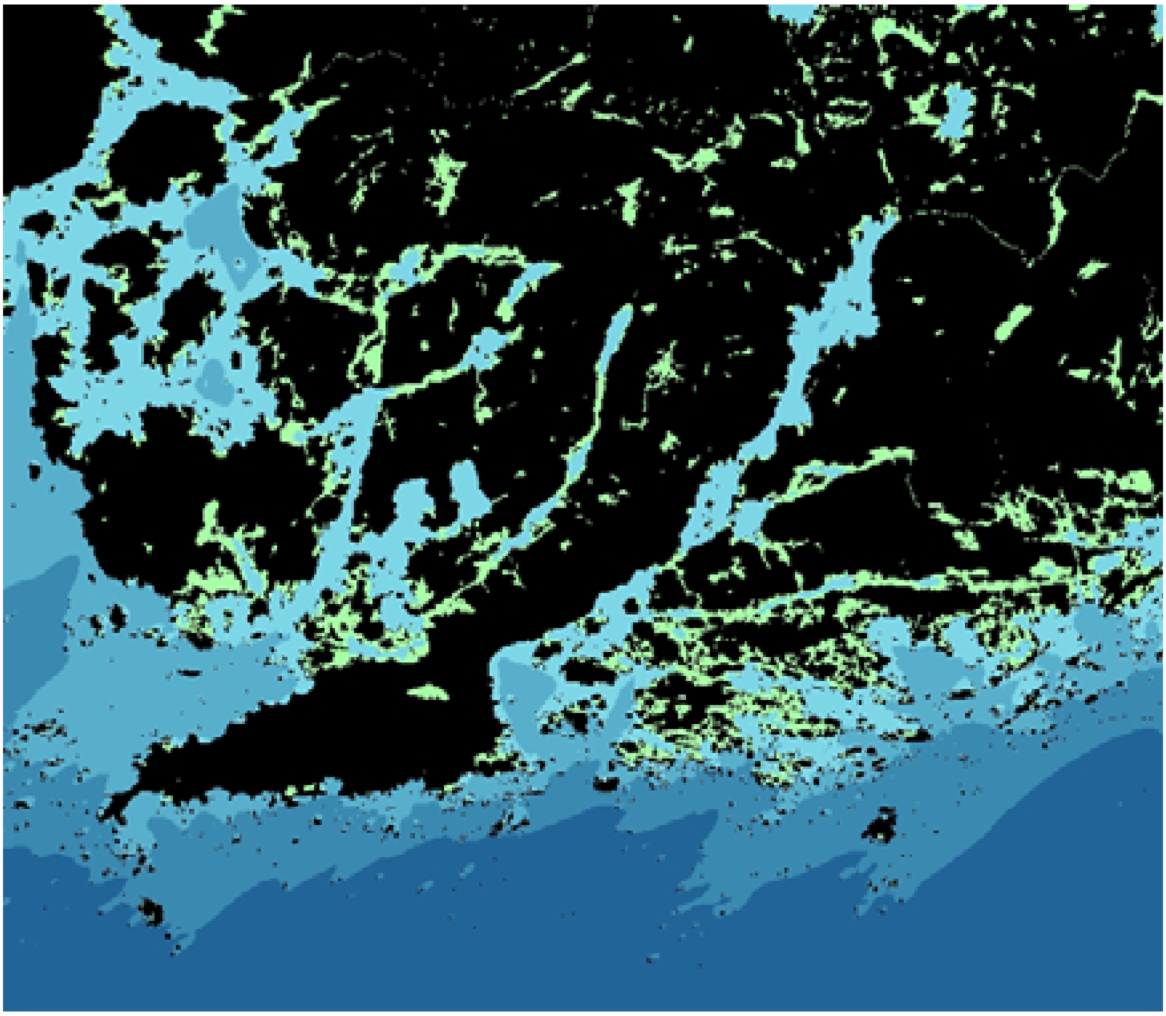
RAPPORT LNR 5075-2005

Wave exposure calculations for the Finnish coast



Norwegian institute of water research

REPORT

Head office	Office South	Office East	Office West	Office Central
Postboks 173, Kjelsås 0411 Oslo Phone (47) 22 18 51 00 Ffax (47) 22 18 52 00 Internet: www.niva.no	Televeien 3 4879 Grimstad Phone (47) 37 29 50 55 Fax (47) 37 04 45 13	Sandvikaveien 41 2312 Ottestad Phone (47) 62 57 64 00 Fax (47) 62 57 66 53	Nordnesboder 5 5005 Bergen Phone (47) 55 30 22 50 Fax (47) 55 30 22 51	Postboks 1264 Pirsenteret 7462 Trondheim Phone (47) 73 87 10 34 / 44 Fax (47) 73 87 10 10

