Wave exposure calculations for the Polish coast

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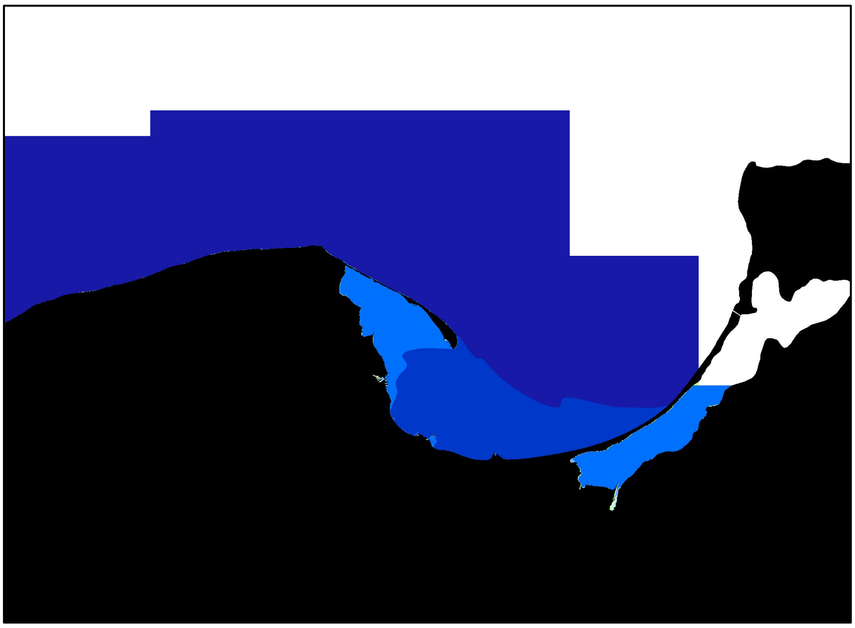
AquaBiota Water Research



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SUMMARY

SUMMARY

Wave exposure is one of the major factors structuring the coastal environment, and is an important parameter in both coastal research and management.

The aim of this project was to construct wave exposure grids covering the entire Polish coast using the Simplified Wave Model method SWM (Isæus 2004). The wave exposure was calculated for mean wind conditions represented by the five-year period between September 1, 2002 and August 31, 2007.

A nested-grids technique was used to ensure long distance effects on the local wave exposure regime, and the resulting grids have a resolution of 25 m. The methods used and described in this report incorporate the division of the shoreline into suitable calculation areas, the selection of wind stations and processing of wind data, the calculation of fetch and wave exposure grids, and subsequently the integration of the separate grids into a seamless description of wave exposure along the Polish coast.

The digital version of the grids was delivered to NIVA in September 2007, and a printed version is found here in Appendix.

INTRODUCTION

1. INTRODUCTION

Geographic Information systems (GIS) have become an important tool for management as well as for research. This development has raised a demand for maps or models describing the environment to be used as input layers for the GIS analyses. Wave exposure is one of the major factors structuring the coastal environment, and the aim of this project was to construct wave exposure grids covering the entire Polish coast.

Wave exposure can be estimated in many ways and the method chosen for this project was the Simplified Wave Model (SWM), calculated with the software WaveImpact 1.0, which is fully described in the thesis by Isæus (2004). The method is called simplified since it uses the shoreline and not the bathymetry as input for describing the coastal shape. This is an adoption to the fact that bathymetry data of sufficient spatial resolution is often unavailable or confidential and therefore of restricted use. The method has been tested successfully in the Stockholm archipelago and it was also found to be the most ecologically relevant method in a comparison with three other wave exposure methods along the Norwegian coast (FWM, STWAVE, Norsk Standard; Bekkby et al., in prep).

SWM has earlier been used for wave exposure calculations of the entire Swedish, Finnish, and Norwegian coasts. The use of the same method for describing the physical environment facilitates the comparison between all these coasts, and the implementation of common classification systems, such as EUNIS.

METHODS AND MATERIALS

2. METHODS AND MATERIALS

2.1. Land/Sea grids

In order to include large areas in the model, but still deliver high-resolution grids, the SWM uses a nested-grids technique that couples grids of different resolution. In this case a coarse grid (500 m cellsize) covering the Baltic Proper and neighbouring seas was created to include all land shapes that possibly affect the fetch measured from the Polish coast (green rectangle in **Figure 1**). The 500 m grid supported seven finer grids (100 m cellsize) with input fetch values (blue rectangles in **Figure 1**). Each 100 m grid was large enough to include a final grid (25 m cellsize) together with surrounding coastline features of importance for the fetch calculations (red rectangles in **Figure 1**). The extent of the 25 m grids was set to fulfil the following criteria:

1. Include coastline features that affect the fetch locally.
2. Together cover the national coastline with an overlap between each grid pair.
3. Be of a manageable size, set by computation capacity.

Figure 2 shows the 25 m grids, named 1-7, together with the locations of the utilized wind stations (see Section 2.3).

