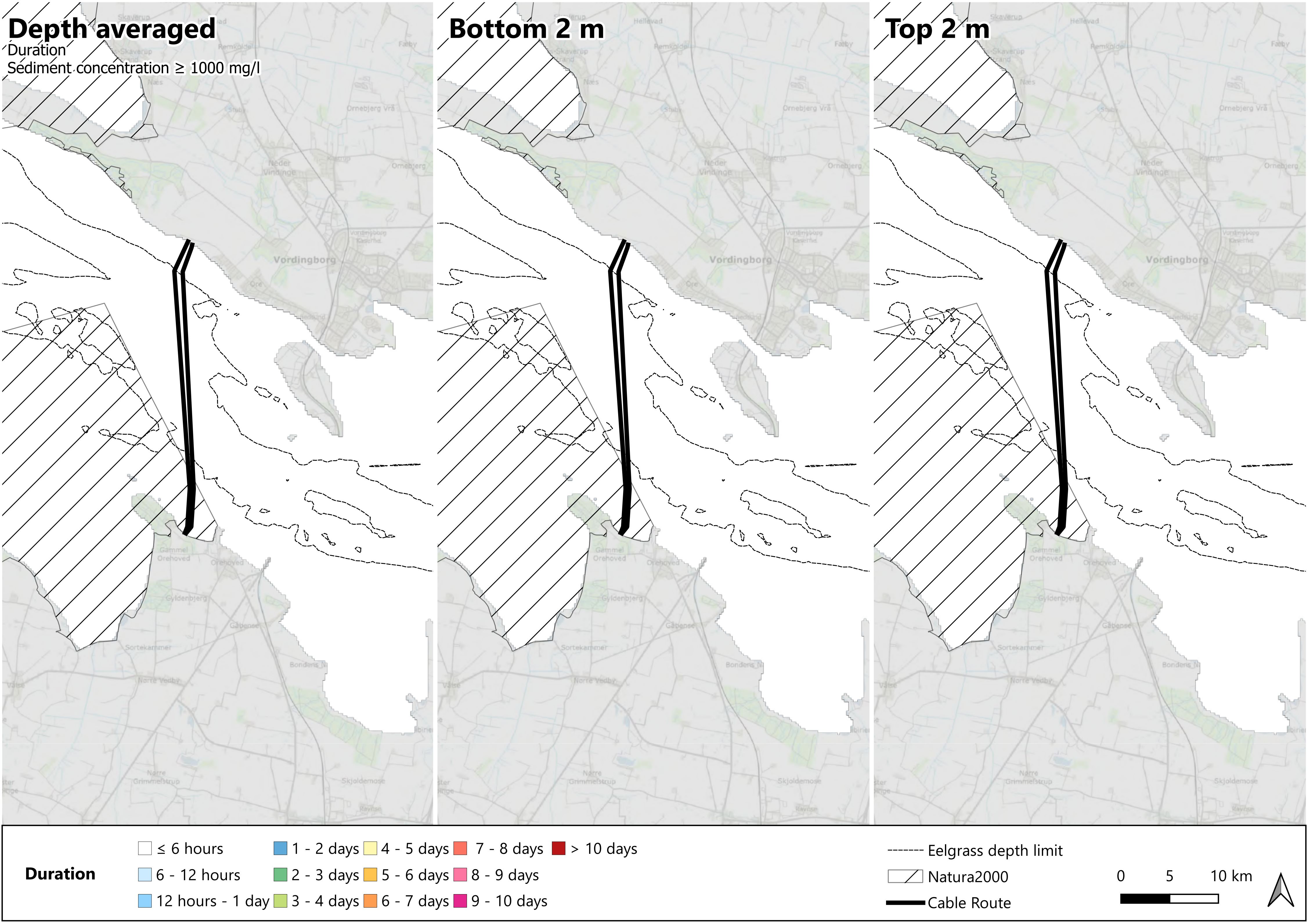

Depth averaged
Duration
Sediment concentration ≥ 100 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km



Depth averaged
Duration
Sediment concentration ≥ 300 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km



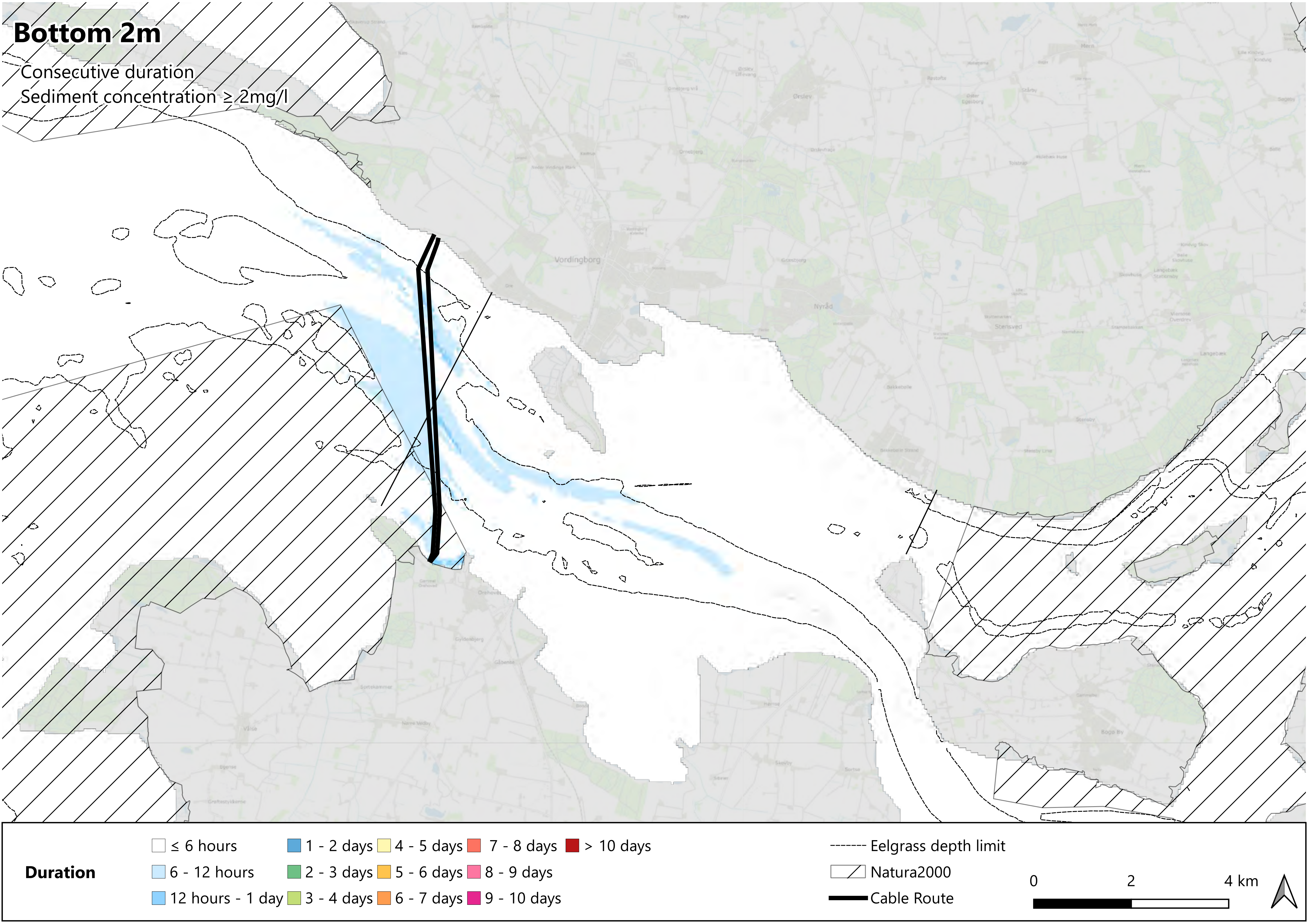
Depth averaged
Duration
Sediment concentration ≥ 500 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

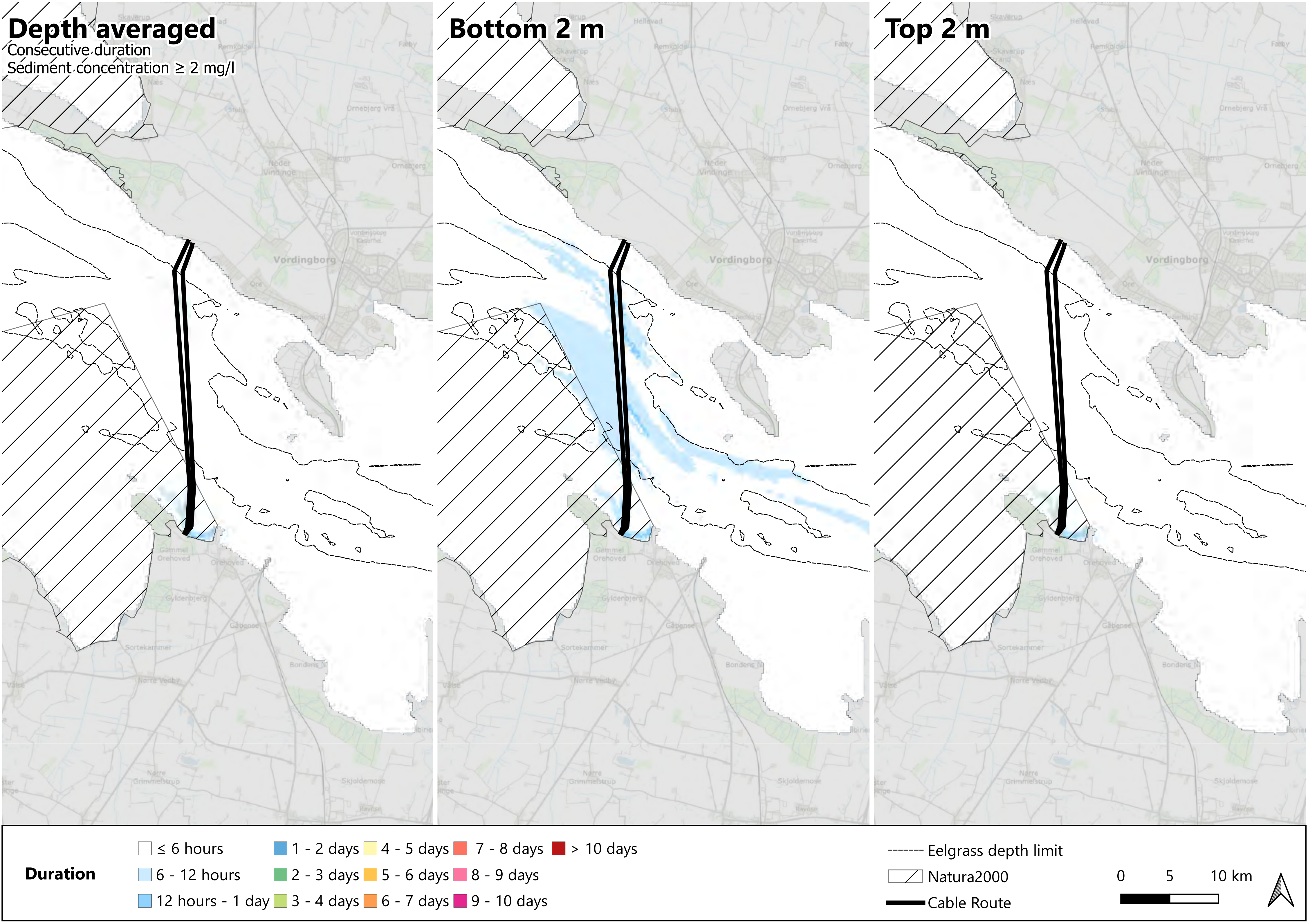


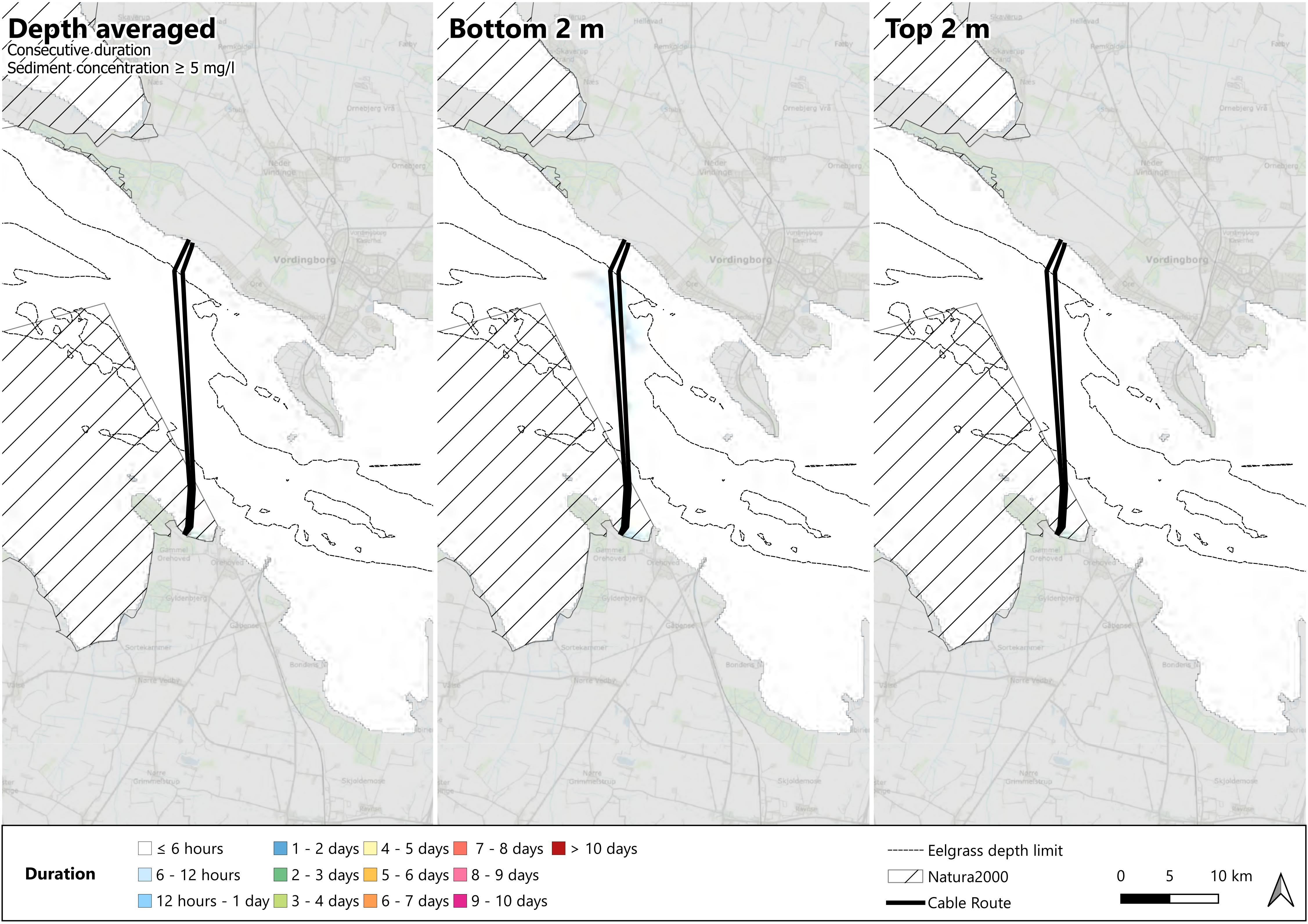
Depth averaged
Duration
Sediment concentration ≥ 1000 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

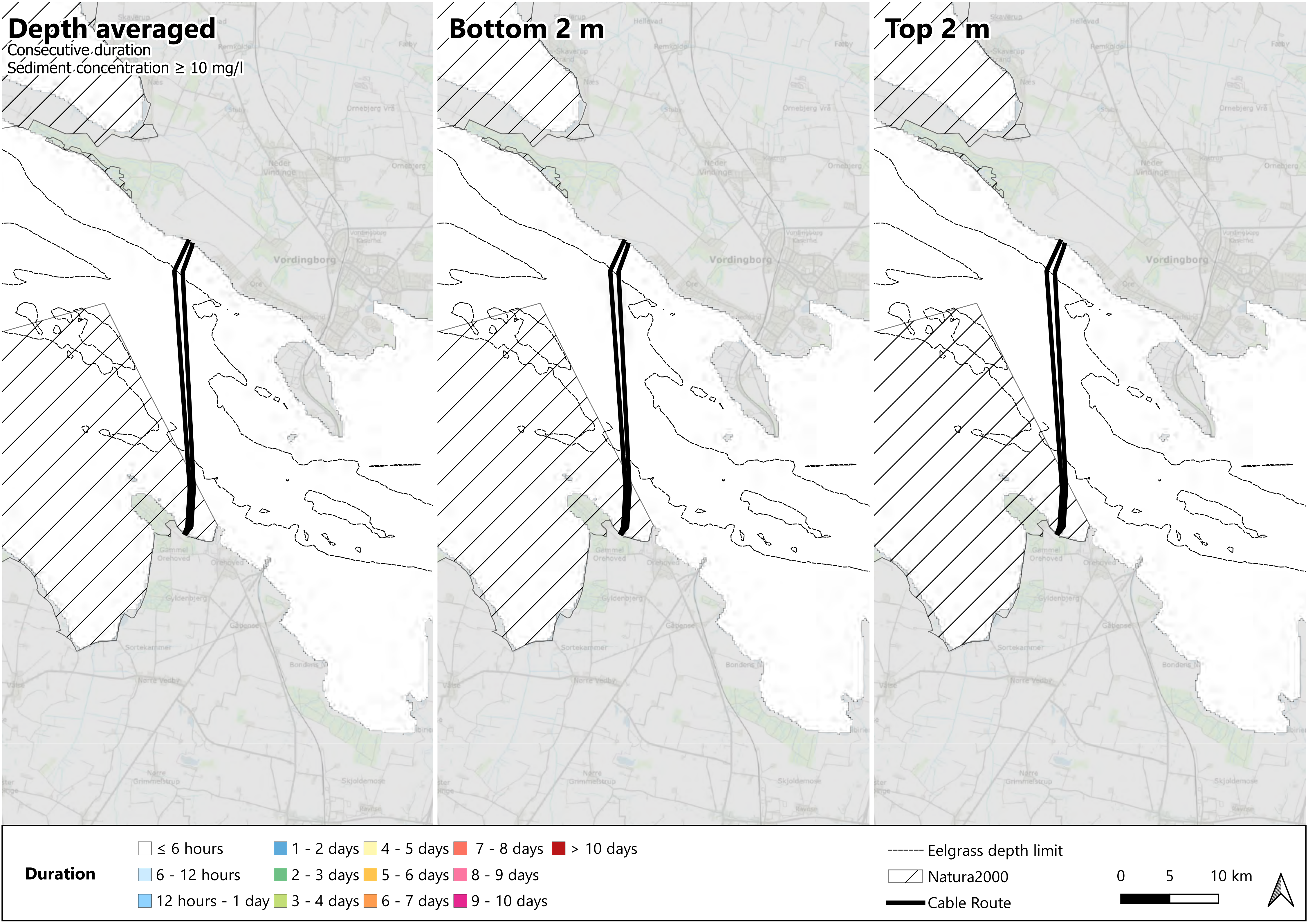
Appendix 6 Longest consecutive concentration exceedance durations

The following maps show the longest consecutive duration a threshold concentration is reached or exceeded.

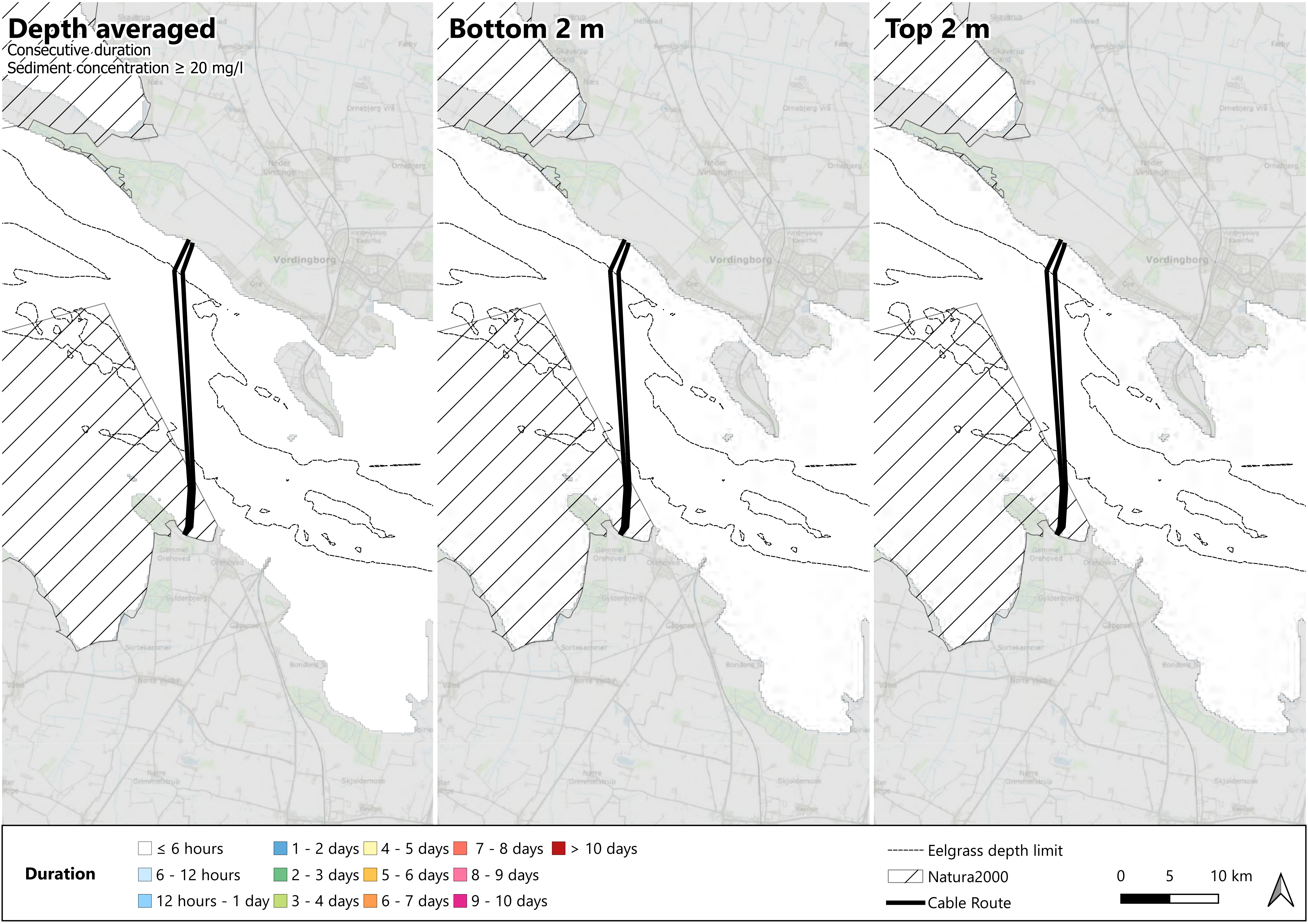

Bottom 2m
Consecutive duration
Sediment concentration ≥ 2mg/l
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km


Depth averaged
Consecutive duration
Sediment concentration ≥ 2 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