Title	Order number	Date
Wave exposure calculations for the Finnish coast	5075-2005	01.12.2005
	Prosjektnr. Undernr. 25134	Sider Pris 24 0
Authors Martin Isæus Brage Rygg Contact author: martin.isaeus@niva.no	Research field Habitat modelling	Distribution Free
	Geographic area Finland	Print NIVA

Client	Reference
Finnish Environmental Institute, SYKE	Anna-Leena Nöjd

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 Finnish coast using the method SWM (Isæus 2004). 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 includes: evaluation of shoreline source map, division of shoreline into suitable calculation areas, converting shape features into grids, recalculation of wind data, calculation of fetch adjusted for refraction/diffraction effects, calculation of wave exposure grids, and merging the separate grids into a seamless description of wave exposure along the Finnish coast. The digital version of the grids was delivered to SYKE June 16 2005, and a printed version is found in Appendix 1.

Norwegian key words		English key words	
1.	Bøljeexponering	1.	Wave exposure
2.	Habitatmodellering	2.	Habitat modelling
3.	GIS	3.	GIS
4.	Kystplanering	4.	Coastal management

Martin Isæus
Project manager

Mats Walday
Dep. reserarch manager

Øyvind Sørensen
Project director

ISBN 82-577-4780-7

Wave exposure calculations for the Finnish coast

Performed by NIVA at the request of
Finnish Environment Institute, SYKE

Preface

Habitat modelling has become an important task for management of coastal areas, driven both by national initiatives and EU. Wave exposure is one of the major factors that structure the littoral environment and is therefore an important input layer in such GIS models. The aim of this project was to produce wave exposure grids useful for habitat modelling along the Finnish coast. The grids are also useful for scientific activities such as marine biological studies on the coastal and communities.

Oslo, 22.10.2005

Martin Isæus
Project leader

Content

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 Finnish coast using the method SWM (Isæus 2004). 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 includes: evaluation of shoreline source map, division of shoreline into suitable calculation areas, converting shape features into grids, recalculation of wind data, calculation of fetch adjusted for refraction/diffraction effects, calculation of wave exposure grids, and merging the separate grids into a seamless description of wave exposure along the Finnish coast. The digital version of the grids was delivered to SYKE June 16 2005, and a printed version is found in Appendix 1.

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 Finnish coast.

1.1 The Simplified Wave Model (SWM)

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 is often poor, or restricted, and is therefore usually not available for larger areas such as a state coastline. The method has been tested successfully in Stockholm archipelago, which resembles Finnish archipelagos. SWM has also been compared to three other methods (FWM, STWAVE, Norsk Standard) and was found to be most ecologically relevant (Bekkby in prep.).
SWM has been used for wave exposure calculations of the whole Swedish and Norwegian coasts, and the values should be comparable between the coasts. The extended use of the same method for describing the physical environment facilitates the implementation of common classification systems, such as EUNIS.

2. Methods and materials

2.1 Land/Sea grids

2.1.1 Comparison of shoreline maps

In order to find the most detailed and accurate shoreline for the wave exposure calculations a comparison was made between the three digital maps that were provided by SYKE. Comparisons were made in area 23 (the Vaasa region) by observing details of the shoreline, occurrence of small islands and manmade constructions.

The available map files for area 23 where:

Meri_Ranta20_Sea	one polygon of all sea water in 1:20 000 scale
Ranta_23m	National Land Survey of Finland, separate water polygons 1:20 000
V23,	National Land Survey of Finland Topographic database; Shoreline water polygons 1:5000 – 1:10 000

The Meri_Ranta20_Sea and Ranta_23m had identical shoreline in the area. Then Ranta_23m was excluded since it is more practical to work with one file such as Meri_Ranta20_Sea.