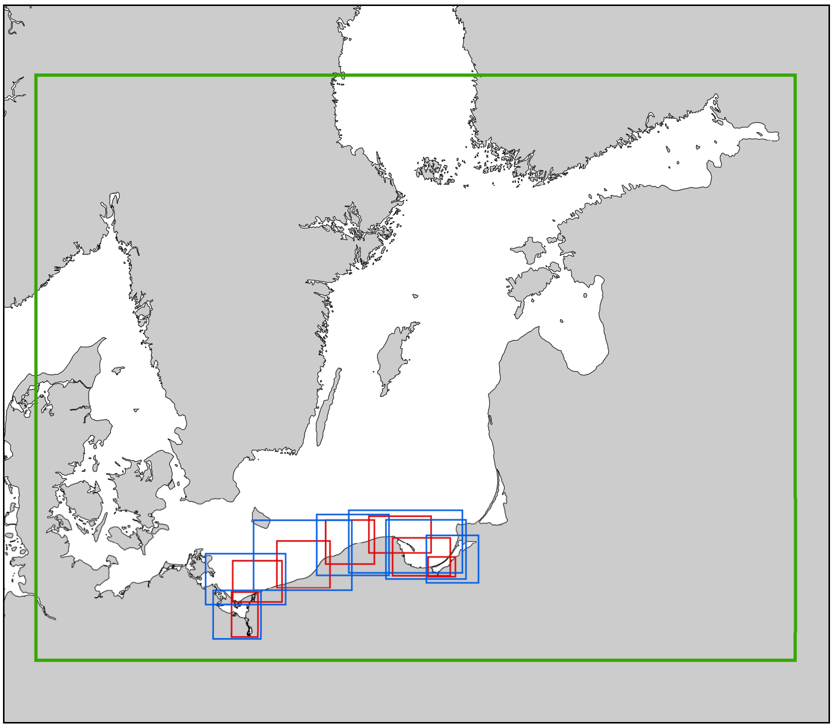

Figure 1. *The extent of the grids used for the nested wave exposure calculations. The green rectangle shows the grid with 500 m resolution, the blue rectangles show the 100 m grids, and the red rectangles the 25 m grids.*

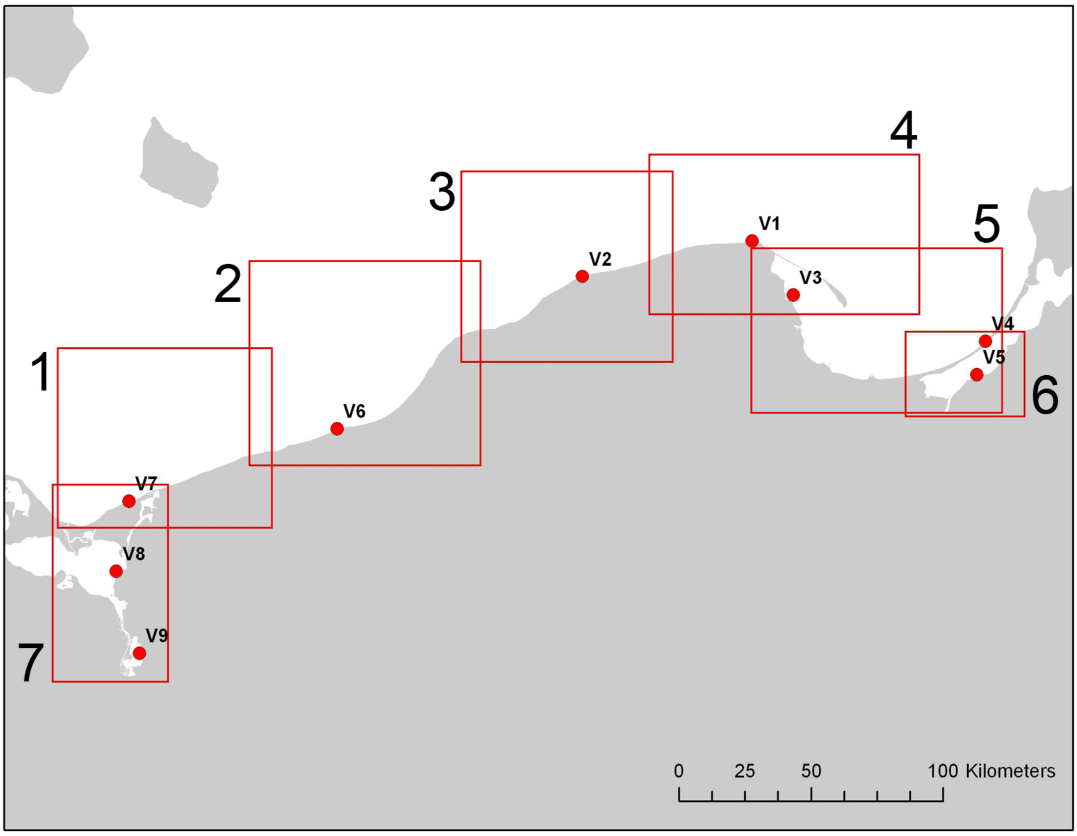

Figure 2. *The location of the utilized wind stations (marked by red dots and their names), and the extent of the land/sea grids with a grid resolution of 25 m.*

The land/sea grids were constructed from the coastline map *admin.shp* which is provided with the ESRI software.

The map projection for the project was the Transverse Mercator projection *WGS1984 UTM_Zone33N*.

However, the end product is also available in the national Gauss-Kruger map projection *PUWG 1992*.

2.2. Fetch calculations

The wave exposure estimates were computed in a geographic information system (GIS) with the software WaveImpact 1.0, which has been particularly developed for this purpose. Grids with only two classes, *Land* and *Sea*, were used for the calculations. WaveImpact uses ASCII grids (text files) of the format that can be exported and imported into the GIS softwares ArcView and ArcMap.

The wave exposure values are based on fetch, i.e. the distance of open water over which the wind can act upon the sea surface and waves can develop. The fetch is calculated for every sea grid cell of the map. Basically, this is done by starting at the map edge of the incident –wind direction and increasing the grid cell values by the size of one cell (in meters) for each sea grid cell in the propagation direction, until land is reached (**Figure 3a**). The procedure starts over again from zero if there are more sea cells on the other side of the land cells.

An advantage of using such a grid solution is that the values of adjacent cells can be used as input data, which facilitates the simulation of the patterns of refraction and diffraction. Instead of adding the cell size to the source-cell value straight behind, the cells behind-to-the-right and behind-to-the-left were used. The procedure is illustrated by an example for a southerly wind in **Figure 3b-c**.

The formula used for calculating a southerly wind/wave direction, when no land pixels obstructed (**Figure 3b**), was:

Formula 1.
OutputMatris(i, J) =
OutputMatris(i + 1, J - 1) * (0.5 - Ref)
+ OutputMatris(i + 1, J + 1) * (0.5 - Ref)
+ OutputMatris(i + 1, J - 2) * Ref
+ OutputMatris(i + 1, J + 2) * Ref
+ Cellsize,

where *OutputMatris(i, J)* is the current cell position in the grid, *i* is increased downwards (southwards) in the grid relative to the current position, *J* is increased to the right (eastwards) in the same way, *Ref* is the calibration value of the refraction/diffraction effect (set to 0.35), and *Cellsize* is the cell size in meters.