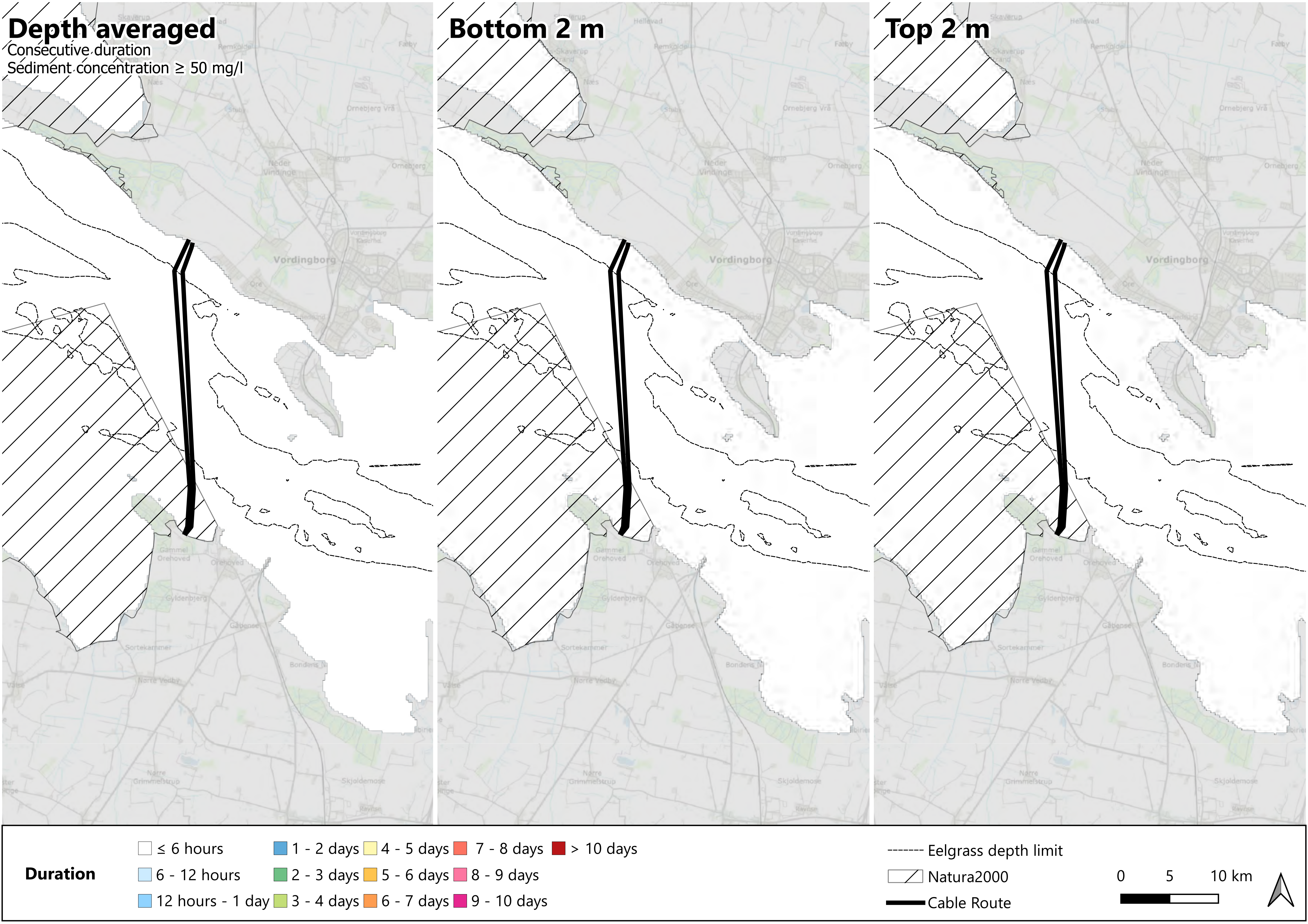

Depth averaged
Consecutive duration
Sediment concentration ≥ 5 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km



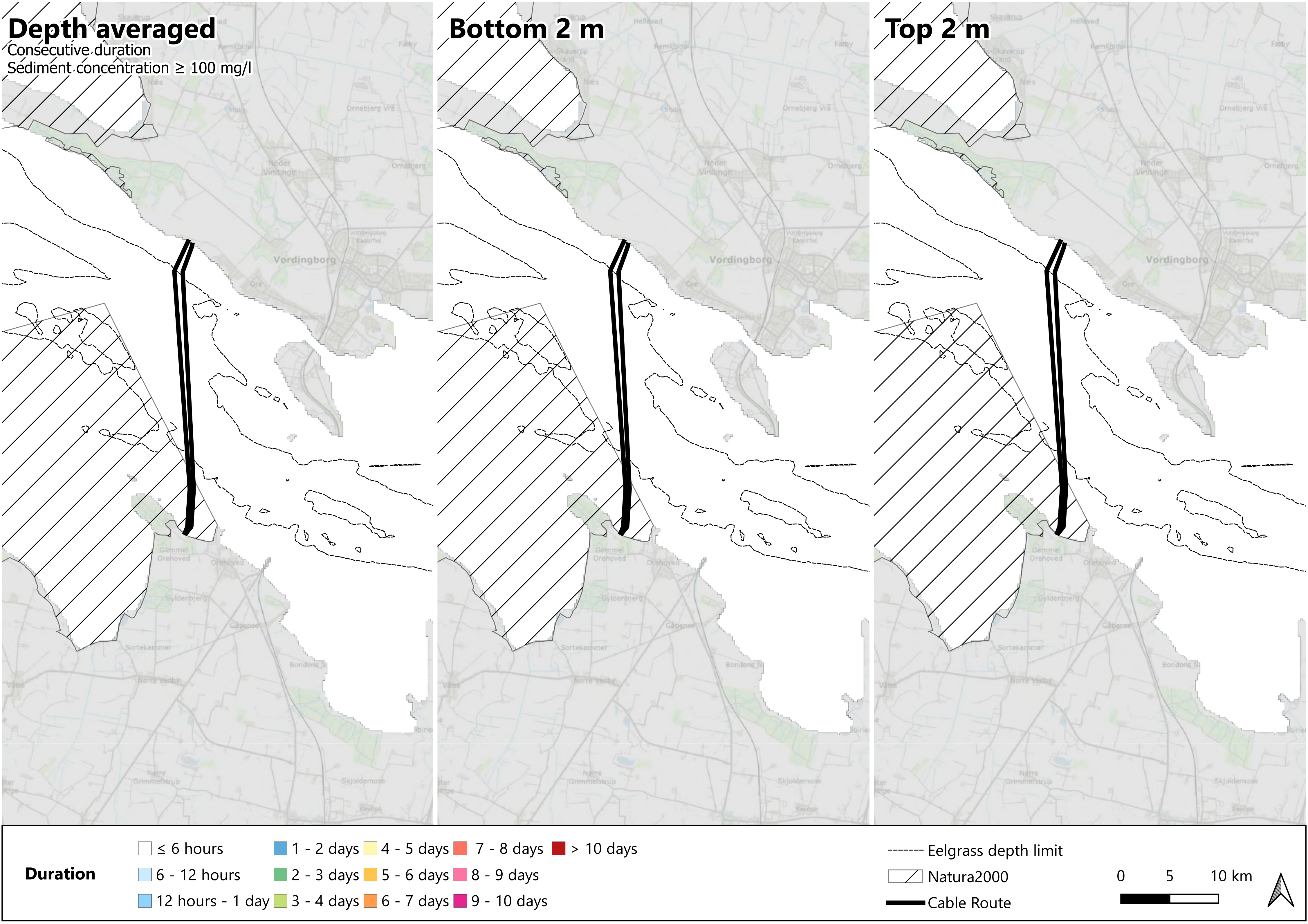
Depth averaged
Consecutive duration
Sediment concentration ≥ 10 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

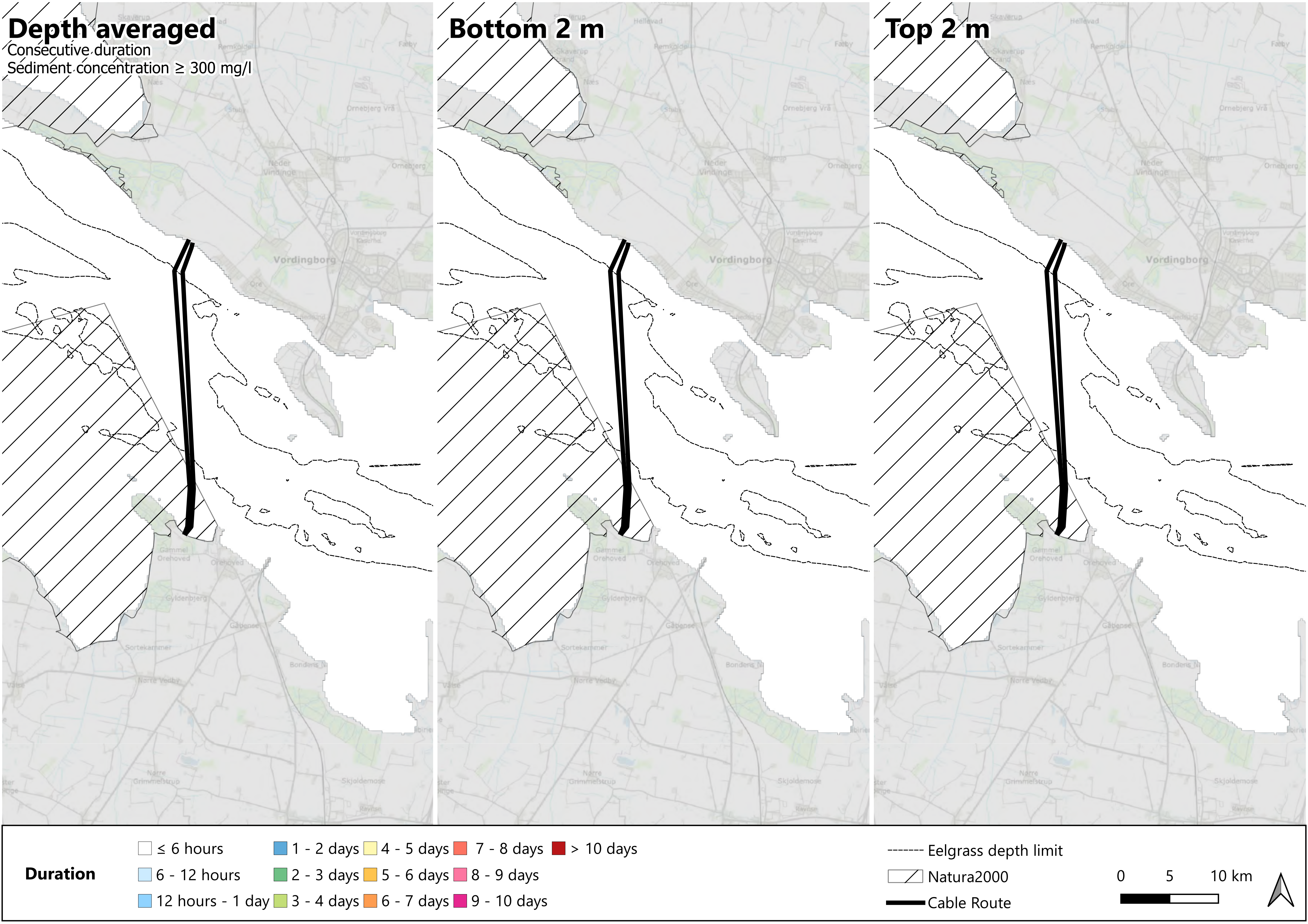


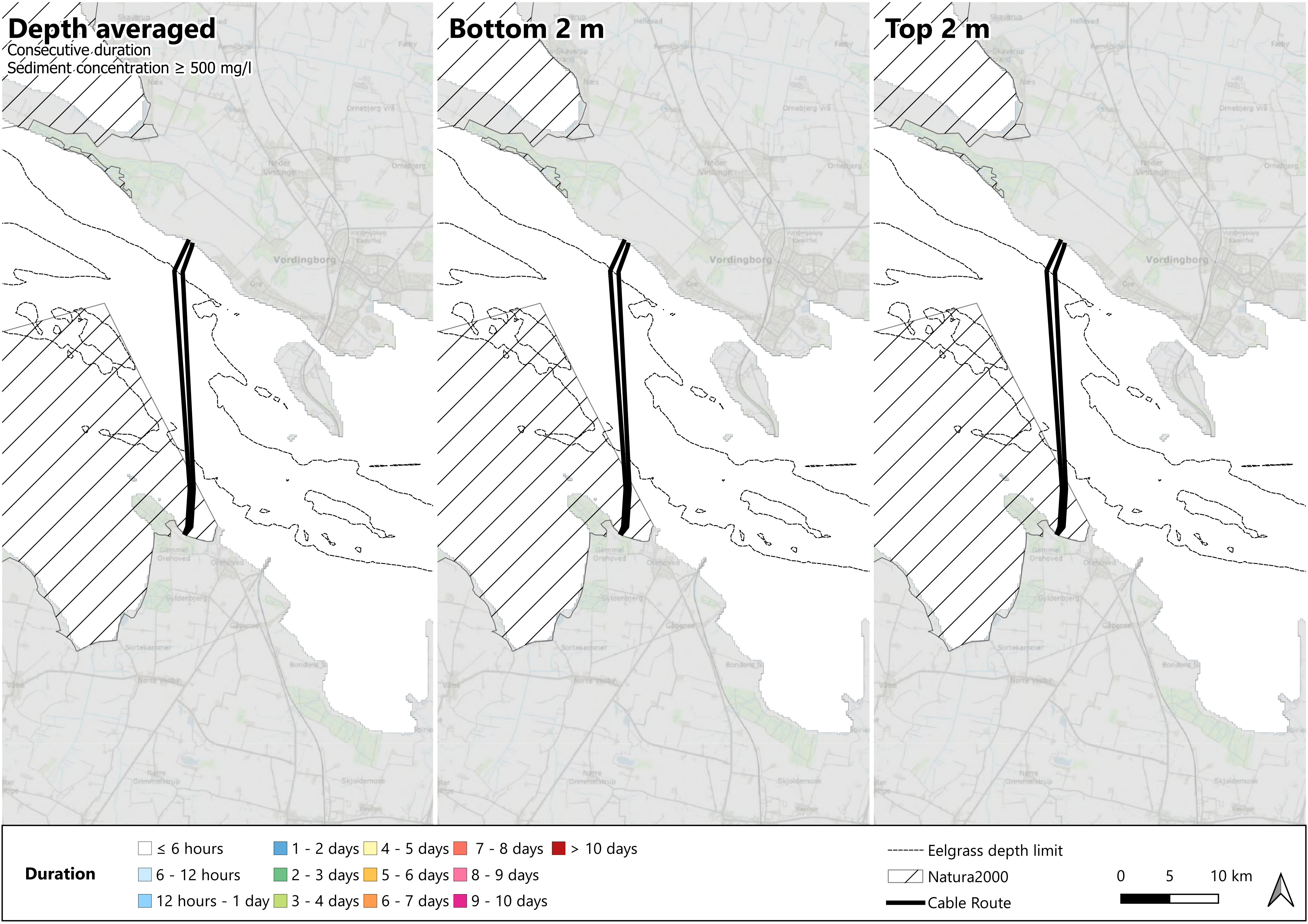
Depth averaged
Consecutive duration
Sediment concentration ≥ 20 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km



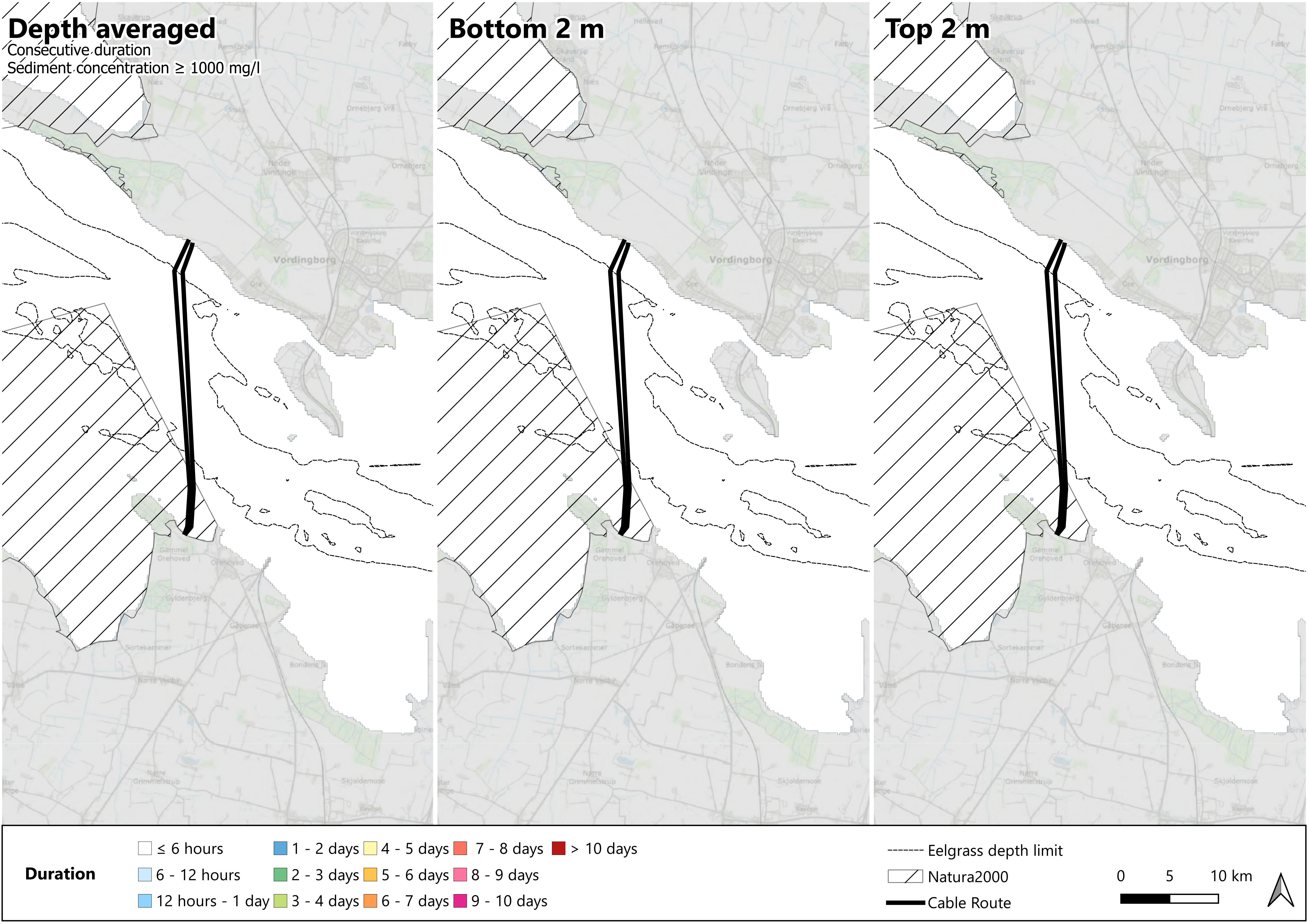
Depth averaged
Consecutive duration
Sediment concentration ≥ 50 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km


Depth averaged
Consecutive duration
Sediment concentration ≥ 100 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

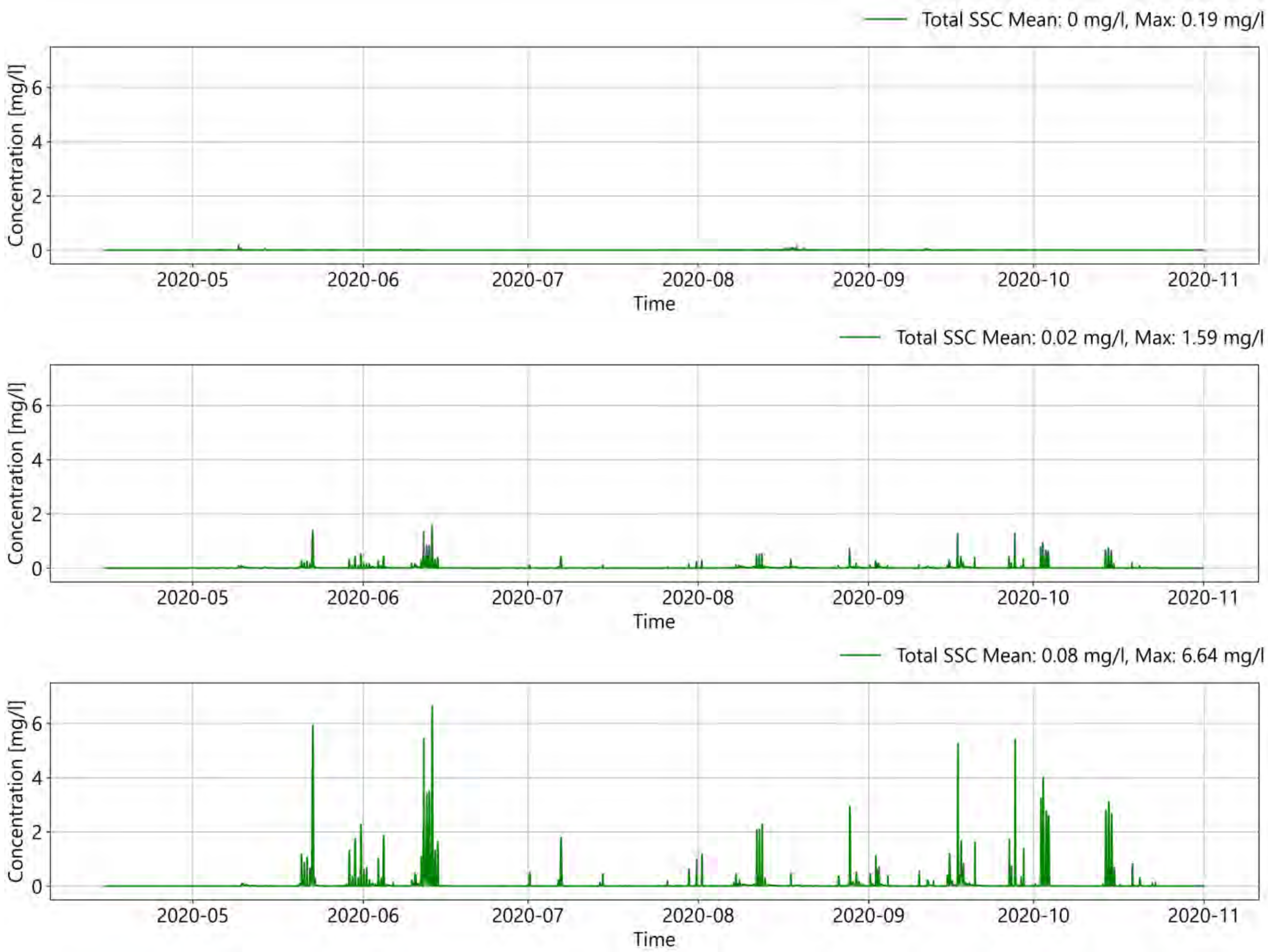

Depth averaged
Consecutive duration
Sediment concentration ≥ 300 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km



Depth averaged
Consecutive duration
Sediment concentration ≥ 500 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