V23 contained much more manmade constructions such as wave breakers and harbour constructions than Meri_Ranta20_Sea. The coastline of V23 was generally more detailed than Meri_Ranta20_Sea but some small islands were missing compared to Meri_Ranta20_Sea, and island were often aggregated in V23 that was drawn separate in Meri_Ranta20_Sea. There were also some islands in Meri_Ranta20_Sea that were not present in V23. The shorelines differ significantly and it was not obvious which one is most accurate even though V23 was more detailed. However, the V23 should be more accurate since it is produced in a finer scale (1:5000 – 1:10 000), and since it also was more detailed and contained more manmade constructions it was chosen for the high resolution grids used in this project (25 and 100 m cellsize, see below for details).

For the overview of the whole Baltic Sea region, a freeware map “admin.shp” delivered together with ESRI software was used. This map file was transformed to Finnish Zone 3 projected coordinate system and used to create the coarse 500 m input grid (see below for detailes).

2.1.2 Division of the coast into calculation areas

In order to include large areas in the model, but still deliver high resolution grids SWM uses a nested-grids technique. In this case a coarse grid (500 m cellsize) covering the whole Baltic Sea was used to support finer grids (100 m cellsize) with input fetch values, and the 100 m grids provides input values for the final 25 m grids. The extent of the 25 m grids was set to fulfil the criteria:

1. together cover the whole coastline with overlap
2. include coastline features that affect the fetch locally
3. a manageable size, set by computation capacity
4. if possible connected to administrative borders.

This resulted in 10 grids (red rectangles in **Figure 1**). The grids were named after the input shoreline files.

Then 10 coarser grids (100 m cell size) were created with an extent large enough to include each 25 m grid together with surrounding coastline features of importance to fetch calculations. These grids were never limited by computation capacity (blue rectangles in **Figure 1**).

The extent of the coarse 500 m grid was set to include all land shapes that possibly could affect the fetch measured form the Finnish coast. Since this grid was not limited by computation capacity it was created to include most of the Baltic Sea (green rectangle in **Figure 1**).

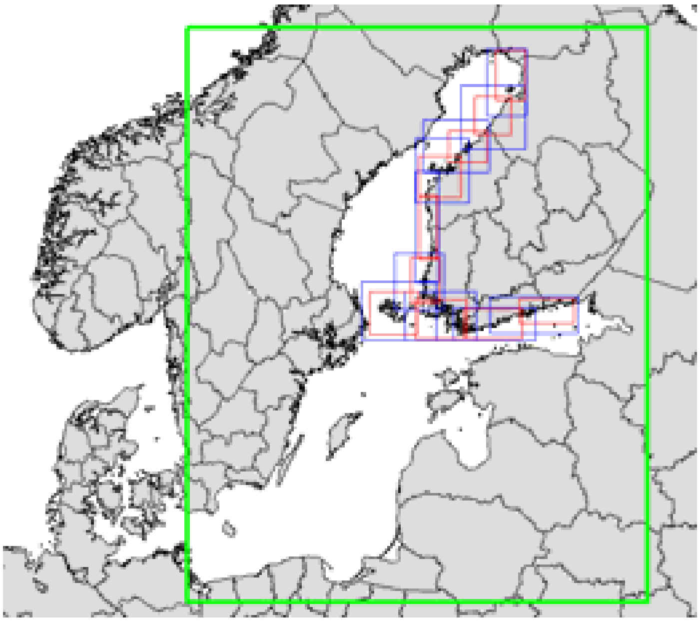


Figure 1. The extent of grids used for nested wave exposure calculations. Green rectangle marks the grid with 500 m resolution, blue rectangles mark 100 m grids, and red rectangles are 25 m grids.