In the case when the adjacent grid cell on the left (western) side of the current grid cell was *Land* only cell values from behind and from behind-to-the-right were used (**c**):

Formula 2.
OutputMatris(i, J) =
OutputMatris(i + 1, J) * (0.5 - Ref)
+ OutputMatris(i + 1, J + 1) * (0.5 + Ref)
+ Cellsize.

Corresponding formulas were used for land obstacles to the right (east), and for all sixteen wind directions (see Section 2.3 below).

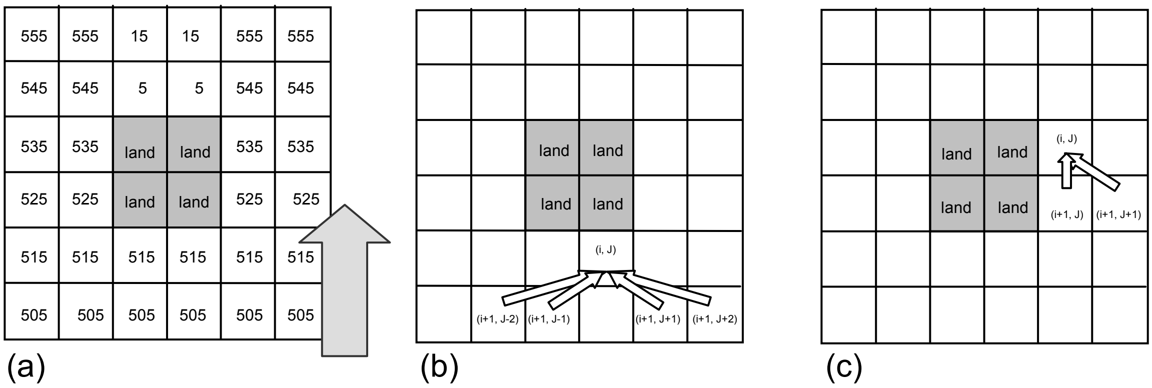

Figure 3. *Examples illustrating the calculation of the fetch values in a land/sea grid, for a southerly wind. a) The basic principle of increasing the fetch values by adding one cellsize (here 10 m) for each new cell. b) Values from the cells adjacent to the source cell are used instead of the source cell itself, in order to simulate refraction/diffraction patterns. c) Calculations when an island limits the use of values from all adjacent cells.*

This method results in a pattern where the fetch values are smoothed out to the sides, and around island and skerries in a similar way that refraction and diffraction make waves deflect around islands. Aerial photographs of wave crests deflected around islands were used to coarsely calibrate the simulation of refraction/diffraction during the construction of the method.

The fetch values were calculated for each 25-m grid with input from the coarser grids in the nested procedure described above (see Section 2.1).

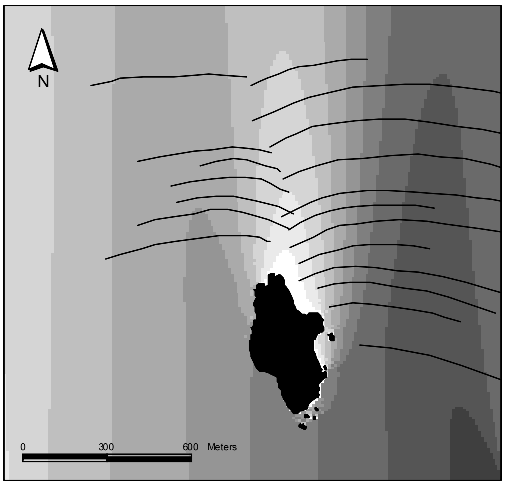

Figure 4. *Aerial photographs of wave crests (black lines) were used to calibrate the refraction/diffraction simulation during construction of SWM.*

2.3. Wind Data

The used wind data were retrieved from the British Unified Model - Polish version, UMPL, which runs for Central Europe and the Baltic Sea by the Interdisciplinary Centre for Mathematical and Computational Modelling, Warsaw University. The horizontal resolution of the model is nine nautical miles.

Archived hourly wind data were extracted for the five-year period between September 1, 2002 and August 31, 2007. A total of nine locations (**Table 1**) were used since a couple of the wave-exposure grids are associated with more than one wind station (see **Figure 2**).

For the calculations, the wind data were divided in sixteen compass directions (N, NNE, NE, ENE etc.), each representing an angular sector of 22.5°. For each sector the mean of all available wind-velocity measurements was calculated for further use in the exposure calculations.

Table 1. *The locations from which modelled wind data were extracted, and the numbers of the associated land/sea grid. The wind was measured at 10 m height at all locations.*

Station Name	Latitude (dg, WGS84)	Longitude (dg, WGS84)	Grid No
V1	54.8362	18.2934	4
V2	54.7379	17.2869	3
V3	54.6447	18.5179	5
V4	54.4504	19.6231	5, 6
V5	54.3382	19.5599	6
V6	54.2385	15.8348	2
V7	53.9949	14.6271	1, 7
V8	53.7554	14.5579	7
V9	53.4768	14.6923	7

2.4. Wave exposure calculations

For each wind direction sector the value of each cell in the corresponding fetch grid was multiplied by the mean wind speed. In this case this resulted in sixteen new grids. The mean value of all grids was calculated in an overlay analysis, which can be summarized by the formula:

Formula 3.

$$E_{SWM} = \frac{\sum_{i=1}^{16}(F_i * W_i)}{16},$$

where E_{SWM} is the wave exposure value, F_i is the adjusted fetch value for the direction i, and W_i is the mean wind speed in direction i.

This was repeated for each one of the seven sub-regions along the Polish coast (the red rectangles in **Figure 2**).

RESULTS AND DISCUSSION

3. RESULTS AND DISCUSSION

Since the separate wave exposure grids are calculated from different wind data, it leads to somewhat different wave exposure values in areas where the grids overlap. To avoid two different wave exposure values in cells of overlapping grids, and to level out the discrepancies between adjacent grids, the grids were merged using the script SpatialGridMosaic (ESRI 1998). This script creates a seamless grid and smooth transition in overlapping areas. The merged grid was then clipped again into seven separate grids to get grids of manageable sizes.