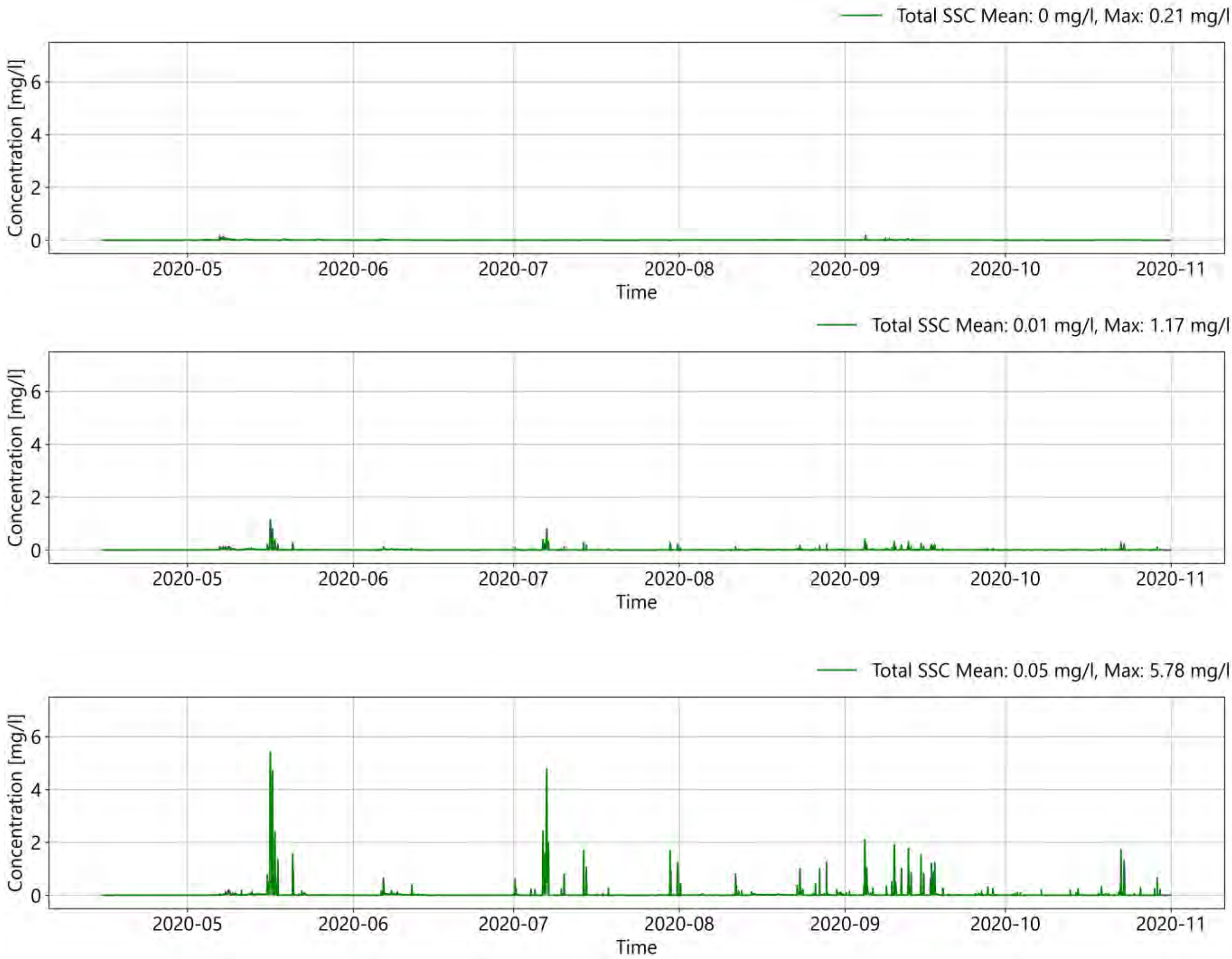

Depth averaged
Consecutive duration
Sediment concentration ≥ 1000 mg/l
Bottom 2 m
Top 2 m
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Eelgrass depth limit
Natura2000
Cable Route
0
5
10 km

Appendix 7 Concentration variations in time



Point 1 : *Timeseries of concentration for: the: top 2 meters (top figure), depth-averaged over the entire water column (middle figure) and bottom 2 meters (bottom figure). Geographical location in Figure 6.1.*

Point 2 : *Timeseries of concentration for: the: top 2 meters (top figure), depth-averaged over the entire water column (middle figure) and bottom 2 meters (bottom figure). Geographical location in Figure 6.1.*



Point 3 : *Timeseries of concentration for: the: top 2 meters (top figure), depth-averaged over the entire water column (middle figure) and bottom 2 meters (bottom figure). Geographical location in Figure 6.1.*

Point 4 : *Timeseries of concentration for: the: top 2 meters (top figure), depth-averaged over the entire water column (middle figure) and bottom 2 meters (bottom figure). Geographical location in Figure 6.1.*

Point 5 : *Timeseries of concentration for: the: top 2 meters (top figure), depth-averaged over the entire water column (middle figure) and bottom 2 meters (bottom figure). Geographical location in Figure 6.1.*

NIRAS

Appendix 8 Cumulative exceedance durations of light attenuation

The following maps show the cumulative duration a threshold of light attenuation is reached or exceeded.

The present Appendix is divided in two subsections, which present the same results with two different scales.

Light attenuation
Compared to initial state
Cumulative duration with reduction ≥20 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

Light attenuation
Compared to initial state
Cumulative duration with reduction ≥30 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

Light attenuation
Compared to initial state
Cumulative duration with reduction ≥40 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

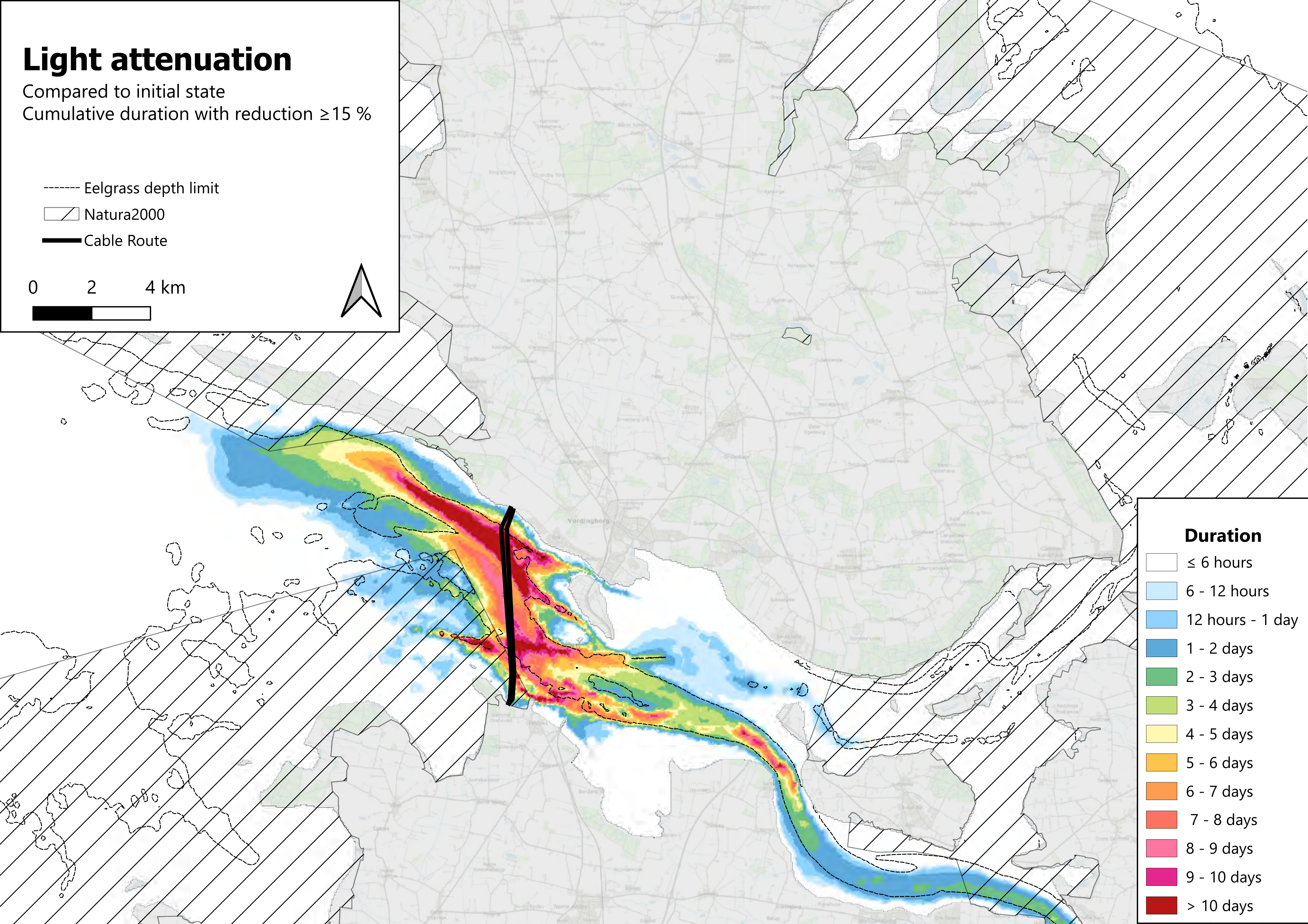
Light attenuation
Compared to initial state
Cumulative duration with reduction ≥50 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

Light attenuation
Compared to initial state
Cumulative duration with reduction ≥60 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

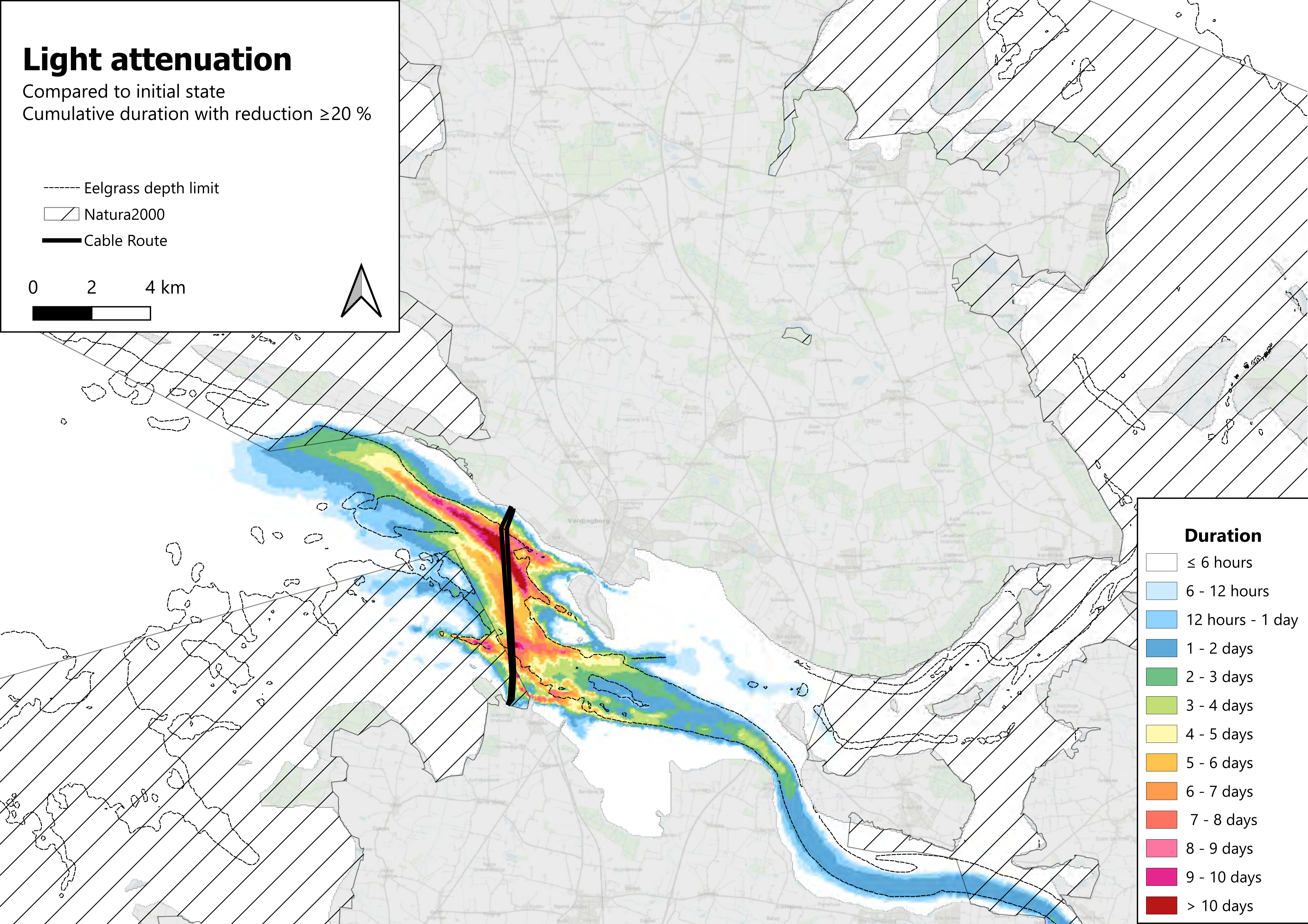
Light attenuation
Compared to initial state
Cumulative duration with reduction ≥70 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

Light attenuation
Compared to initial state
Cumulative duration with reduction ≥80 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

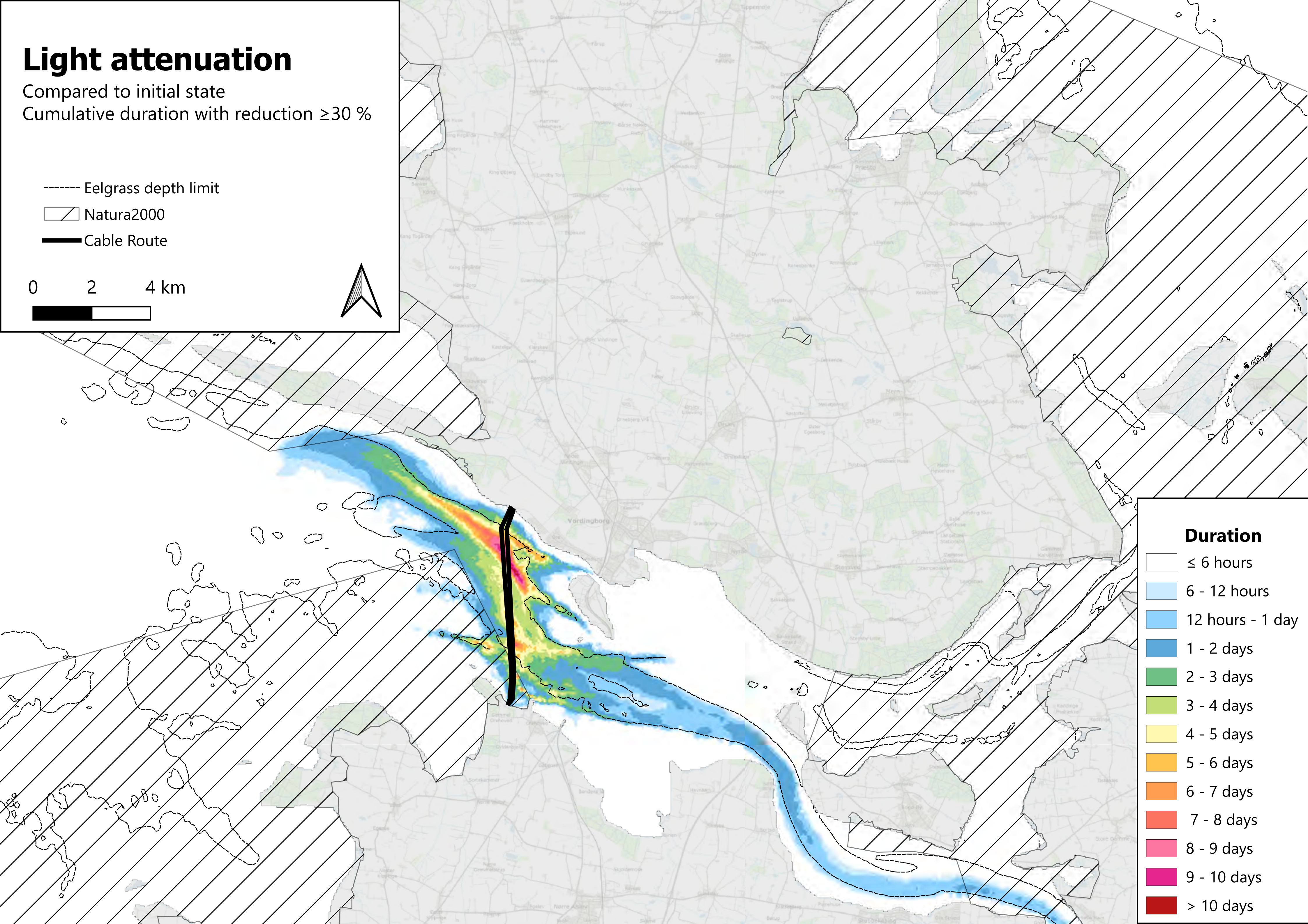

Light attenuation
Compared to initial state
Cumulative duration with reduction ≥90 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

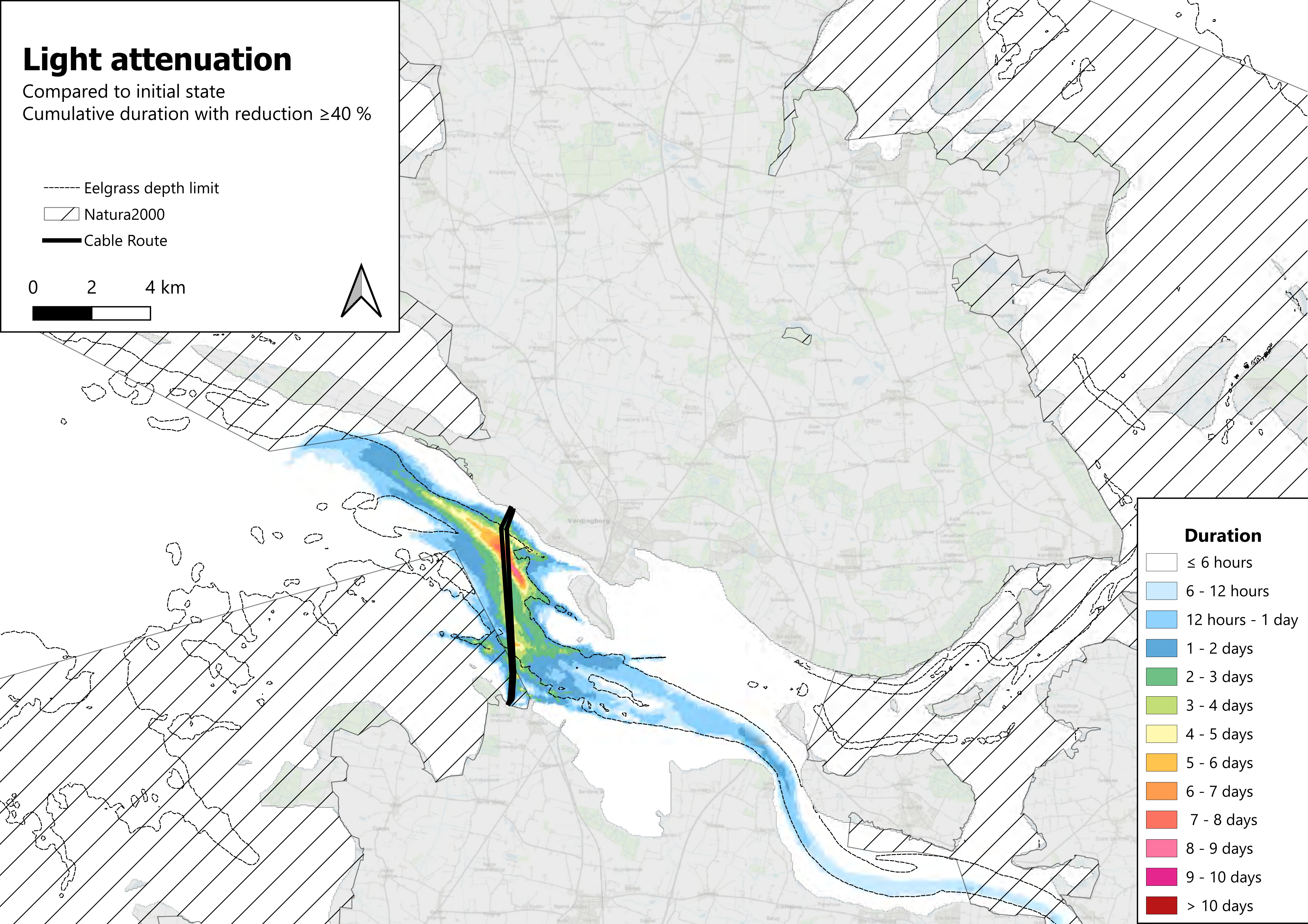


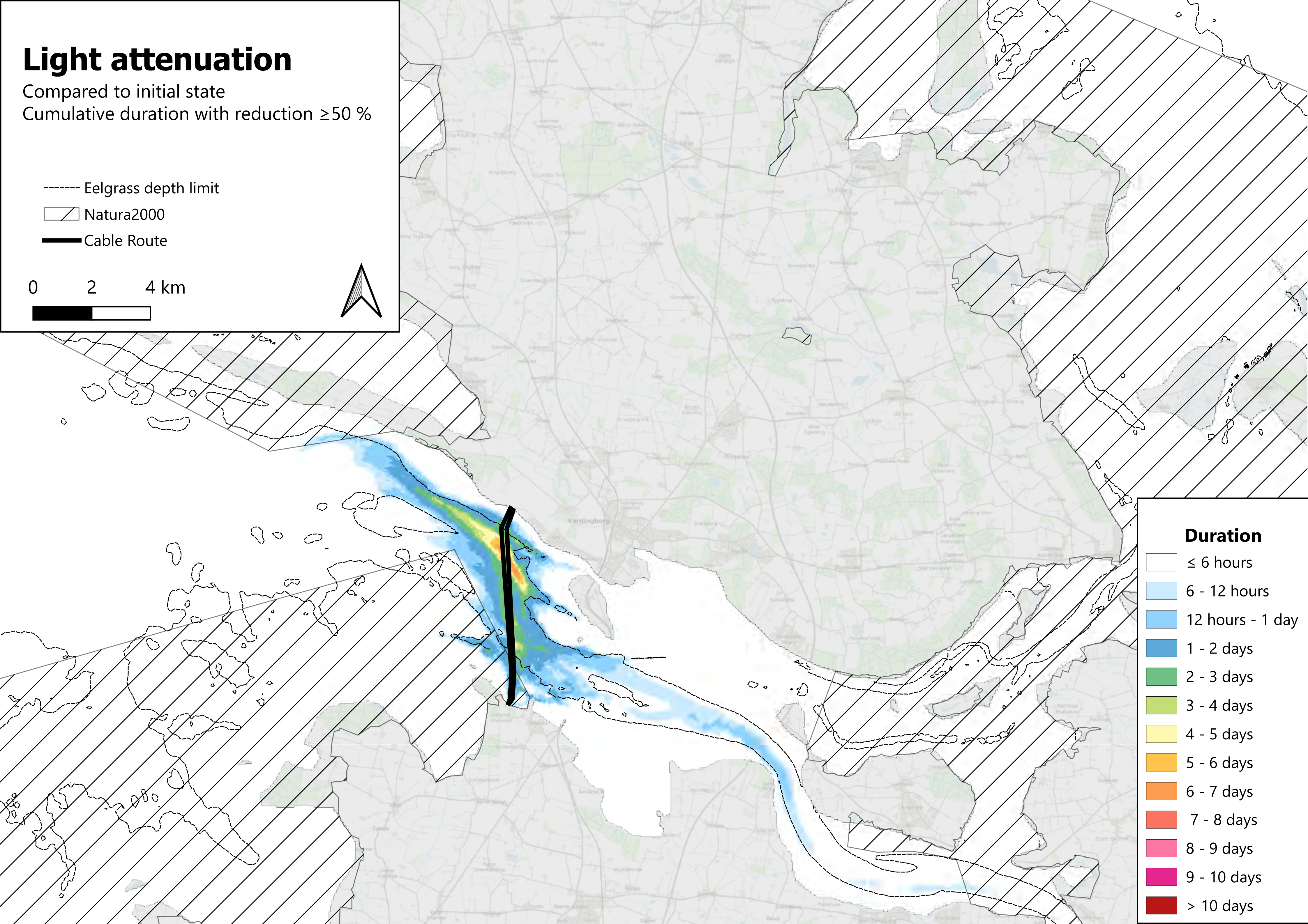
Light attenuation
Compared to initial state
Cumulative duration with reduction ≥15 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days