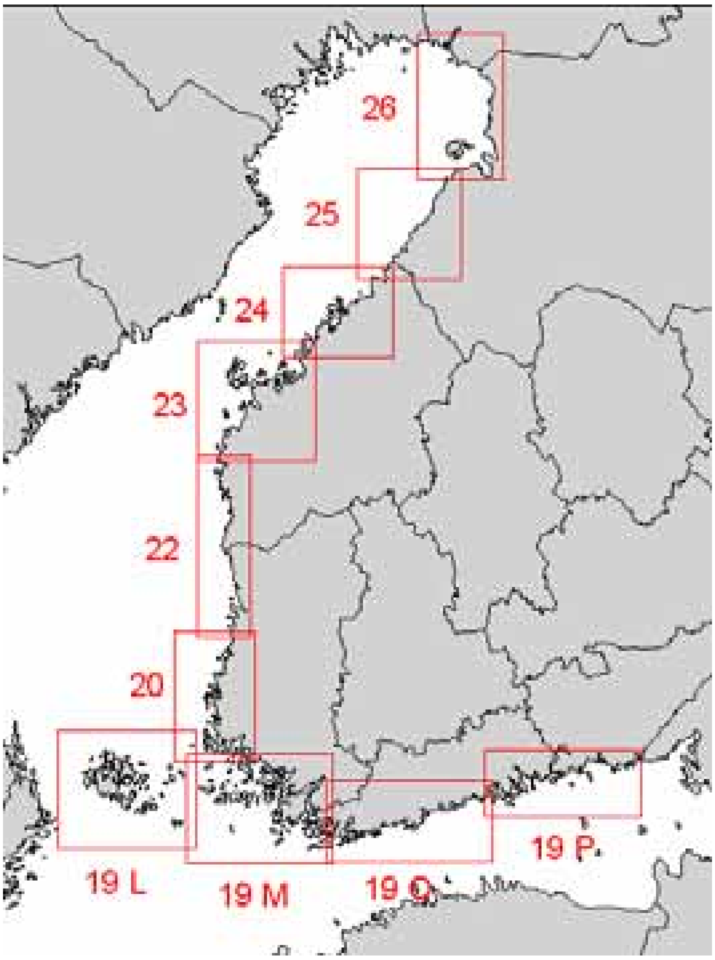


Figure 2. The extent and names of the resulting wave exposure grids. The grids resolution is 25 m.

2.2 Wind data

Wind stations
For each 25 m grid a wind station was chosen (**Table 1**). The criteria for the choice of wind stations were:

1. positioned in the grid area
2. openly located in the outer shore or off-shore area
3. measurements available for a period of at least 10 years.

Table 1. Wind stations with positions, elevation above sea level for wind speed measurments and start date fore measurements, and the grid it is associated with. * The elevation is estimated.

WMO	LPNN	Station name	Lat	Long	Zone3 Y	Zone3 X	Elevation	Start date	Grid
2873	5310	Hailuoto Marjaniemi	6502	2434	7217443	3385366	8.0	1974-12-01	26
5243	5201	Nahkiainen	6436	2354	7170549	3351611	5.8*	1997-09-25	25
2920	4108	Pietarsaari Kallan	6345	2232	7079869	3279612	2.0	1995-09-21	24
5196	3020	Strömmingsbådan	6258	2044	7000330	3182445	2.0	1997-07-10	23
2932	2009	Kristiinankaupunki Karhusaar	6215	2119	6917927	3204906	1.0	1974-01-01	22
5562	1018	Rauma Kylmäpihlaja	6109	2118	6795748	3193298	4.0	1990-06-06	20
2993	14	Märket	6018	1908	6712524	3074870	3.0	1977-11-10	19L (north)
2980	3	Lemland Nyhamn	5958	1958	6671404	3107620	8.0	1958-10-01	19L(south)
2981	2	Korppoo Utö	5947	2123	6643456	3184777	9.0	1881-02-01	19M
5794	331	Kirkkonummi Mäkiluoto	5955	2421	6647911	3351777	2.0	1989-01-01	19O
2992	510	Pernaja Orrengrund	6016	2627	6684067	3469556	5.0	1974-05-01	19P

All wind speed measurements were recalculated to represent the wind speed at 10 m above sea level by using the formula:

Formula 1.

$$U_{10} = U_z \left(\frac{10}{z} \right)^{1/7}$$

Where U_{10} is the wind speed at 10 m above sea level, U_z is the measured wind speed, and z is the elevation above sea level for wind speed measurements (Coastal engineering manual 2003).