For grid 5, the wind regime was expected to be different between the west, central and east parts, and therefore the results from three separate wave exposure runs were combined. The wind station V3 was used for the western part, station V4 for the central part and station V5 for the eastern part, respectively, as shown in **Figure 5**.

For grid 6, the wind regime was expected to be different between the northwest and southeast parts and, in an analogous manner as above, the results from two separate wave-exposure runs were combined. The wind station V4 was used for the north-western part and station V5 for the south-eastern part (see **Figure 6**).

For grid 7, the wind regime was expected to be different between the north, central and south parts, and the wave exposure from three separate model runs were combined; wind station V7 was used for the northern part, station V8 for the central part and station V9 for the southern part (**Figure 7**).

An overview of all wave exposure grids along the Polish coast is shown in **Figure 8**. The colours indicate preliminary EUNIS classes according to the legend. The five separate grids, as shown in Appendix, were delivered digitally to NIVA.

Figure 5. *The resulting wave exposure of grid 5 is the merged outcome from three separate runs in which different wind stations (V3-V5) were used.*

Figure 6. *The resulting wave exposure of grid 6 is a combination between two separate runs using the wind stations V4 and V5, respectively.*

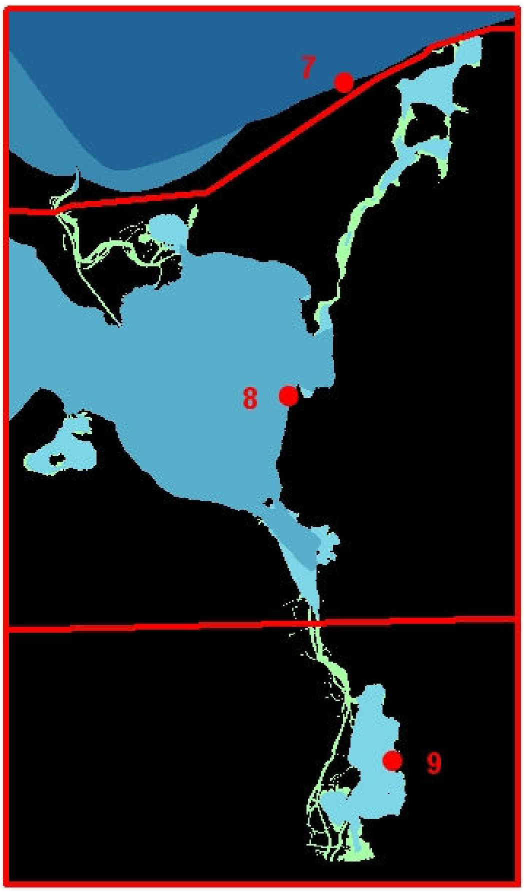

Figure 7. *The resulting wave exposure of grid 7 is a combination between three separate runs using the wind stations V7-V9, respectively.*

The gridcell resolution of 25 m was a compromise between the need for high resolution and manageable amounts of data. However, in a study by the Swedish Board of Fisheries on the effects of scale on wave exposure values calculated with the same method as in this study (WaveImpact, method SWM) it was concluded that the results for a 25 m resolution differed only little from those of finer resolution, but 50 m and coarser differed significantly (Göran Sundblad, pers. comm.). The 25 m resolution was therefore considered to be an acceptable compromise even though studies of the narrowest bays might benefit from a higher resolution.