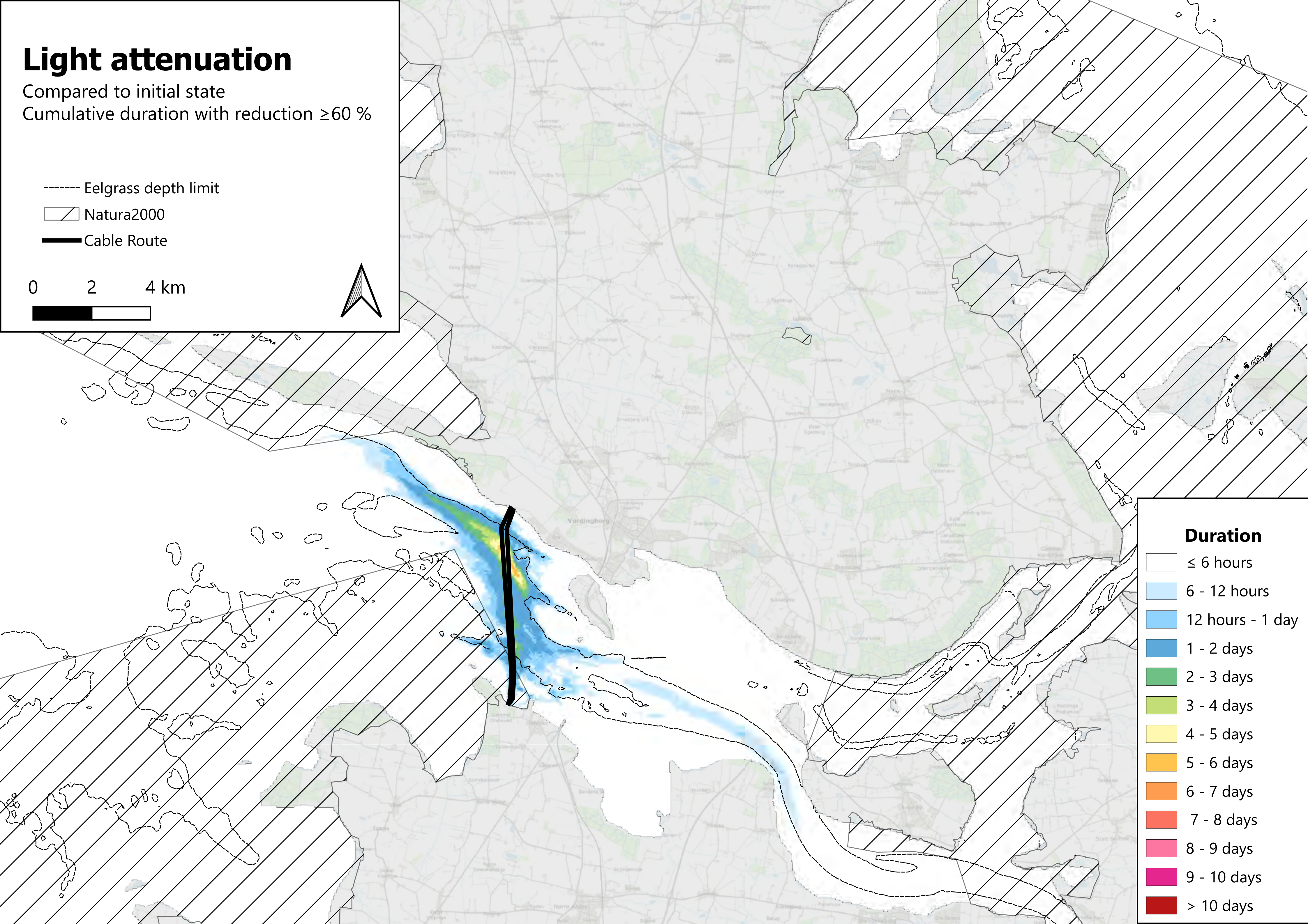
Light attenuation
Compared to initial state
Cumulative duration with reduction ≥20 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Vordingborg


Light attenuation
Compared to initial state
Cumulative duration with reduction ≥30 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

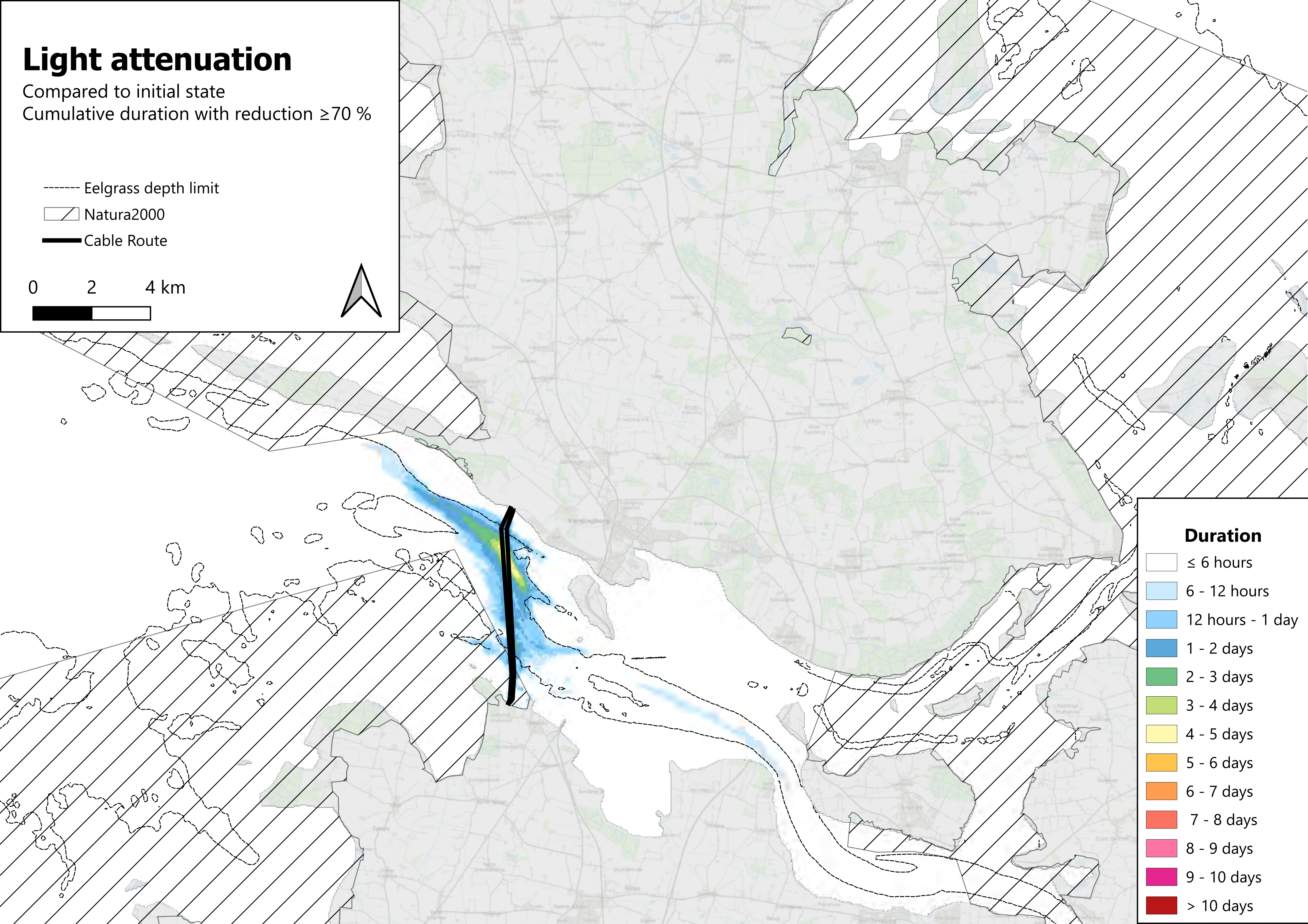

Light attenuation
Compared to initial state
Cumulative duration with reduction ≥40 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Vordingborg

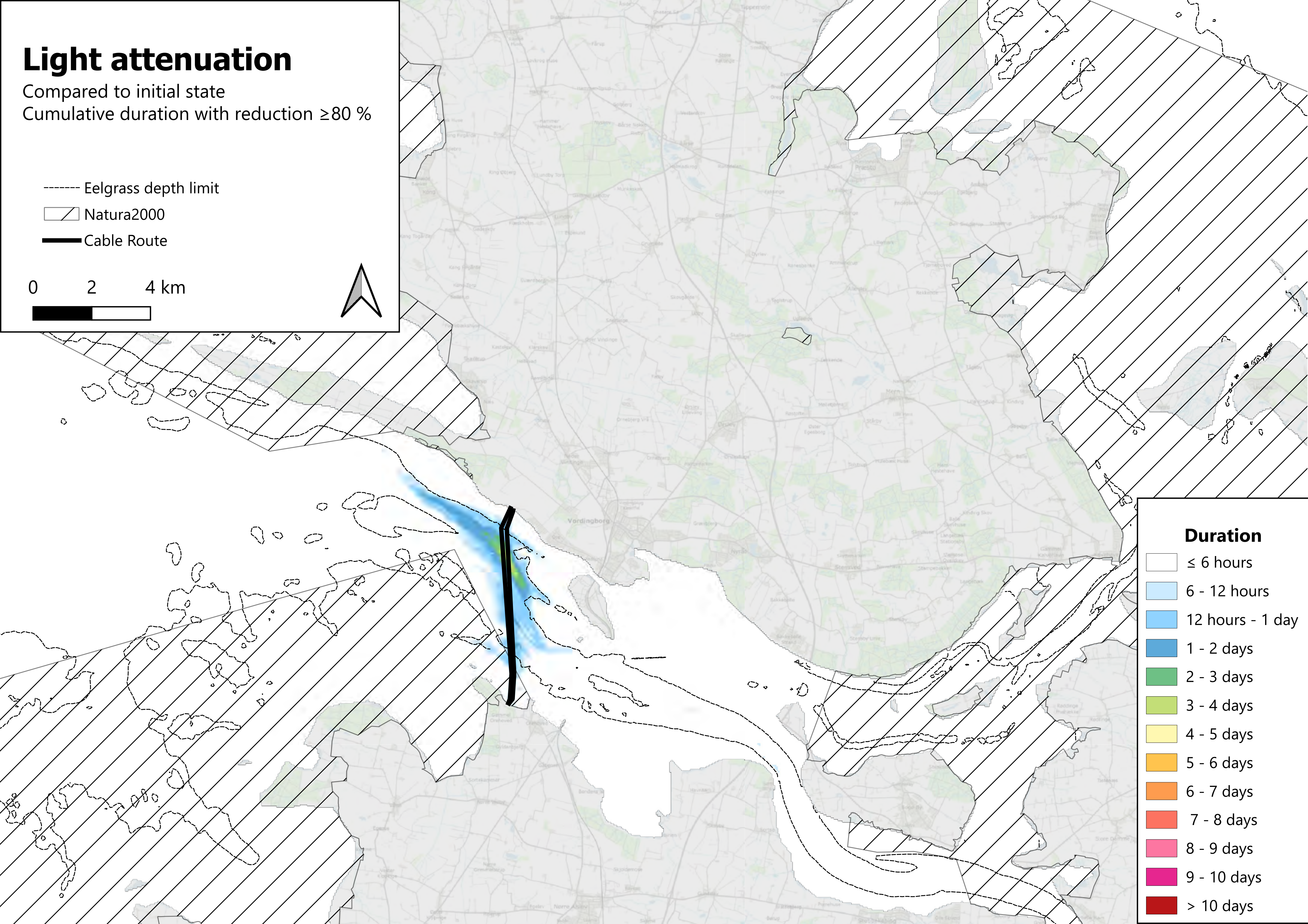


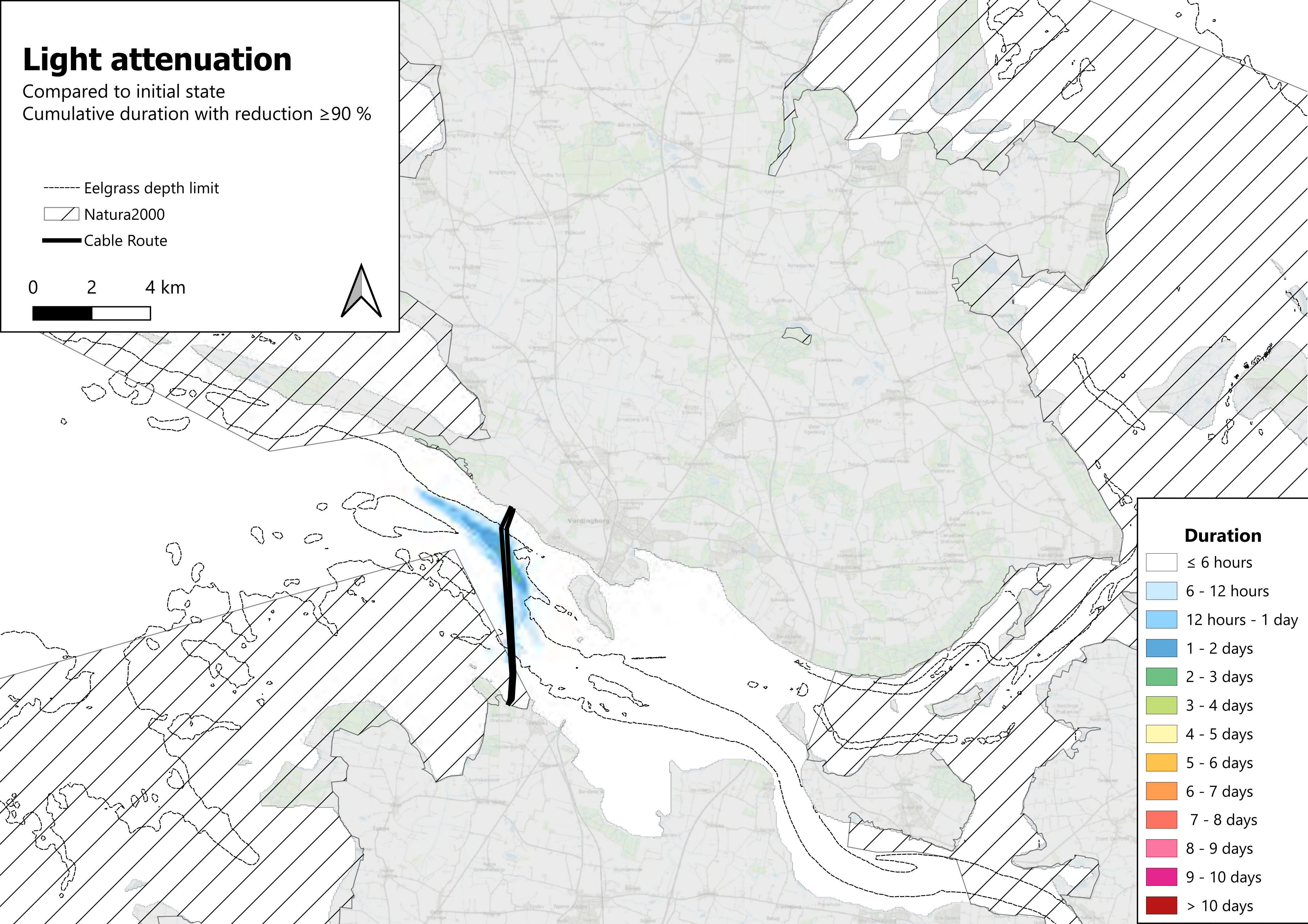
Light attenuation
Compared to initial state
Cumulative duration with reduction ≥50 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Vordingborg



Light attenuation
Compared to initial state
Cumulative duration with reduction ≥60 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Vordingborg


Light attenuation
Compared to initial state
Cumulative duration with reduction ≥70 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days


Light attenuation
Compared to initial state
Cumulative duration with reduction ≥80 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

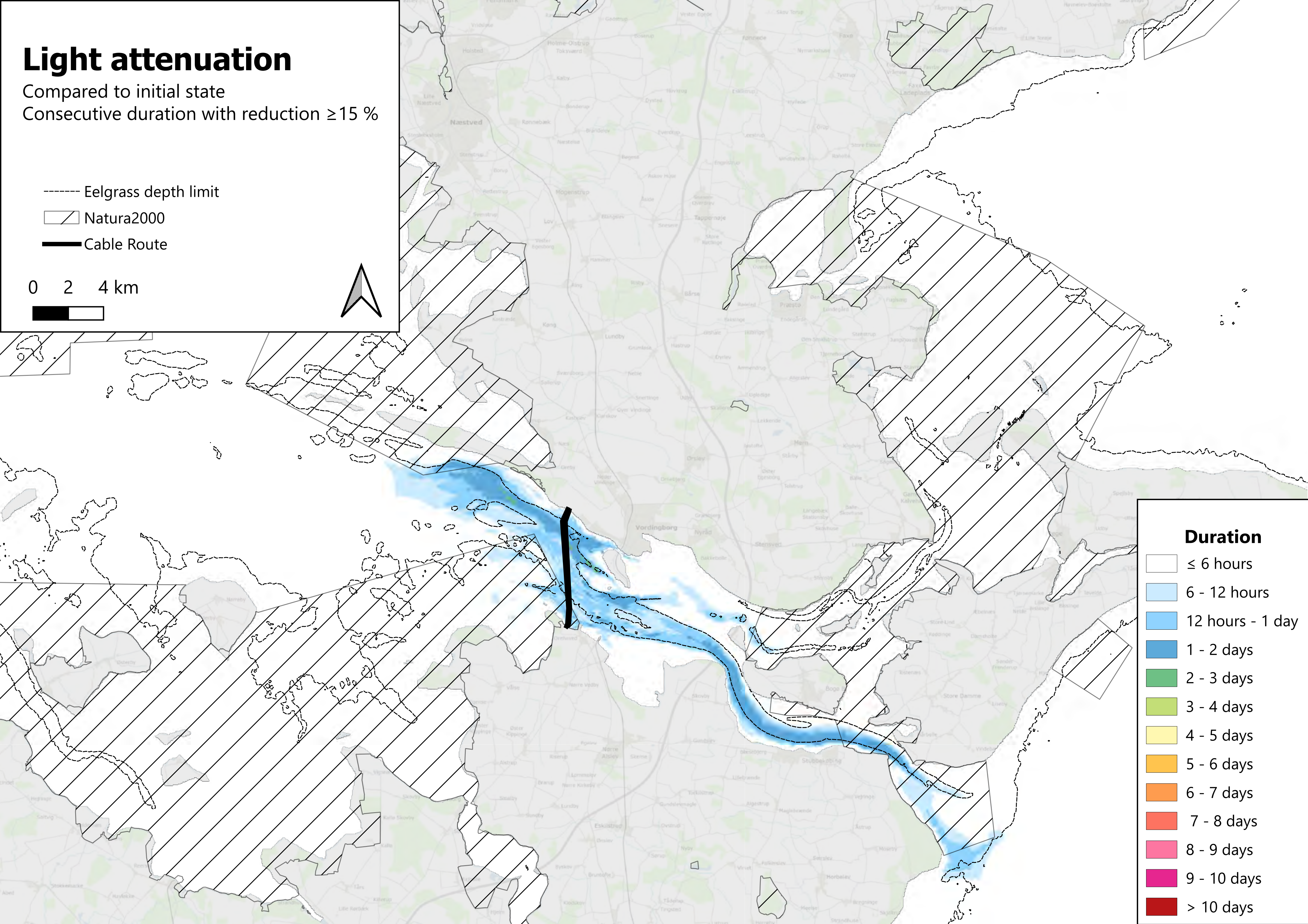


Light attenuation
Compared to initial state
Cumulative duration with reduction ≥90 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

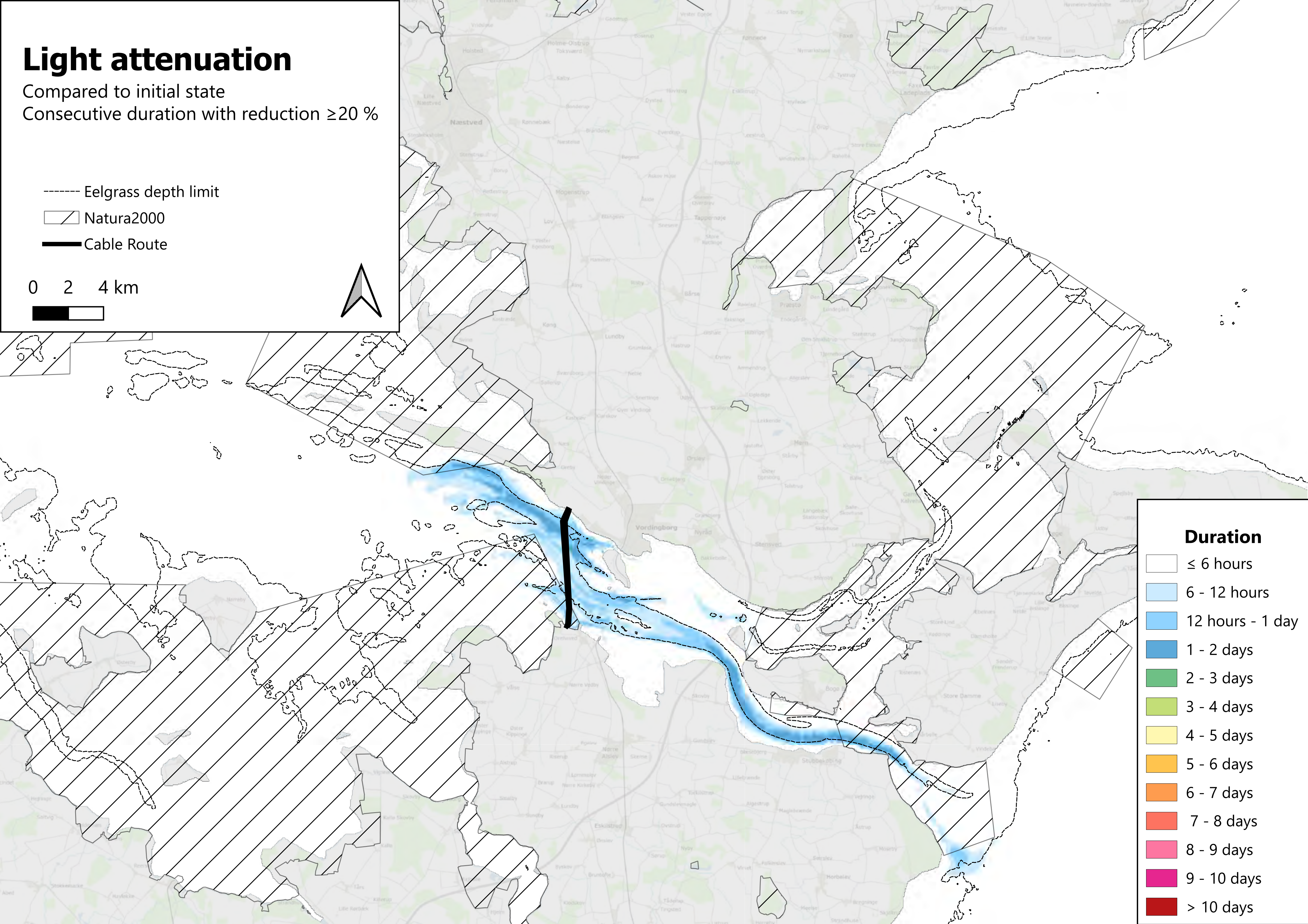
Appendix 9 Longest consecutive exceedance durations of light attenuation

The following maps show the longest consecutive duration a threshold of light attenuation is reached or exceeded.