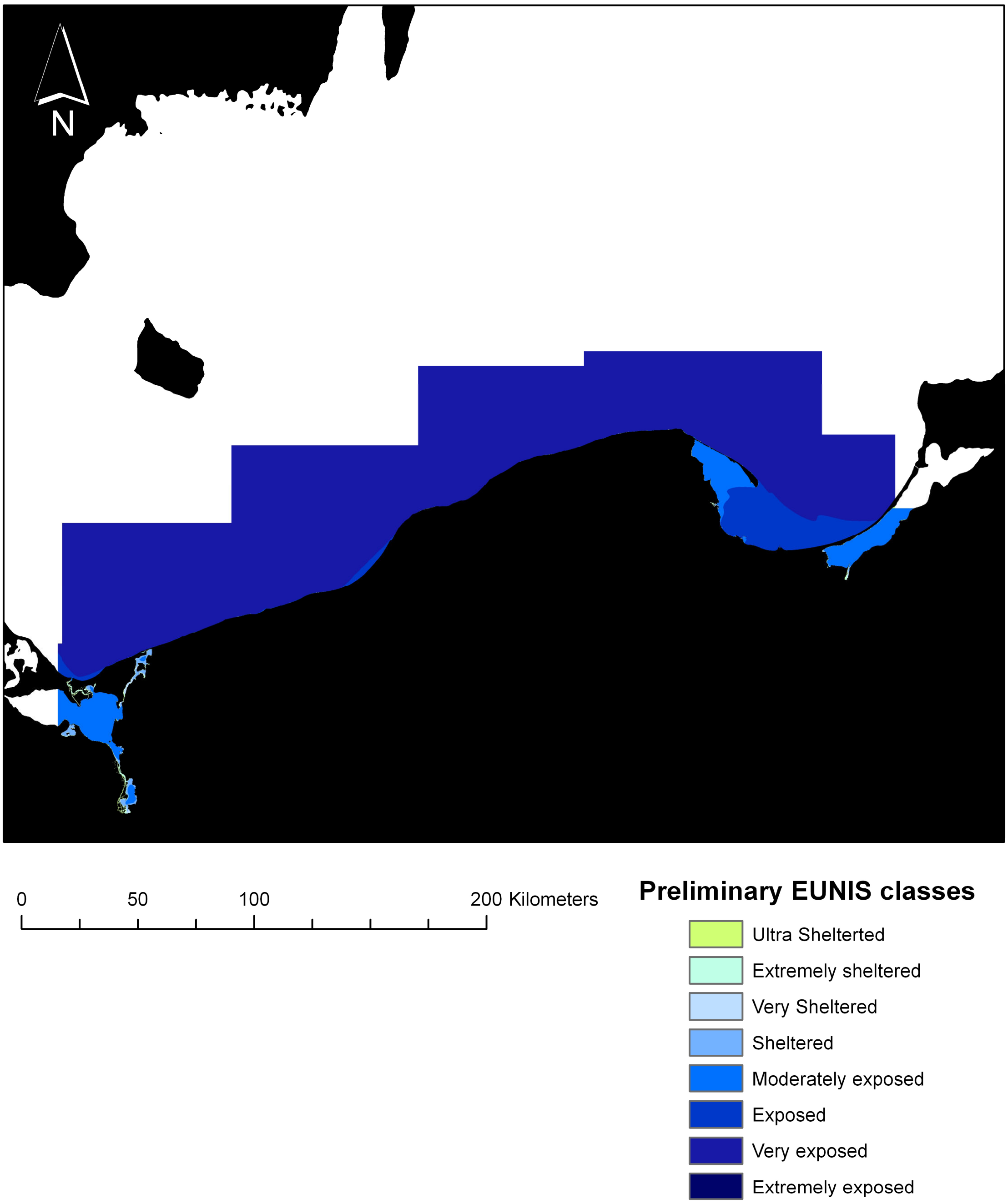

Figure 8. *An overview showing a mosaic of the calculated seven wave-exposure grids.along the coast of Poland. The colors indicate preliminary EUNIS classes according