The present Appendix is divided in two subsections, which present the same results with two different scales.



Light attenuation
Compared to initial state
Consecutive duration with reduction ≥15 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days
Næstved
Vordingborg



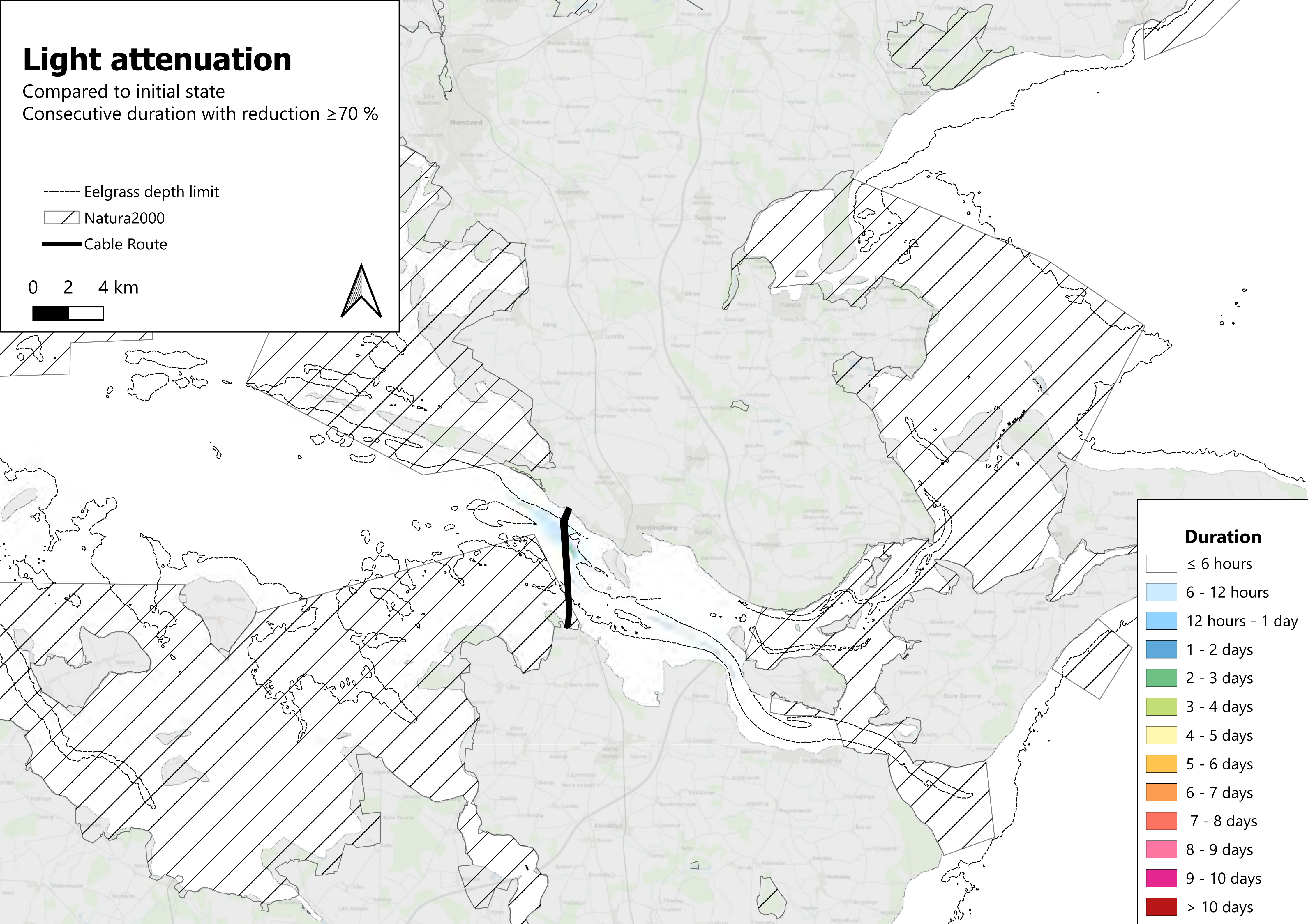
Light attenuation
Compared to initial state
Consecutive duration with reduction ≥20 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

Light attenuation
Compared to initial state
Consecutive duration with reduction ≥30 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

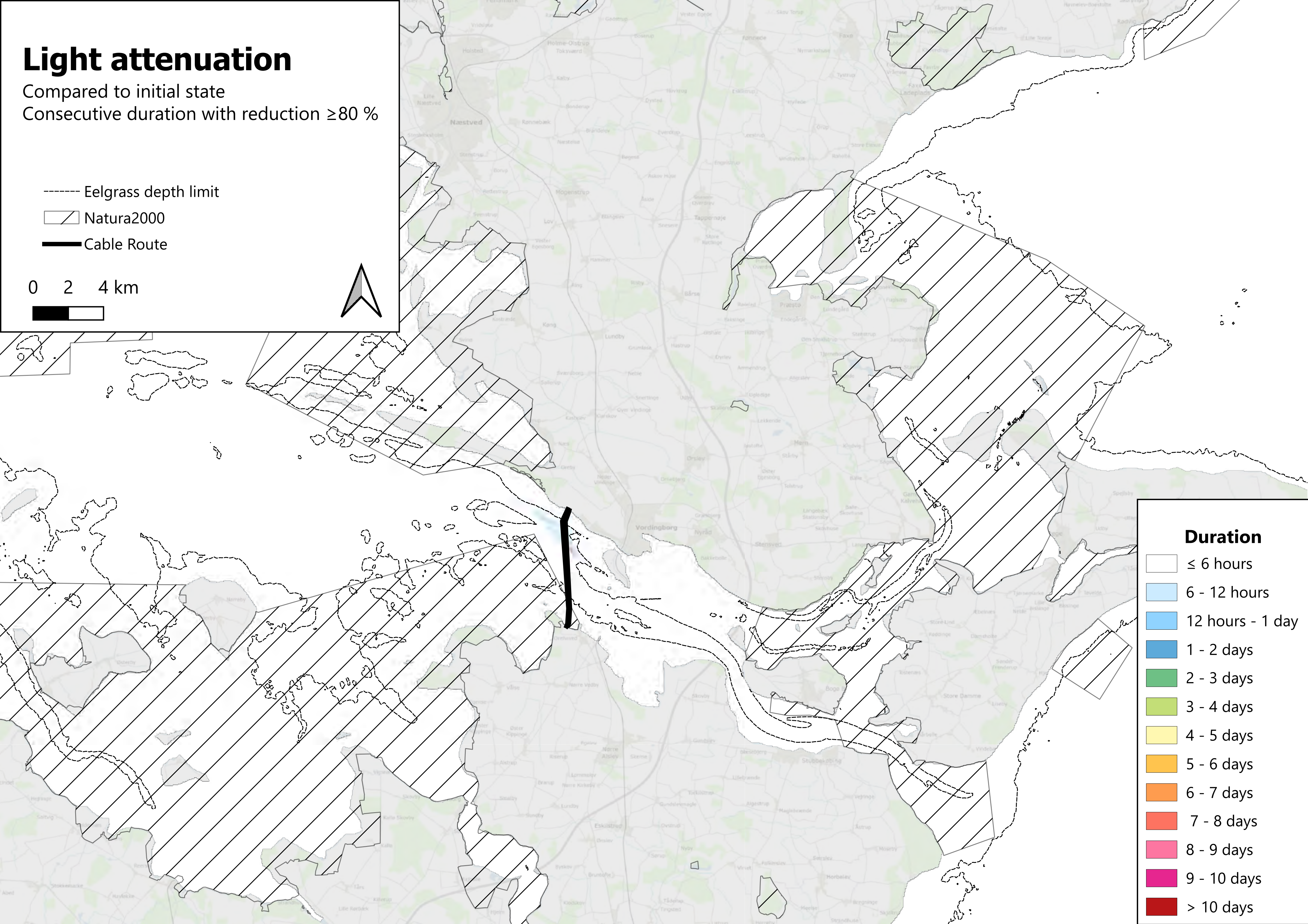
Light attenuation
Compared to initial state
Consecutive duration with reduction ≥40 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days


Light attenuation
Compared to initial state
Consecutive duration with reduction ≥50 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

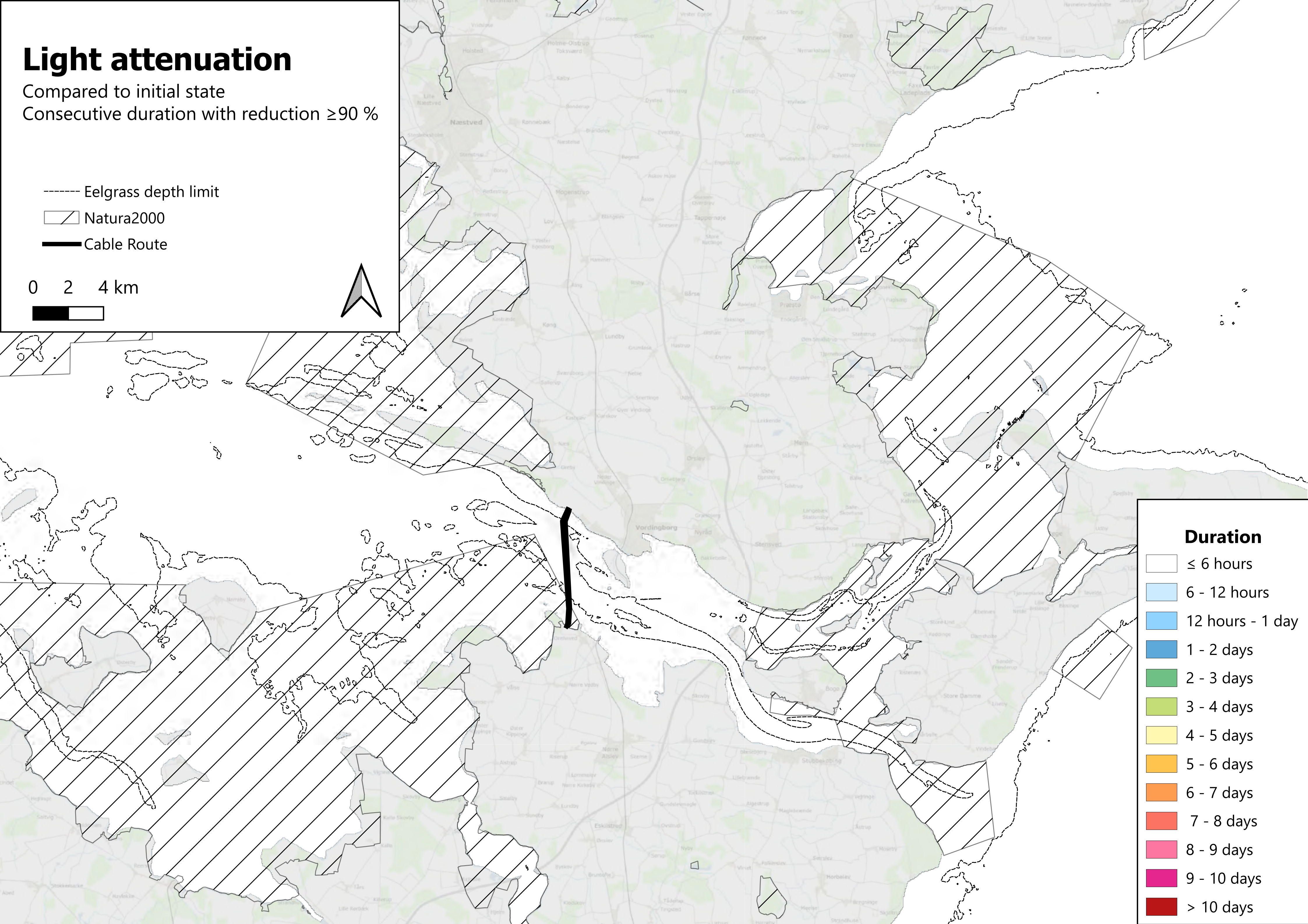
Light attenuation
Compared to initial state
Consecutive duration with reduction ≥60 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days



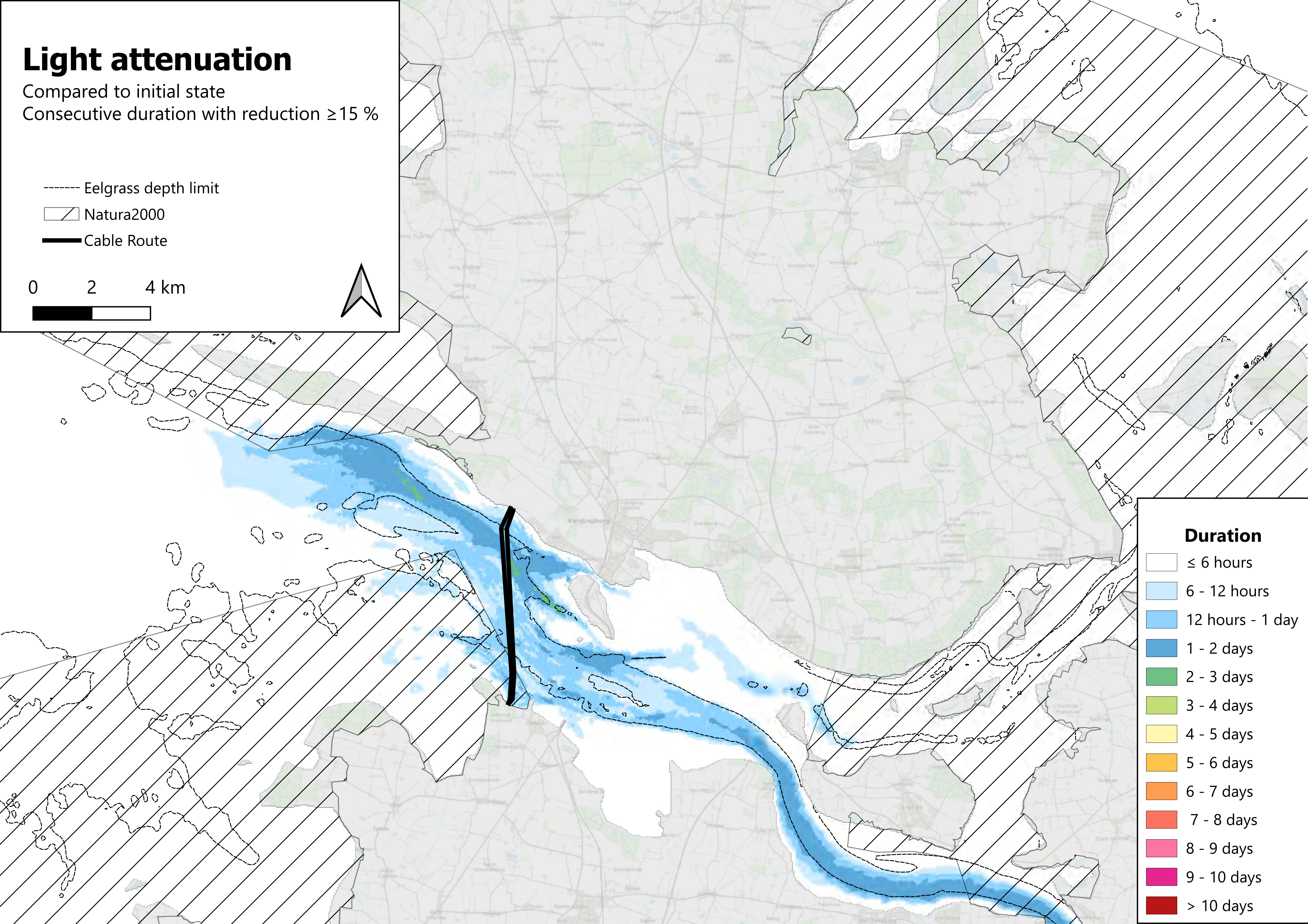
Light attenuation
Compared to initial state
Consecutive duration with reduction ≥70 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days



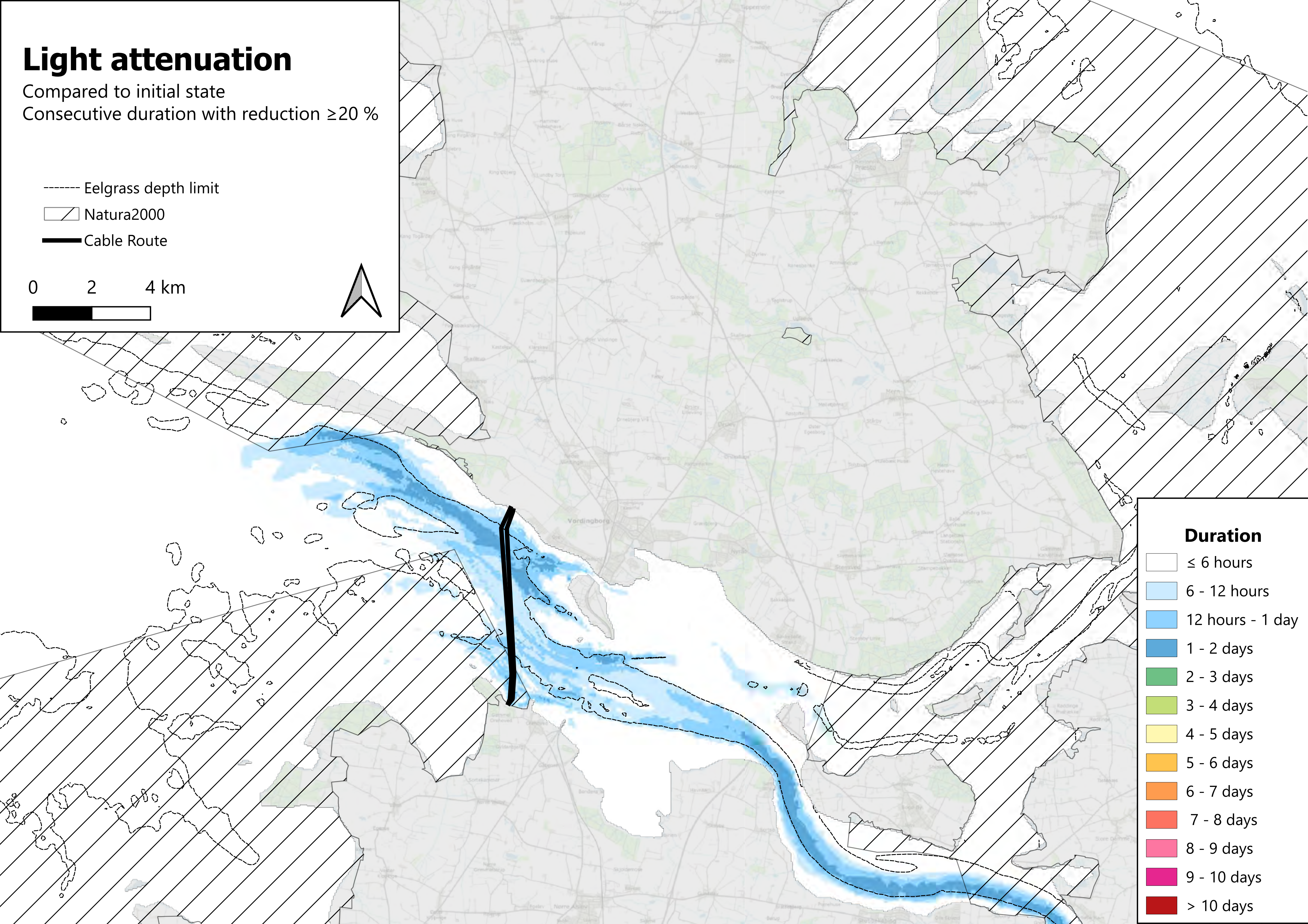
Light attenuation
Compared to initial state
Consecutive duration with reduction ≥80 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days



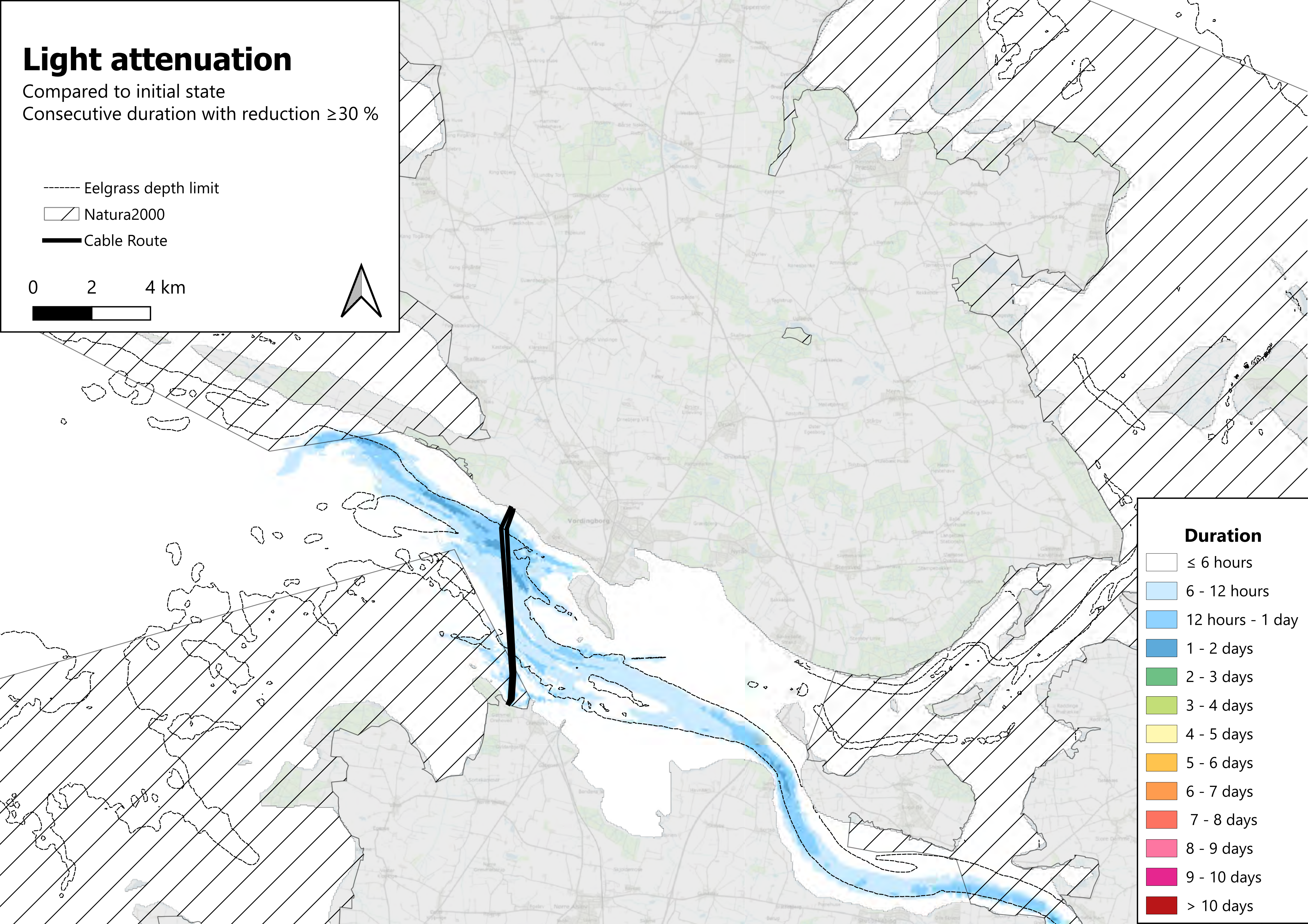
Light attenuation
Compared to initial state
Consecutive duration with reduction ≥90 %
Eelgrass depth limit
Natura2000
Cable Route
0 2 4 km
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