to the legend. Each grid is shown separately in Appendix.*

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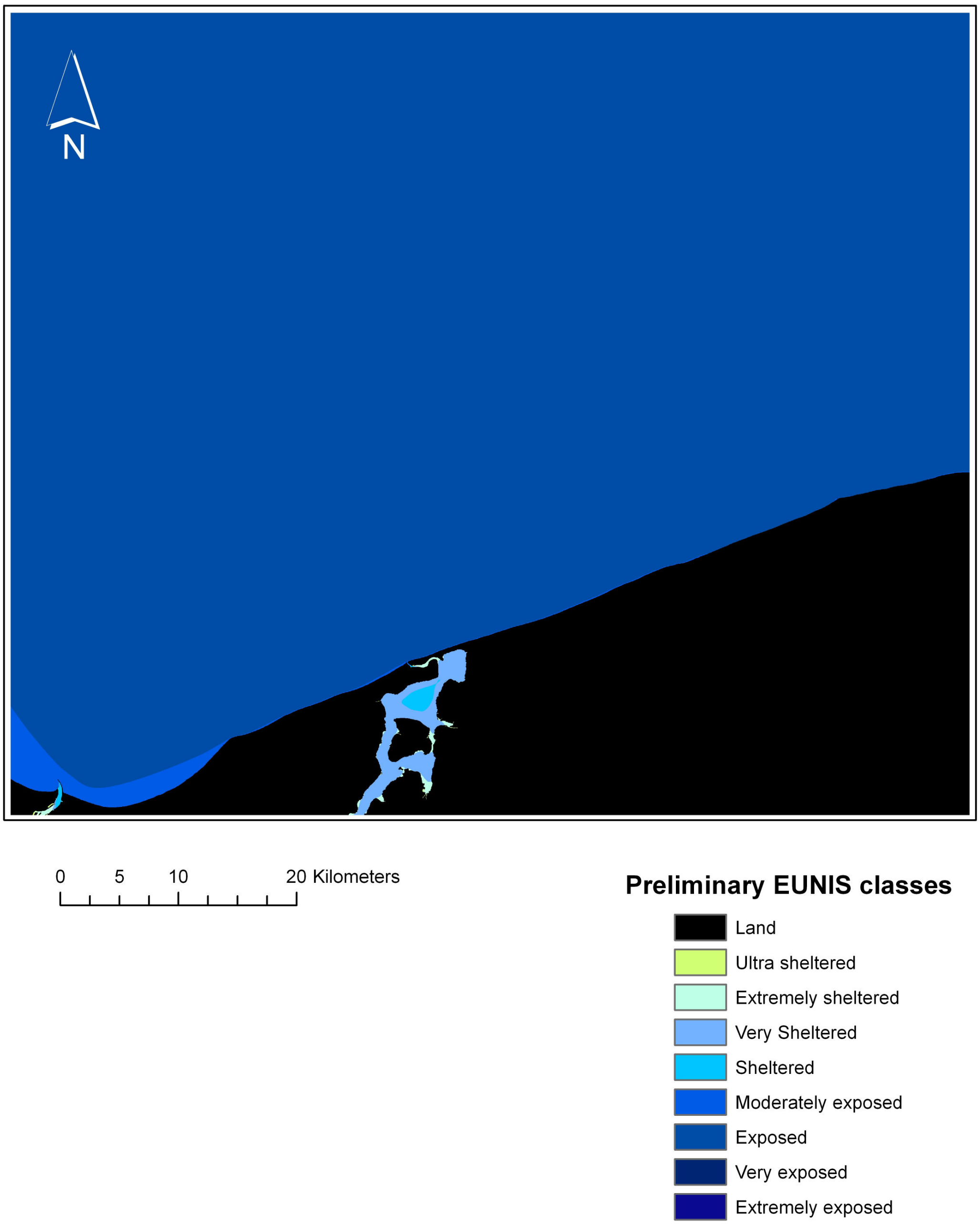
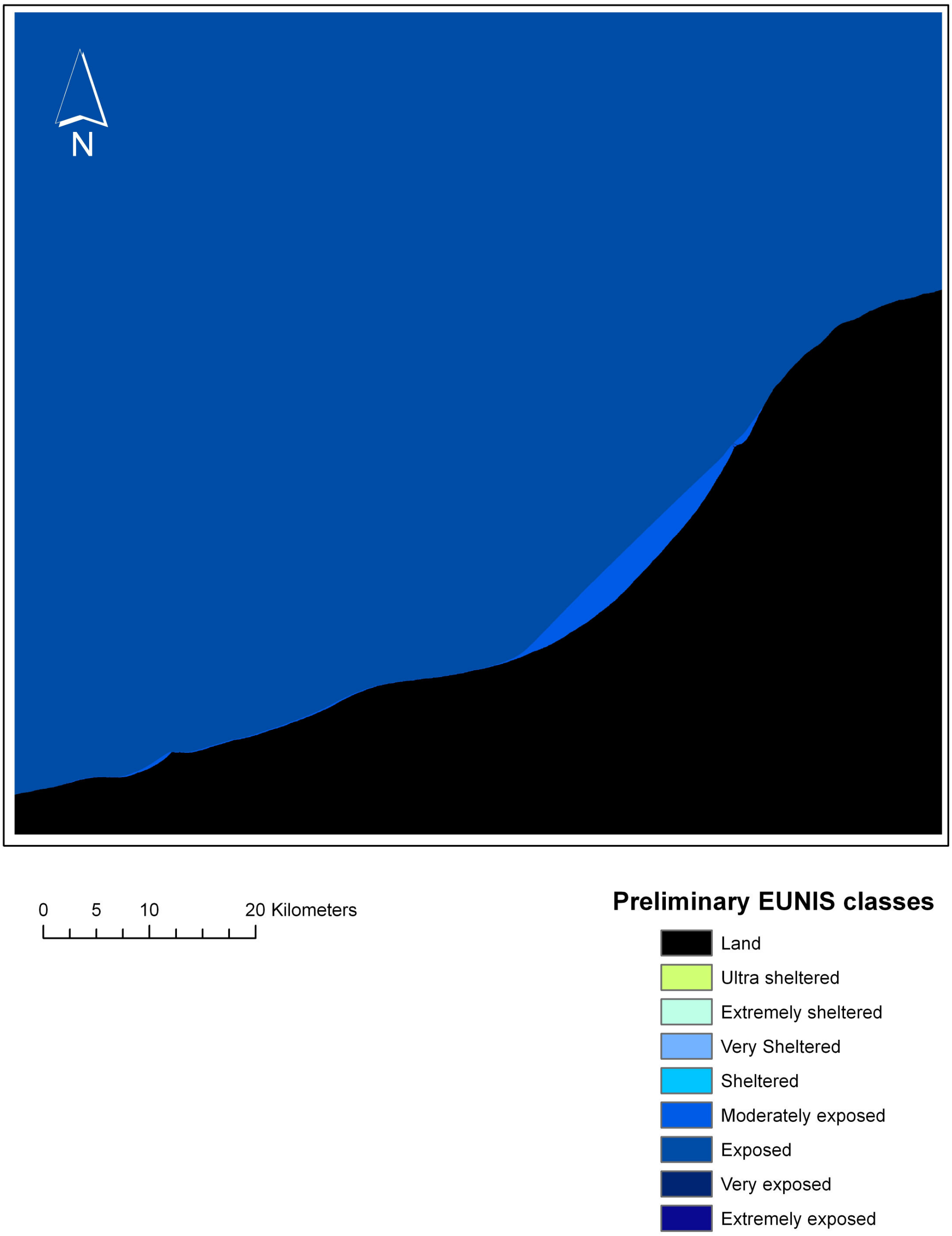
APPENDIX

APPENDIX: WAVE EXPOSURE GRIDS 1-7

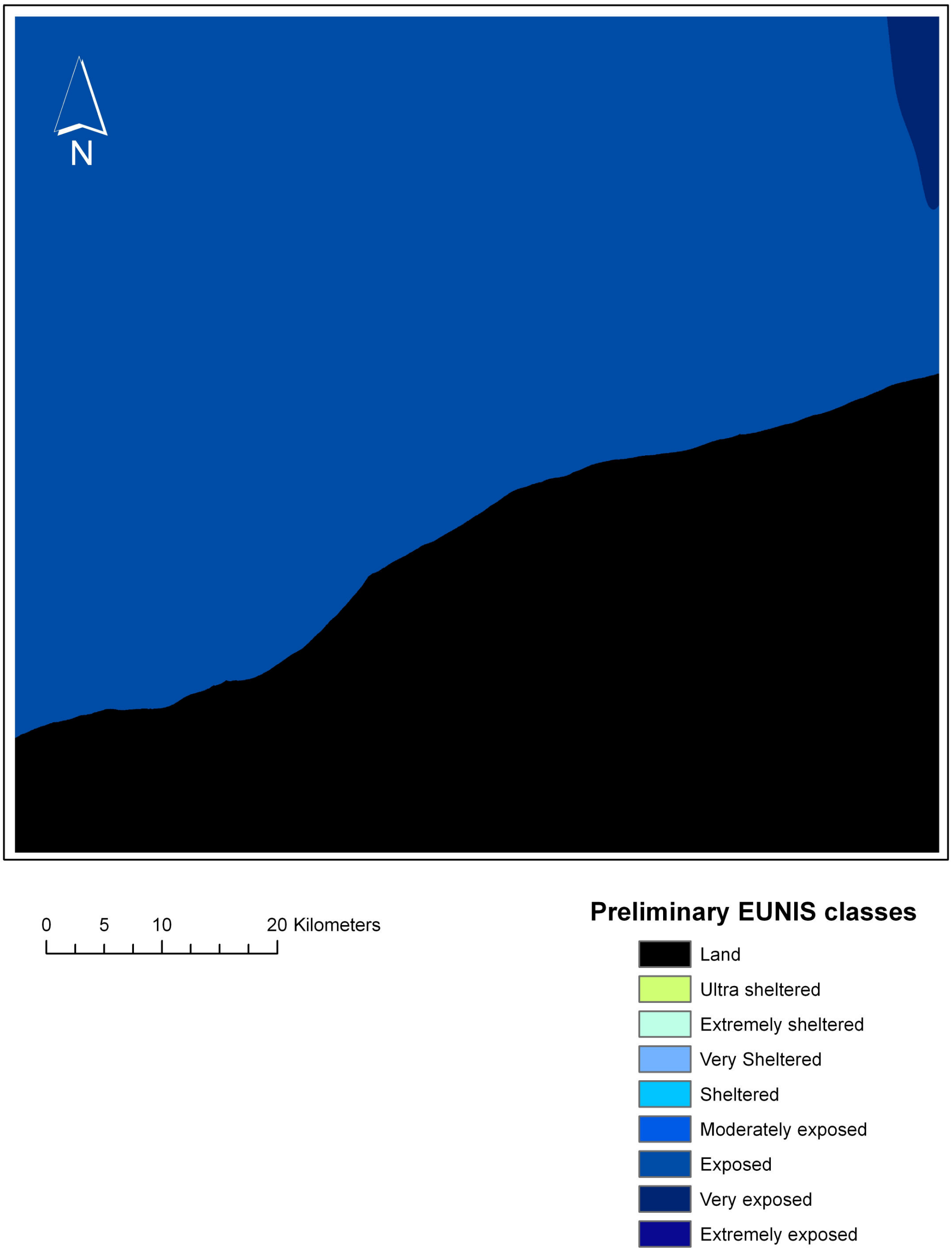
SWM 1



SWM 2


N
0 5 10 20 Kilometers
Preliminary EUNIS classes
Land
Ultra sheltered
Extremely sheltered
Very Sheltered
Sheltered
Moderately exposed
Exposed
Very exposed
Extremely exposed

SWM 3


N
0 5 10 20 Kilometers
Preliminary EUNIS classes
Land
Ultra sheltered
Extremely sheltered
Very Sheltered
Sheltered
Moderately exposed
Exposed
Very exposed
Extremely exposed