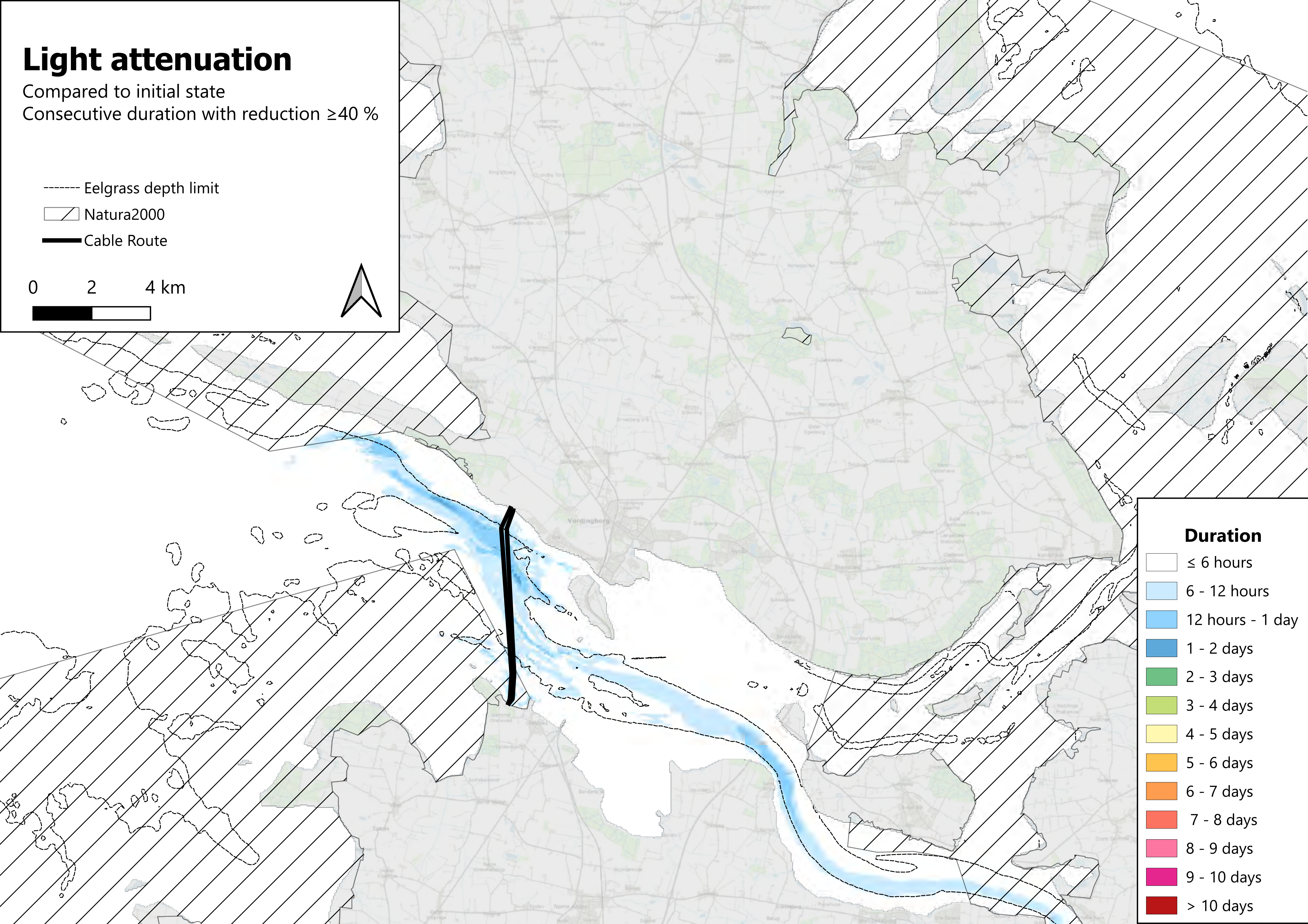


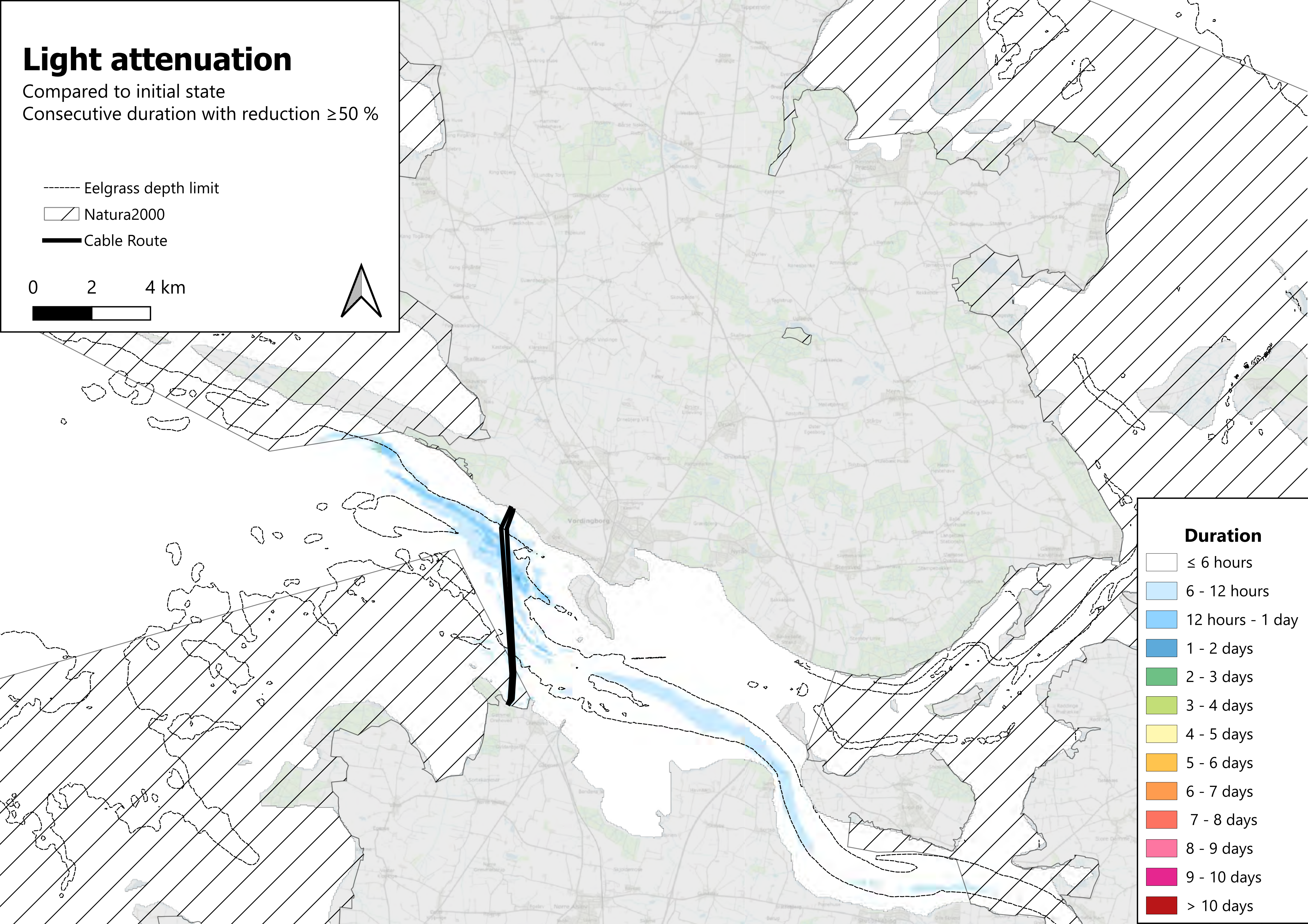
Light attenuation
Compared to initial state
Consecutive duration with reduction ≥15 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

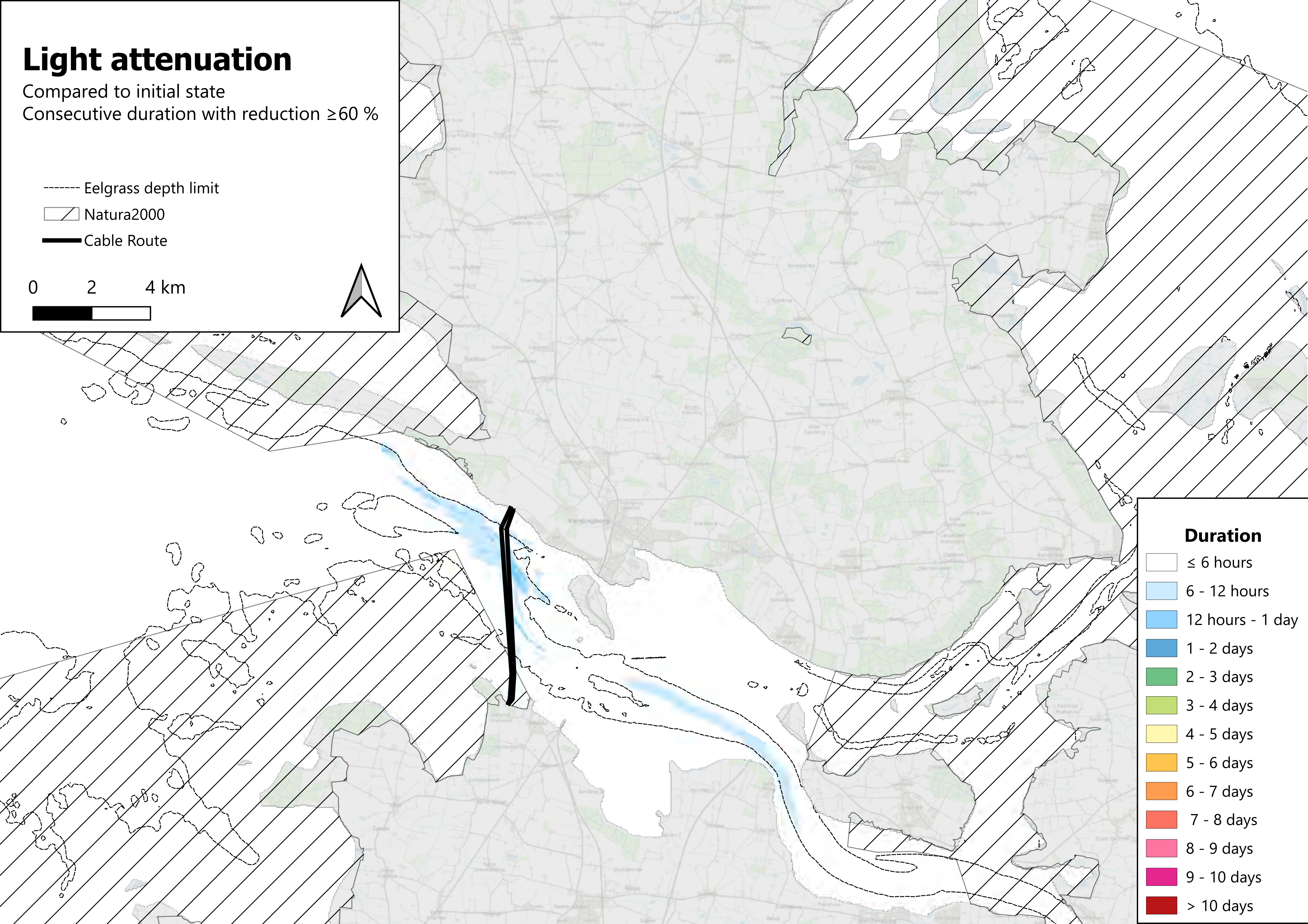


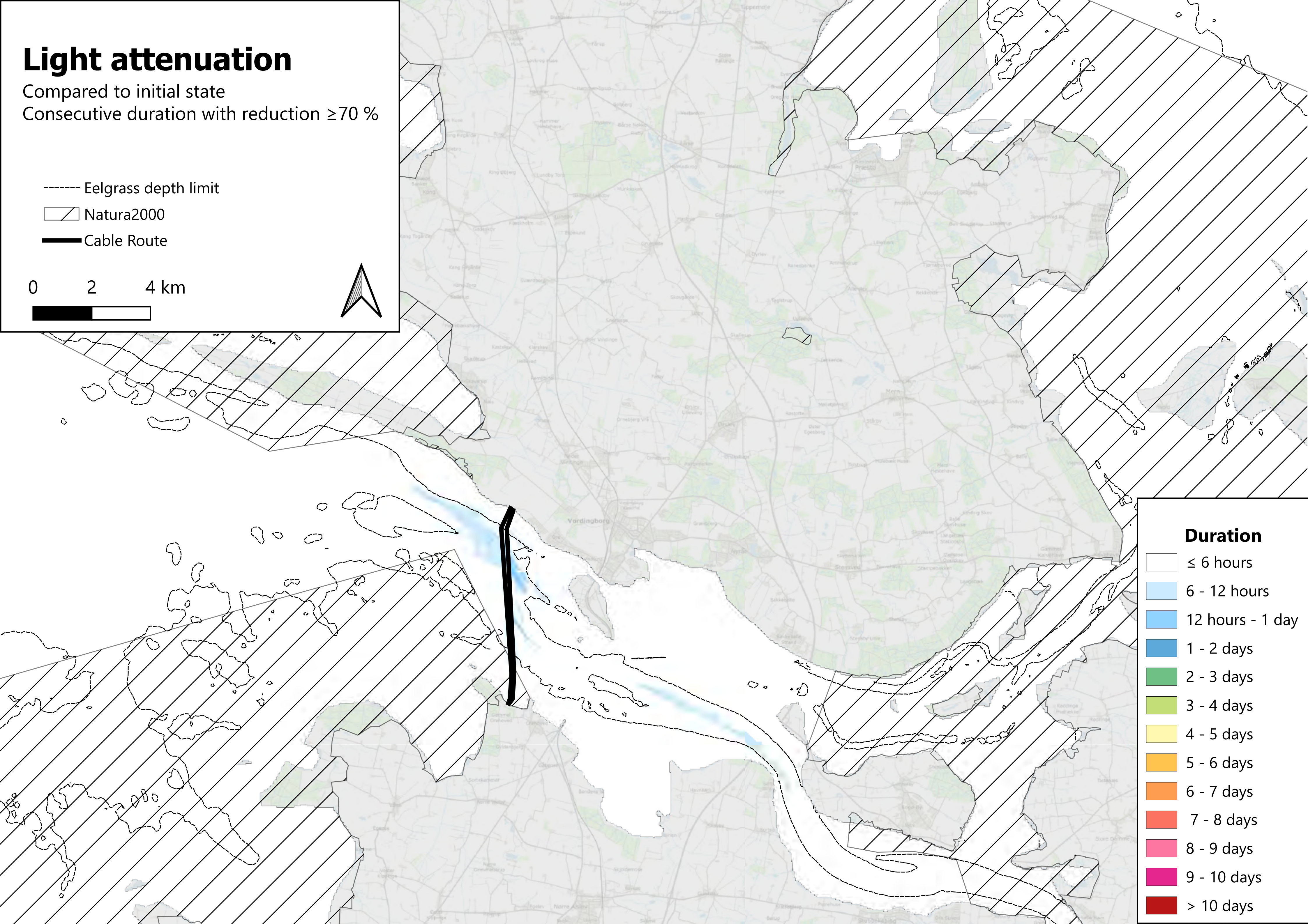
Light attenuation
Compared to initial state
Consecutive duration with reduction ≥20 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days


Light attenuation
Compared to initial state
Consecutive duration with reduction ≥30 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

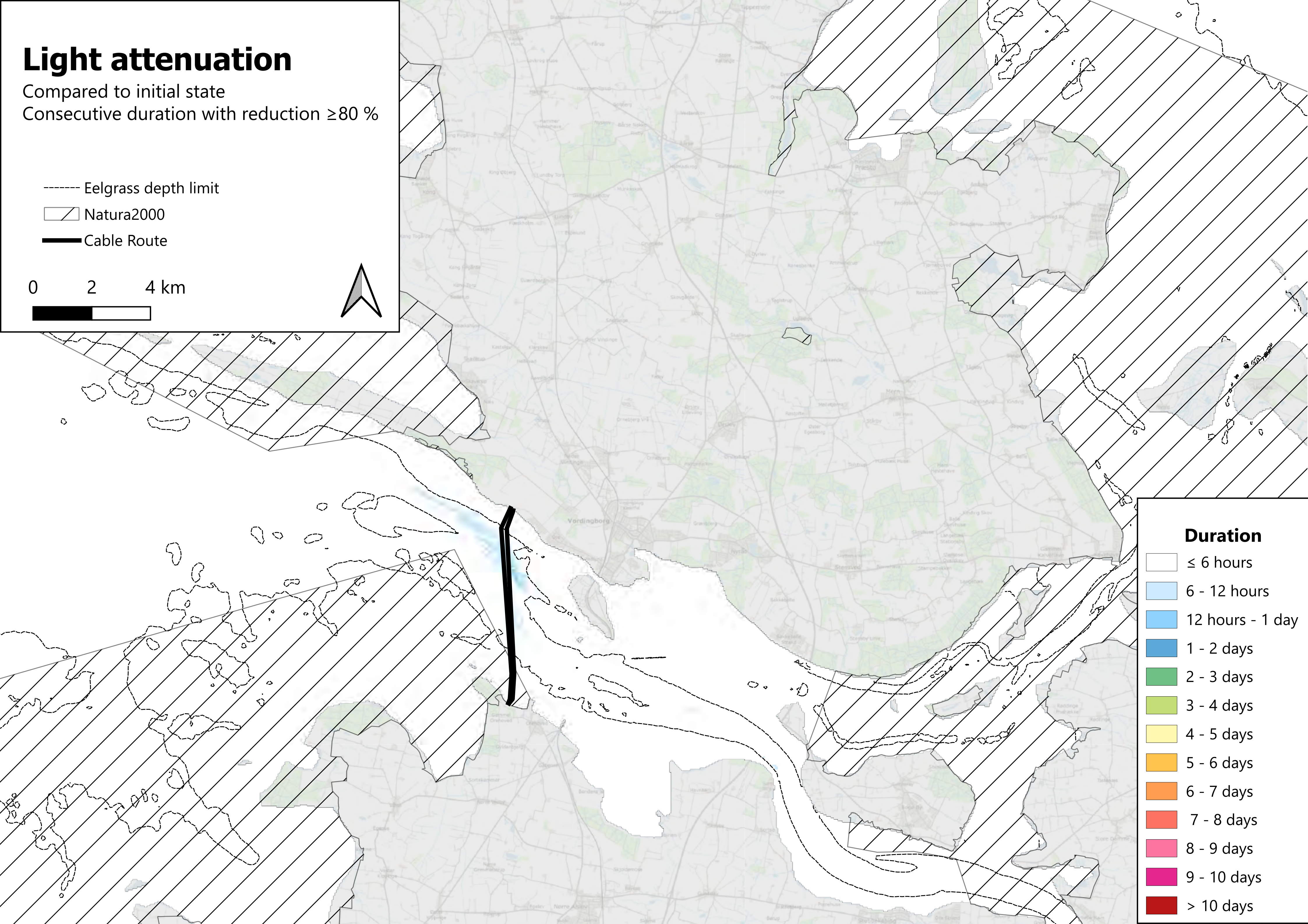

Light attenuation
Compared to initial state
Consecutive duration with reduction ≥40 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days


Light attenuation
Compared to initial state
Consecutive duration with reduction ≥50 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

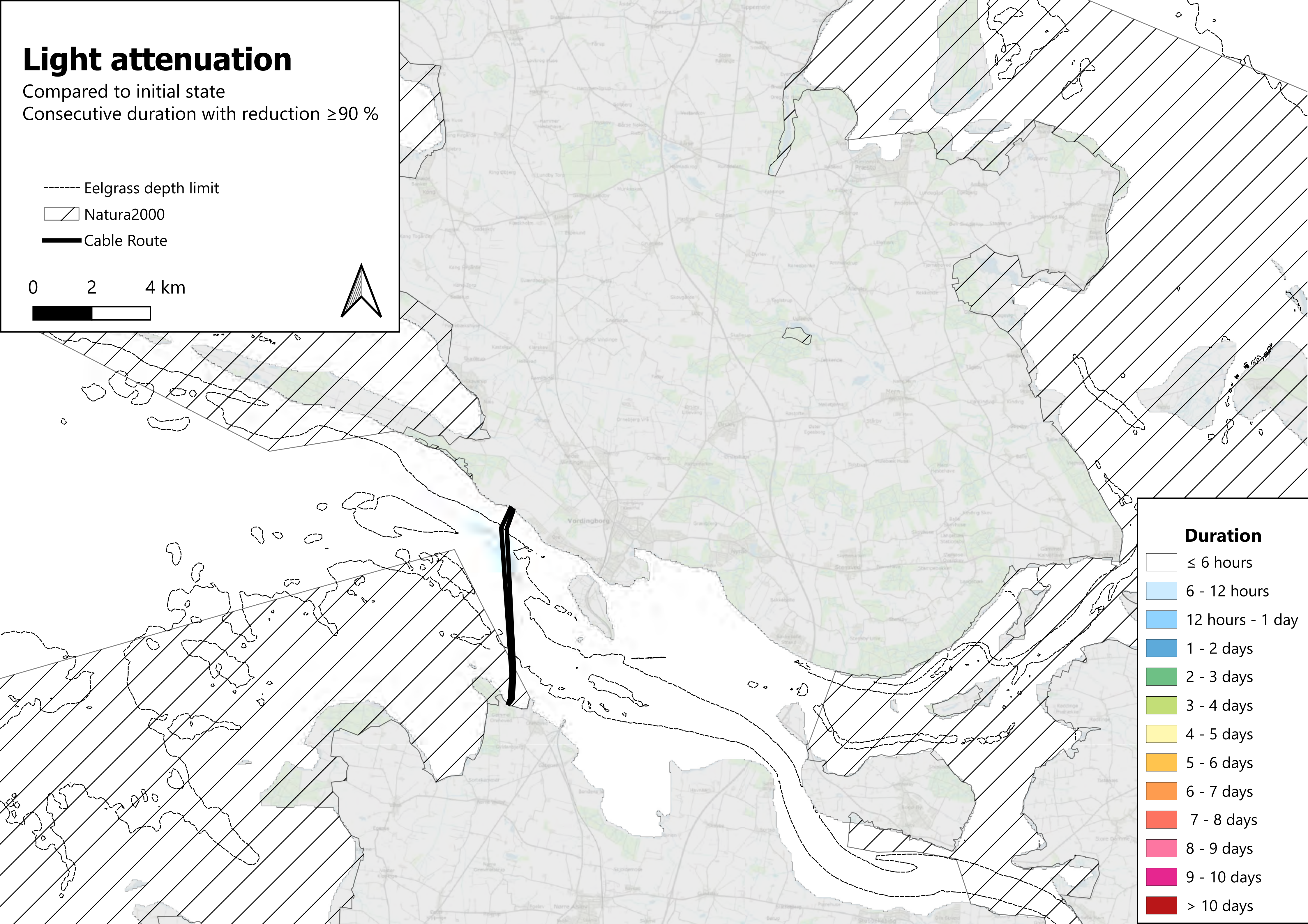

Light attenuation
Compared to initial state
Consecutive duration with reduction ≥60 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days



Light attenuation
Compared to initial state
Consecutive duration with reduction ≥70 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