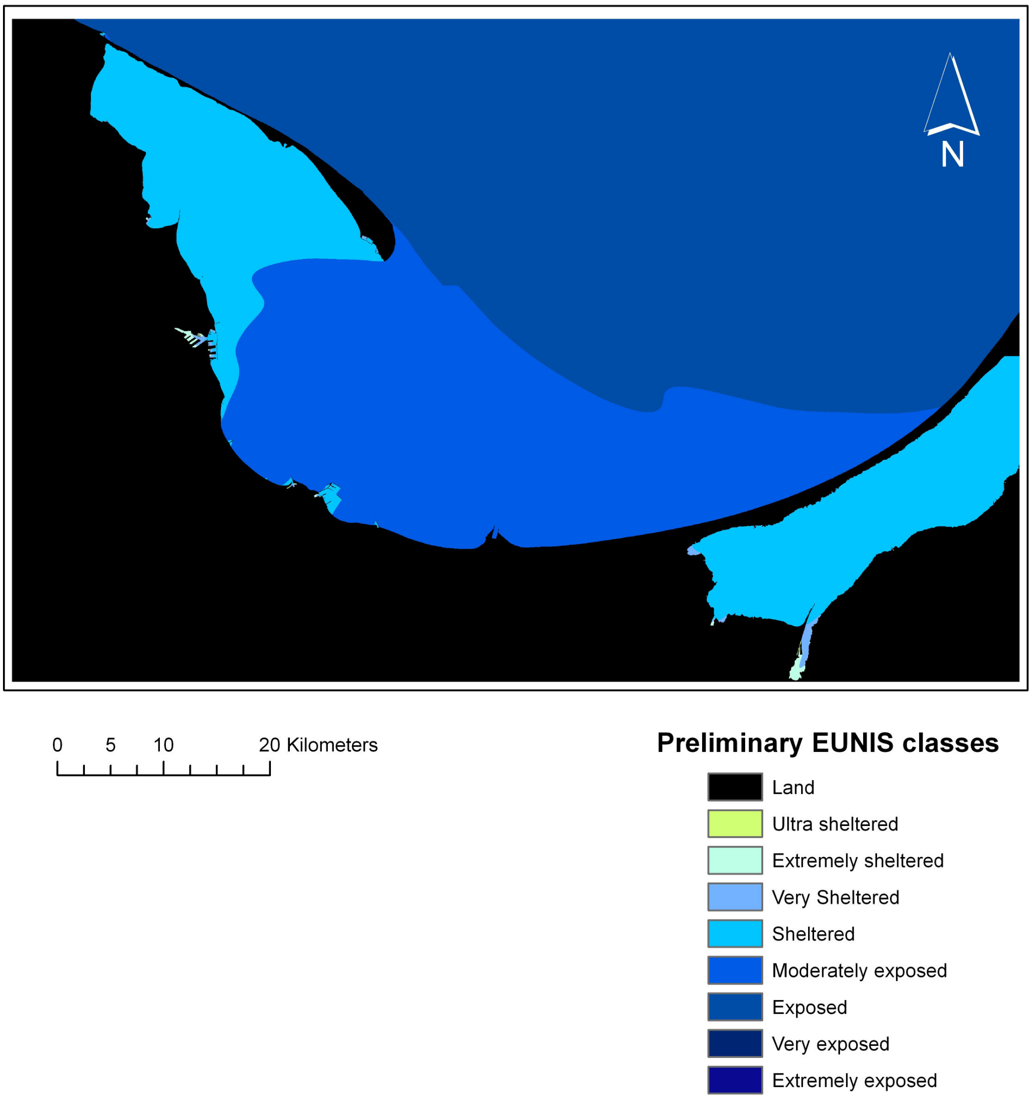
SWM 4

0 5 10 20 Kilometers

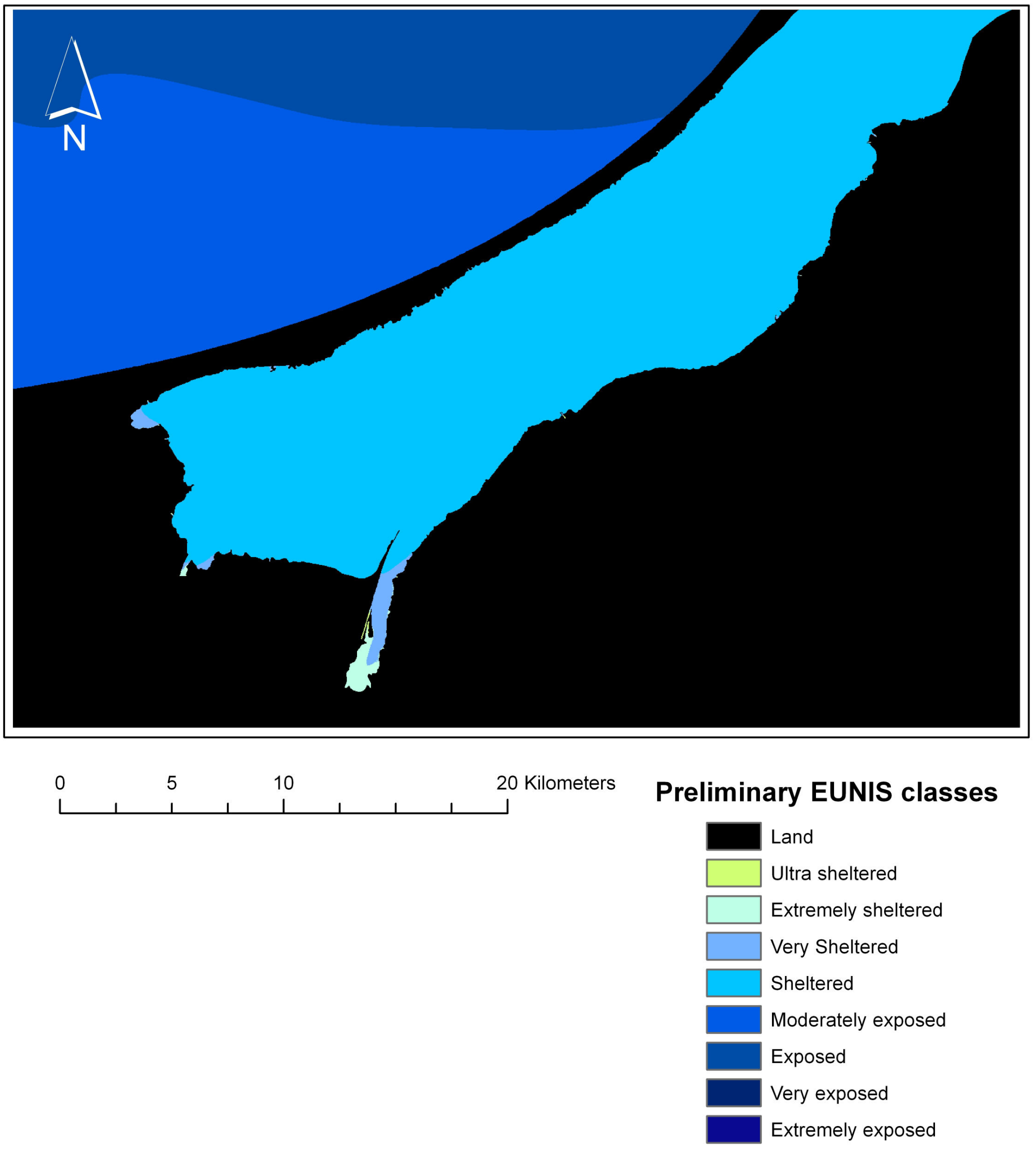
Preliminary EUNIS classes

- Land
- Ultra sheltered
- Extremely sheltered
- Very Sheltered
- Sheltered
- Moderately exposed
- Exposed
- Very exposed
- Extremely exposed

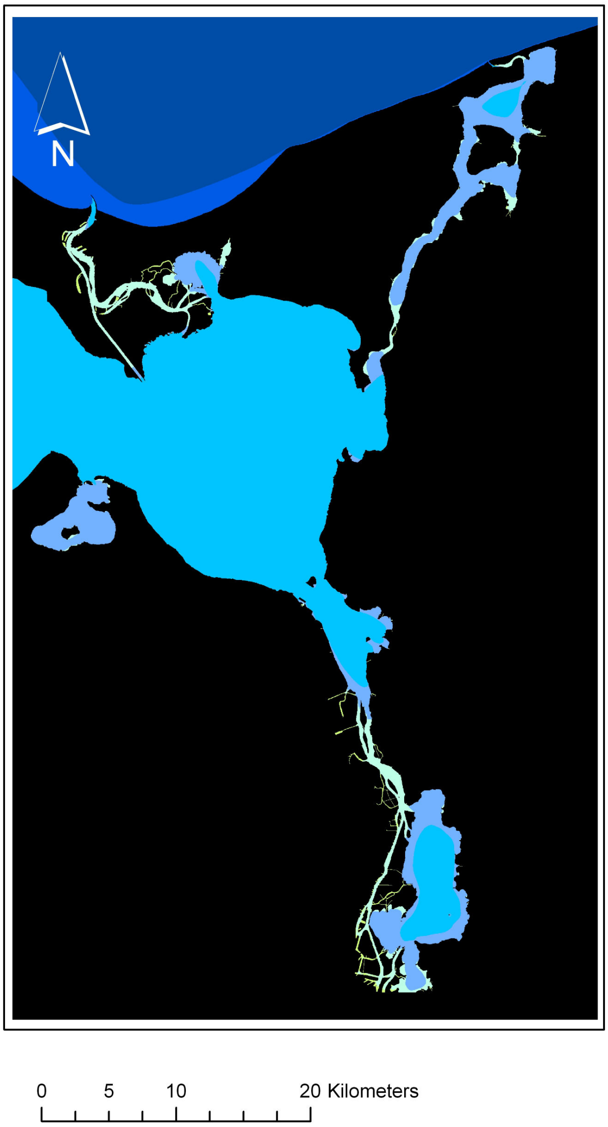
SWM 5


N
0 5 10 20 Kilometers
Preliminary EUNIS classes
Land
Ultra sheltered
Extremely sheltered
Very Sheltered
Sheltered
Moderately exposed
Exposed
Very exposed
Extremely exposed

SWM 6


N
0
5
10
20 Kilometers
Preliminary EUNIS classes
Land
Ultra sheltered
Extremely sheltered
Very Sheltered
Sheltered
Moderately exposed
Exposed
Very exposed
Extremely exposed

SWM 7



Preliminary EUNIS classes

- Land
- Ultra sheltered
- Extremely sheltered
- Very Sheltered
- Sheltered
- Moderately exposed
- Exposed
- Very exposed
- Extremely exposed

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