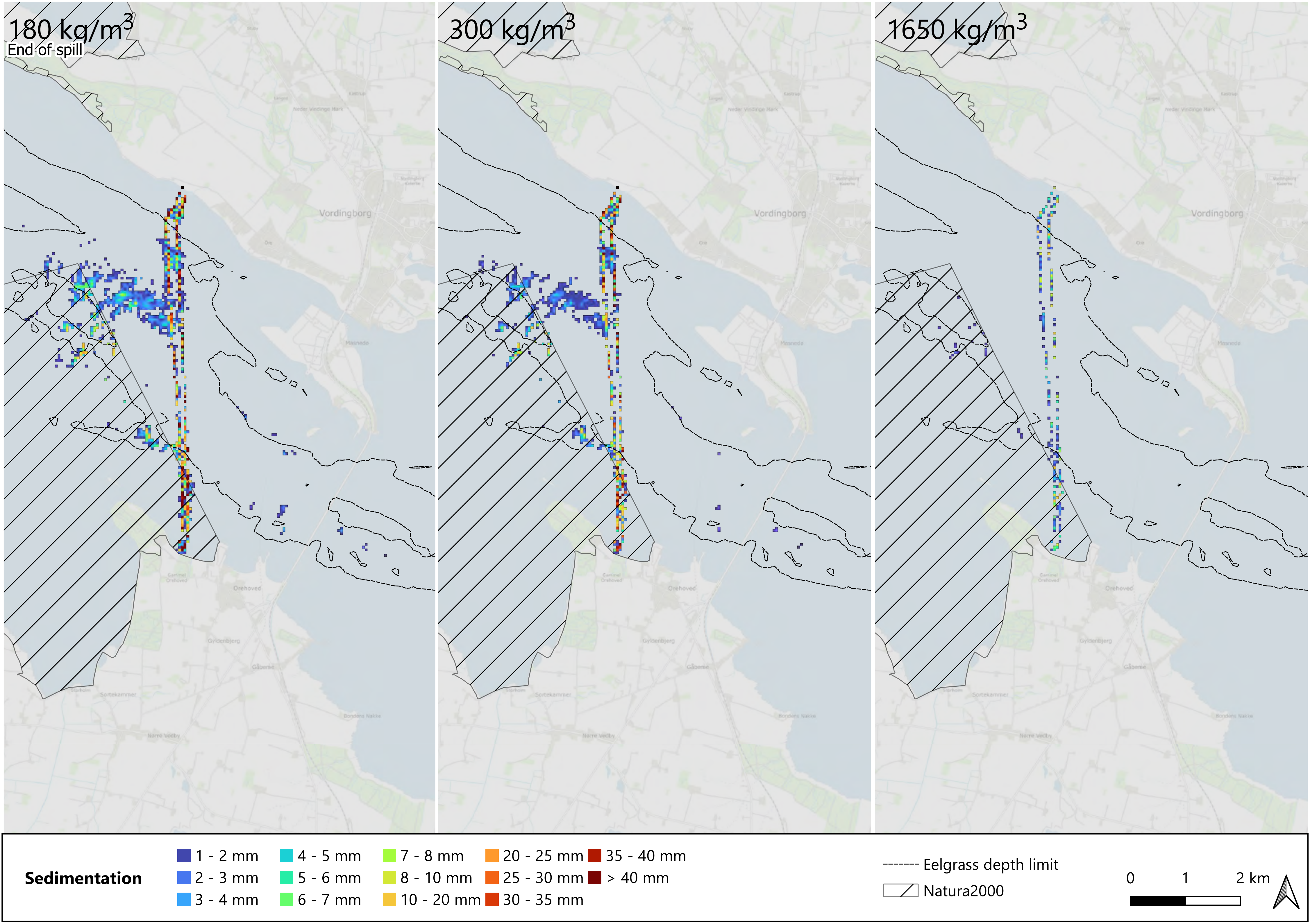


Light attenuation
Compared to initial state
Consecutive duration with reduction ≥80 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

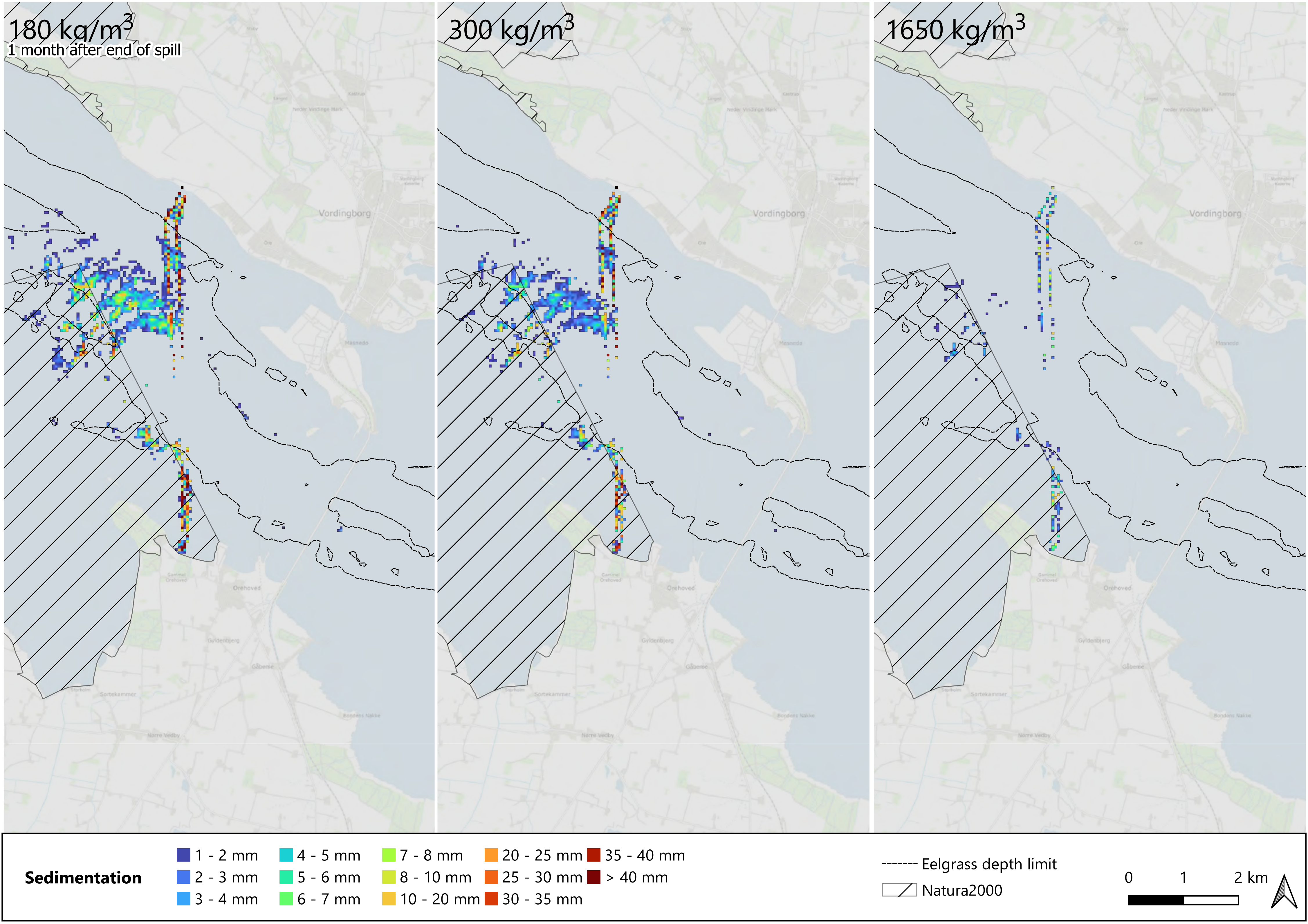

Light attenuation
Compared to initial state
Consecutive duration with reduction ≥90 %
Eelgrass depth limit
Natura2000
Cable Route
0
2
4 km
Vordingborg
Duration
≤ 6 hours
6 - 12 hours
12 hours - 1 day
1 - 2 days
2 - 3 days
3 - 4 days
4 - 5 days
5 - 6 days
6 - 7 days
7 - 8 days
8 - 9 days
9 - 10 days
> 10 days

Appendix 10 Sedimentation heights

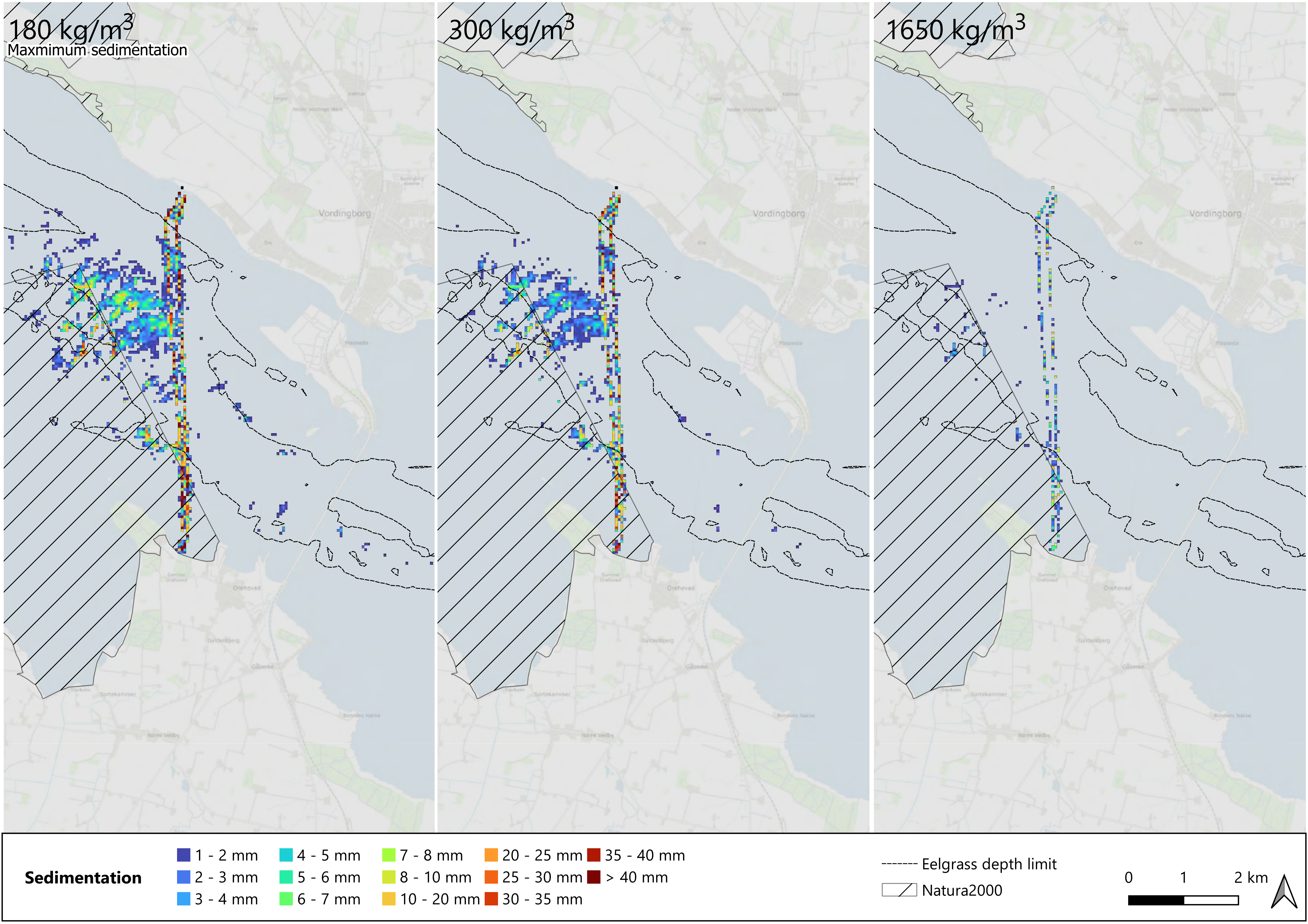
The following maps show the deposition heights at different stages for different values of density of sediment.



180 kg/m3
End of spill
300 kg/m3
1650 kg/m3
Vordingborg
Vordingborg
Vordingborg
Sedimentation
1 - 2 mm
2 - 3 mm
3 - 4 mm
4 - 5 mm
5 - 6 mm
6 - 7 mm
7 - 8 mm
8 - 10 mm
10 - 20 mm
20 - 25 mm
25 - 30 mm
30 - 35 mm
35 - 40 mm
> 40 mm
Eelgrass depth limit
Natura2000
0
1
2 km



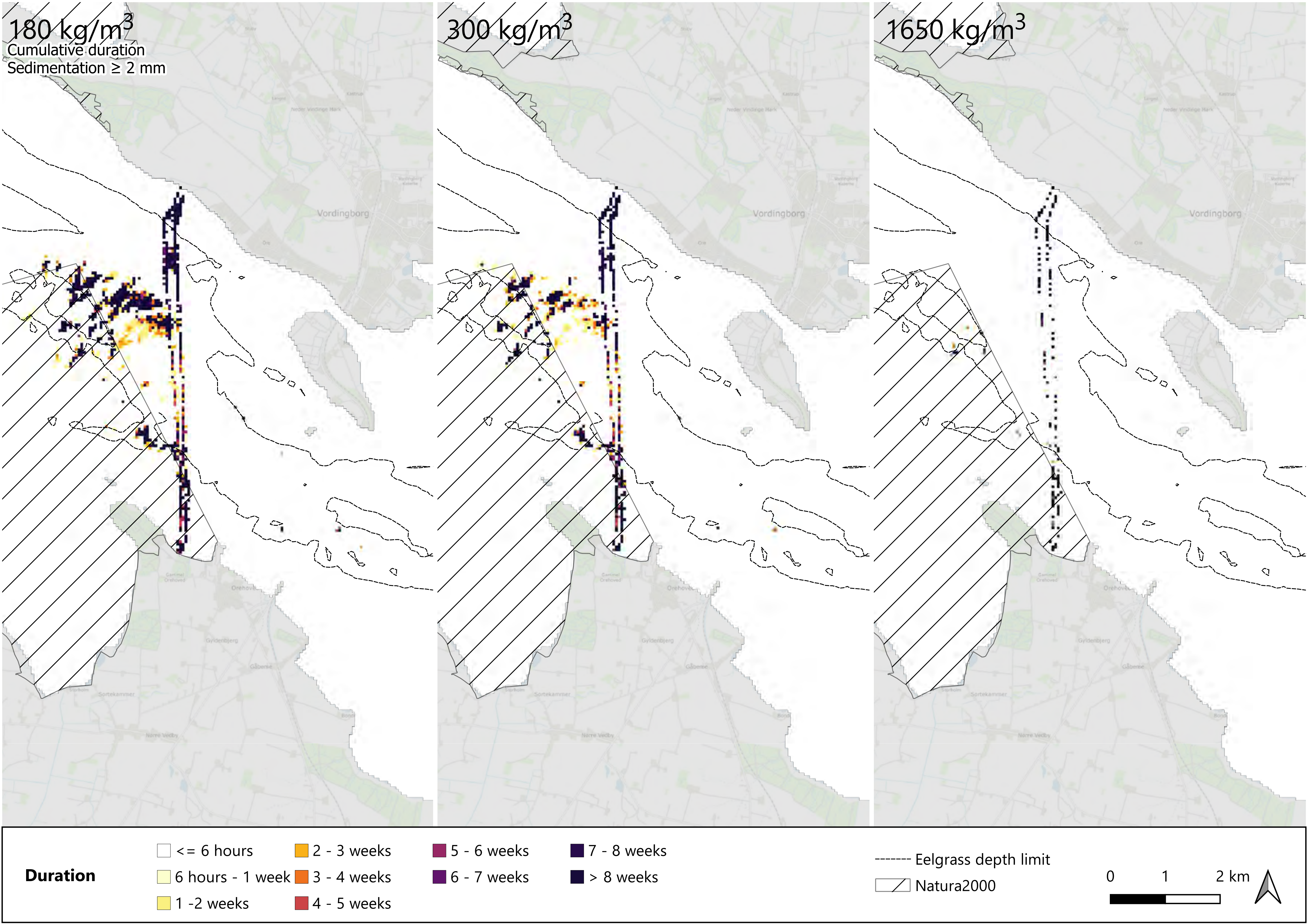
180 kg/m3
1 month after end of spill
300 kg/m3
1650 kg/m3
Vordingborg
Sedimentation
1 - 2 mm
2 - 3 mm
3 - 4 mm
4 - 5 mm
5 - 6 mm
6 - 7 mm
7 - 8 mm
8 - 10 mm
10 - 20 mm
20 - 25 mm
25 - 30 mm
30 - 35 mm
35 - 40 mm
> 40 mm
Eelgrass depth limit
Natura2000
0
1
2 km

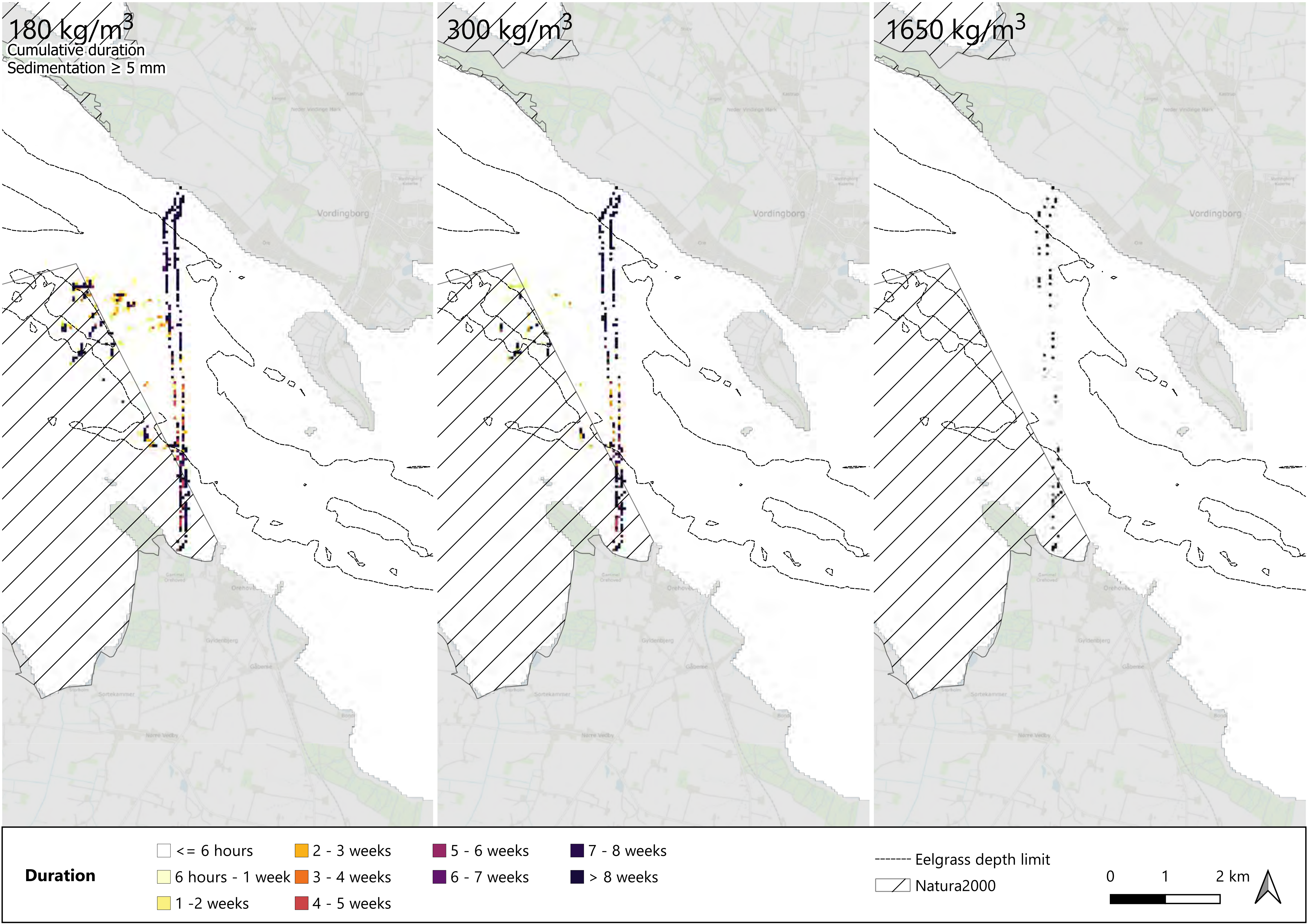


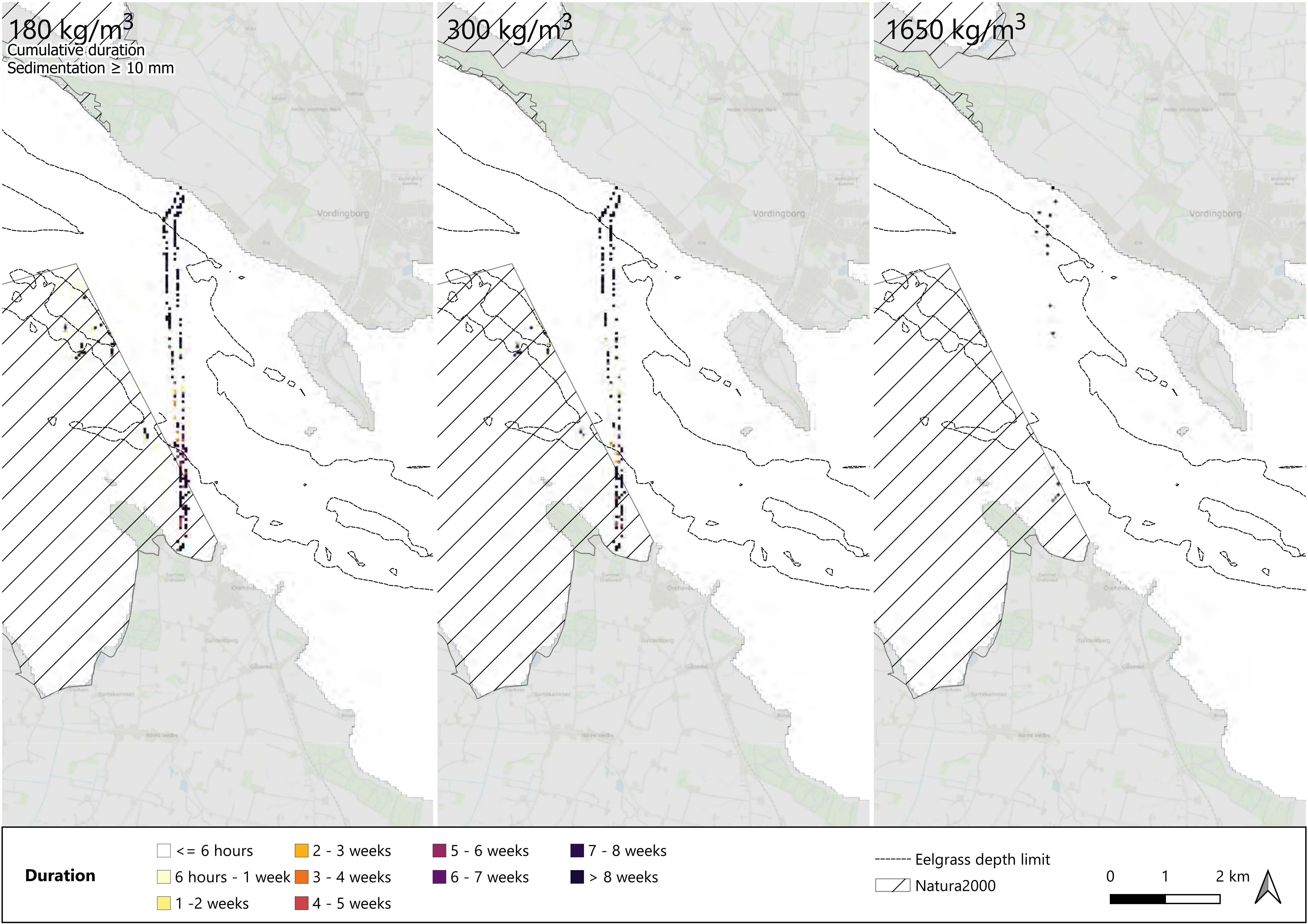
180 kg/m3
Maxmimum sedimentation
300 kg/m3
1650 kg/m3
Vordingborg
Sedimentation
1 - 2 mm
2 - 3 mm
3 - 4 mm
4 - 5 mm
5 - 6 mm
6 - 7 mm
7 - 8 mm
8 - 10 mm
10 - 20 mm
20 - 25 mm
25 - 30 mm
30 - 35 mm
35 - 40 mm
> 40 mm
Eelgrass depth limit
Natura2000
0
1
2 km

Appendix 11 Cumulative exceedance durations of sedimentation

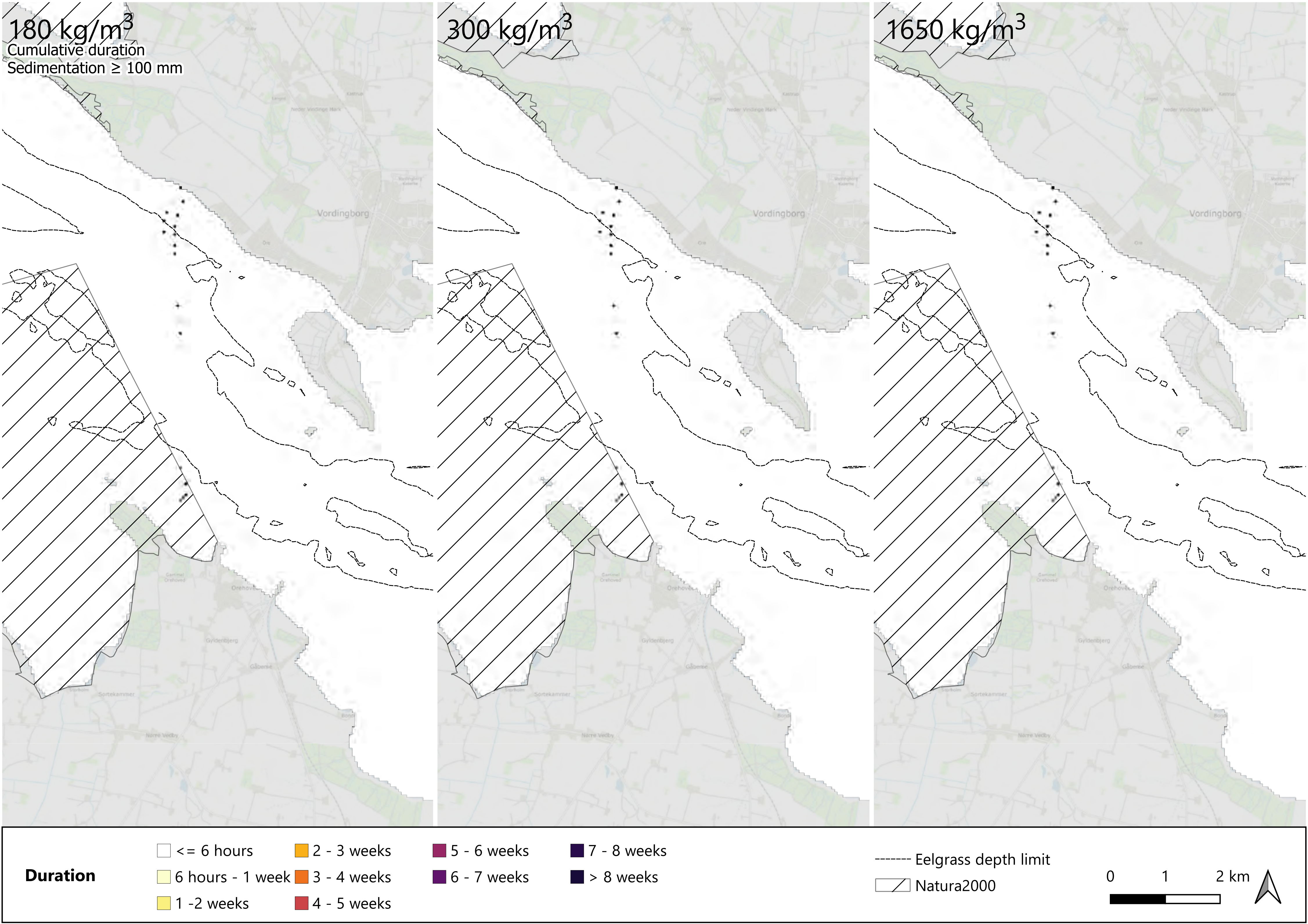
The following maps show the cumulative duration a threshold of sediment height is reached or exceeded for different values of density of sediment.


180 kg/m3
Cumulative duration
Sedimentation ≥ 2 mm
300 kg/m3
1650 kg/m3
Vordingborg
Duration
<= 6 hours
6 hours - 1 week
1 -2 weeks
2 - 3 weeks
3 - 4 weeks
4 - 5 weeks
5 - 6 weeks
6 - 7 weeks
7 - 8 weeks
> 8 weeks
Eelgrass depth limit
Natura2000
0
1
2 km


180 kg/m3
Cumulative duration
Sedimentation ≥ 5 mm
300 kg/m3
1650 kg/m3
Vordingborg
Vordingborg
Vordingborg
Duration
<= 6 hours
6 hours - 1 week
1 -2 weeks
2 - 3 weeks
3 - 4 weeks
4 - 5 weeks
5 - 6 weeks
6 - 7 weeks
7 - 8 weeks
> 8 weeks
Eelgrass depth limit
Natura2000
0
1
2 km



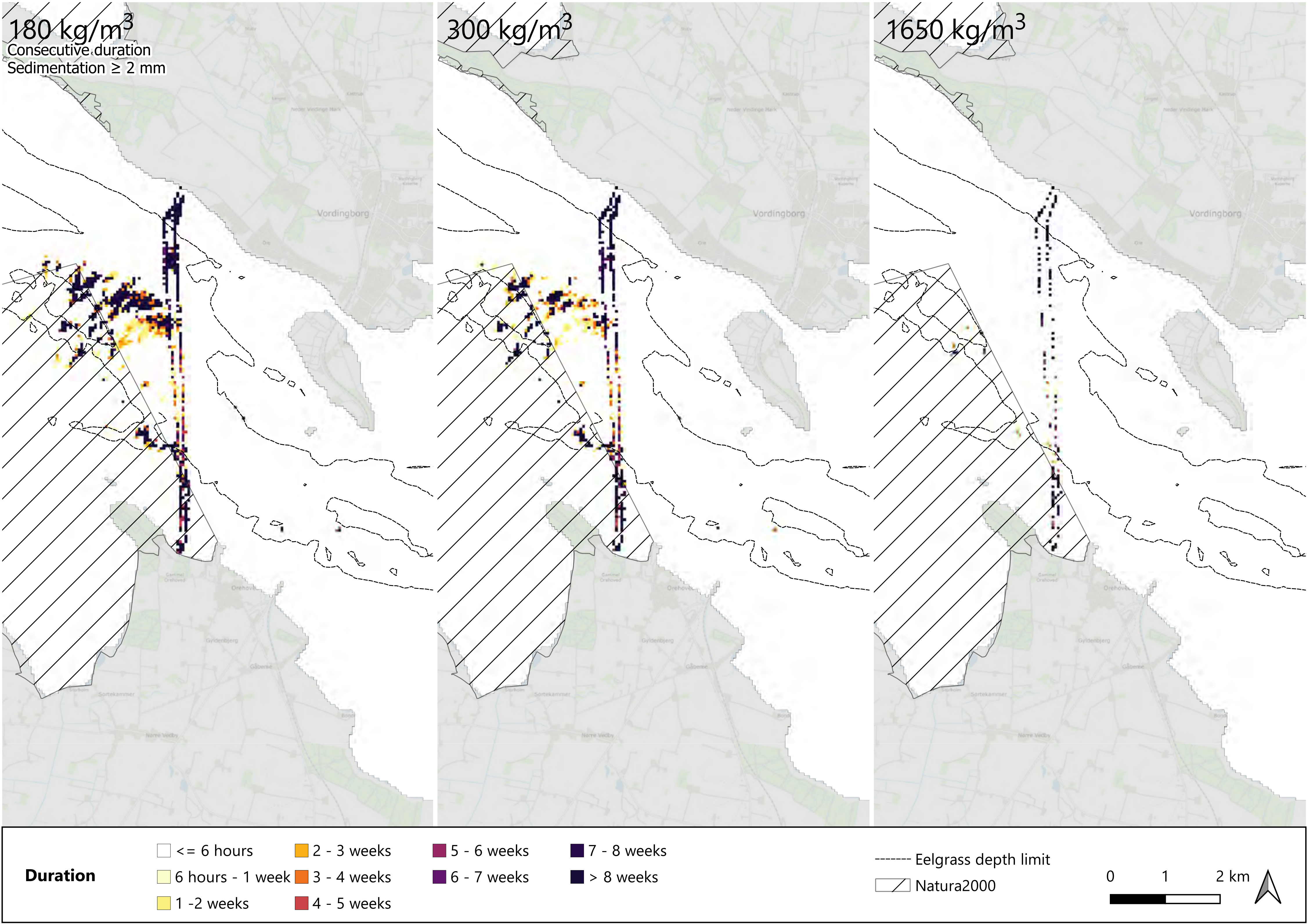
180 kg/m3
Cumulative duration
Sedimentation ≥ 10 mm
300 kg/m3
1650 kg/m3
Vordingborg
Duration
<= 6 hours
6 hours - 1 week
1 -2 weeks
2 - 3 weeks
3 - 4 weeks
4 - 5 weeks
5 - 6 weeks
6 - 7 weeks
7 - 8 weeks
> 8 weeks
Eelgrass depth limit
Natura2000
0
1
2 km



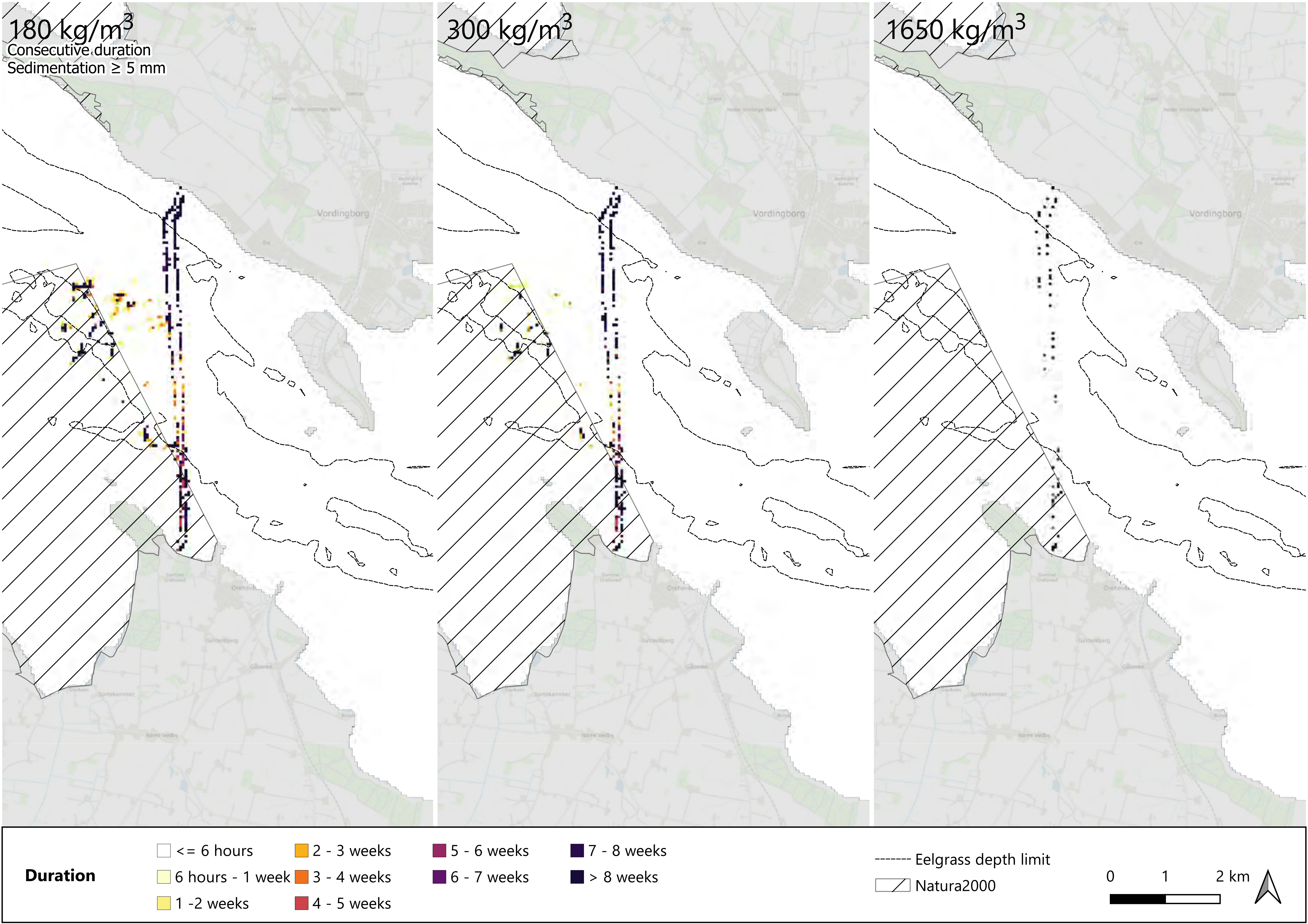
180 kg/m3
Cumulative duration
Sedimentation ≥ 100 mm
300 kg/m3
1650 kg/m3
Vordingborg
Vordingborg
Vordingborg
Duration
<= 6 hours
6 hours - 1 week
1 -2 weeks
2 - 3 weeks
3 - 4 weeks
4 - 5 weeks
5 - 6 weeks
6 - 7 weeks
7 - 8 weeks
> 8 weeks
Eelgrass depth limit
Natura2000
0
1
2 km

Appendix 12 Longest consecutive exceedance durations of sedimentation

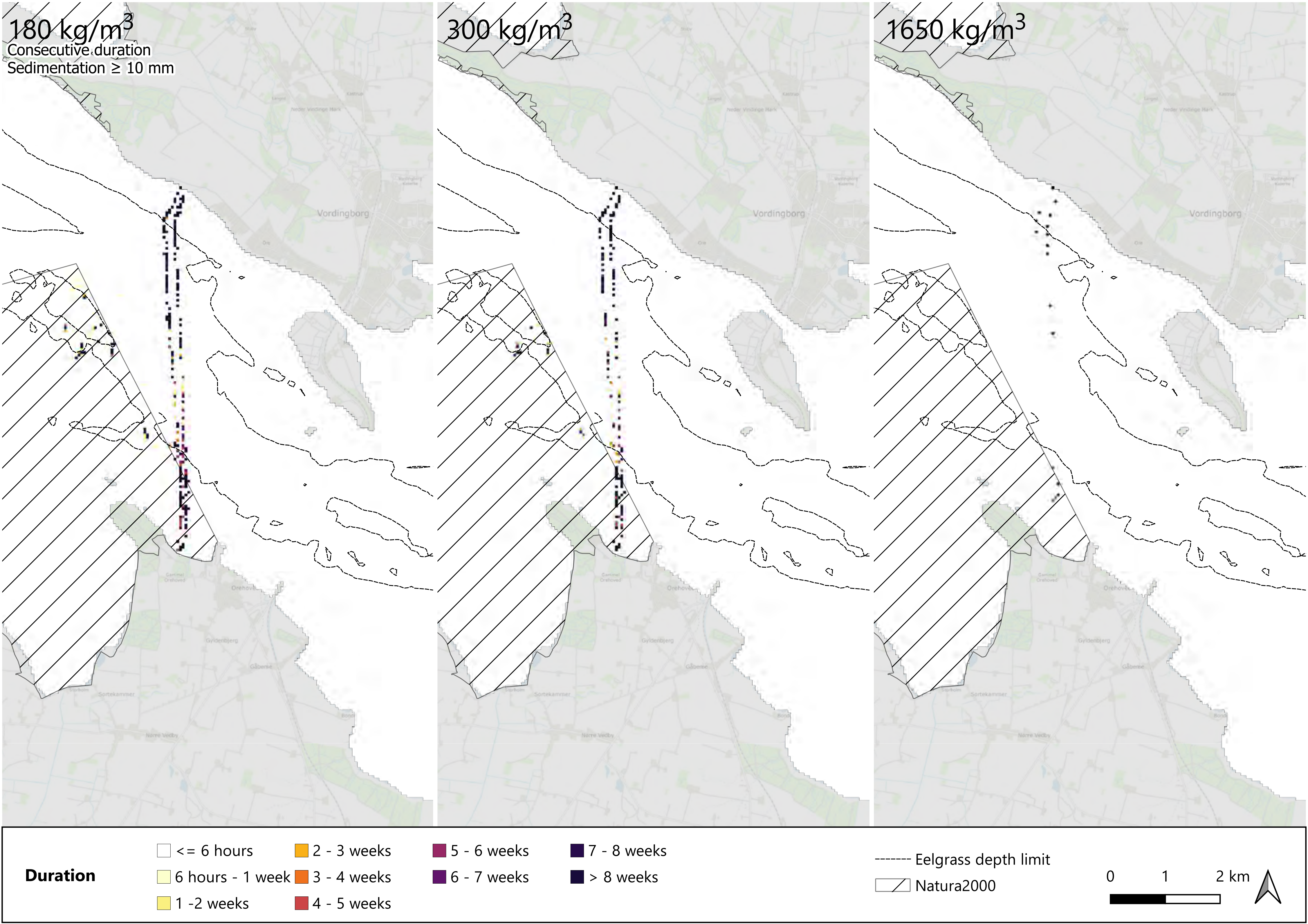
The following maps show the longest consecutive duration a threshold of sediment height is reached or exceeded for different values of density of sediment.



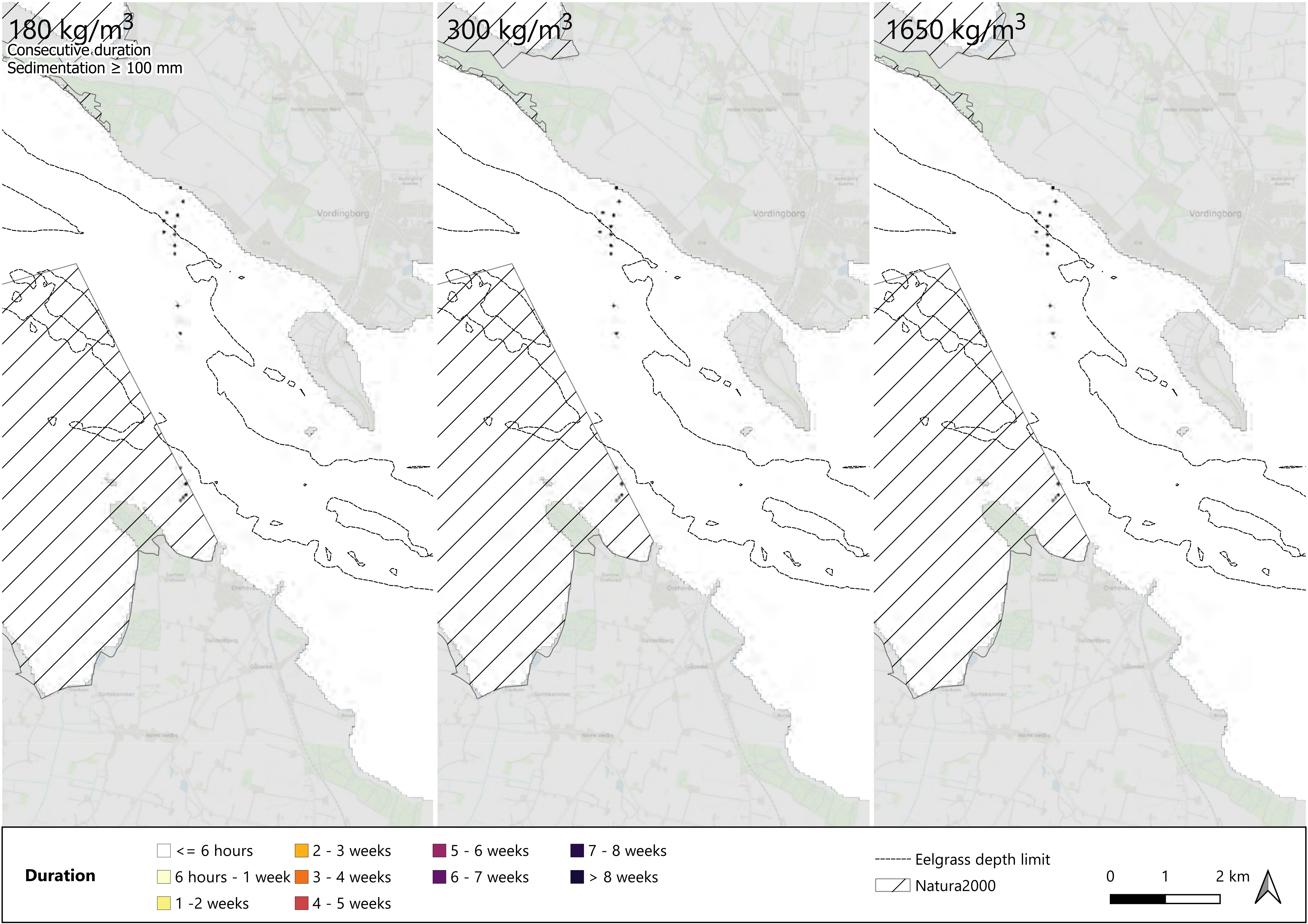
180 kg/m3
Consecutive duration
Sedimentation ≥ 2 mm
300 kg/m3
1650 kg/m3
Vordingborg
Duration
<= 6 hours
6 hours - 1 week
1 -2 weeks
2 - 3 weeks
3 - 4 weeks
4 - 5 weeks
5 - 6 weeks
6 - 7 weeks
7 - 8 weeks
> 8 weeks
Eelgrass depth limit
Natura2000
0
1
2 km



180 kg/m3
Consecutive duration
Sedimentation ≥ 5 mm
300 kg/m3
1650 kg/m3
Vordingborg
Duration
<= 6 hours
6 hours - 1 week
1 -2 weeks
2 - 3 weeks
3 - 4 weeks
4 - 5 weeks
5 - 6 weeks
6 - 7 weeks
7 - 8 weeks
> 8 weeks
Eelgrass depth limit
Natura2000
0
1
2 km



180 kg/m3
Consecutive duration
Sedimentation ≥ 10 mm
300 kg/m3
1650 kg/m3
Vordingborg
Duration
<= 6 hours
6 hours - 1 week
1 -2 weeks
2 - 3 weeks
3 - 4 weeks
4 - 5 weeks
5 - 6 weeks
6 - 7 weeks
7 - 8 weeks
> 8 weeks
Eelgrass depth limit
Natura2000
0
1
2 km



180 kg/m3
Consecutive duration
Sedimentation ≥ 100 mm
300 kg/m3
1650 kg/m3
Vordingborg
Duration
<= 6 hours
6 hours - 1 week
1 -2 weeks
2 - 3 weeks
3 - 4 weeks
4 - 5 weeks
5 - 6 weeks
6 - 7 weeks
7 - 8 weeks
> 8 weeks
Eelgrass depth limit
Natura2000
0
1
2 km