The wind data from the Finnish Meteorological institute were given for each 10°. For this project wind data for 16 directions (N, NNE, NE, ENE etc.) were needed, each representing a sector of 22.5°. The mean of all available wind speed measurements from each sector was calculated.

The wind data from adjacent stations were compared to avoid unreasonable large differences. One station (2873_5310 Hailuoto Marjaniemi, grid 26) was situated at the west coast of a large island and therefore sheltered from east, and there were no replacement station available. The mean wind values for easterly winds (NNE, NE, ENE, E, ESE, SE, SSE) were therefore raised by 1.00 m/s.

For grid 19L, Åland, the wind regime was expected to be different at the north side compared to the south side of the archipelago, and therefore station 2993_14 Märket was used for the northern part and 2980_3 Lemland Nyhamn for the southern part (**Figure 3**).

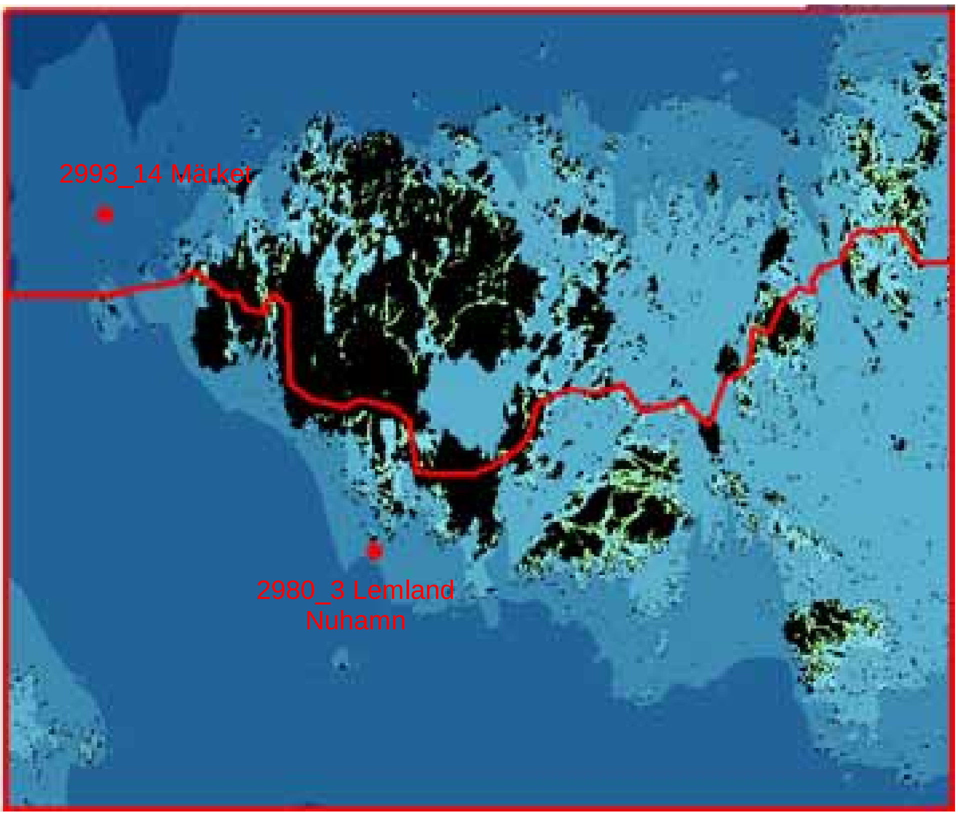


Figure 3. Data from different wind stations were used for the north and south part of area 19L Åland.

2.3 Fetch calculations

The wave exposure estimate was computed in a geographic information system (GIS), and a special software, WaveImpact 1.0, has been 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 software ArcView 3.x and 9.0. The wave exposure values were based on fetch, i.e. the distance of open water at which the wind can act upon the sea and waves can develop. The fetch was calculated for every sea grid cell of the map, in 16 directions, which resulted in 16 maps. Basically this was done by starting at the map edge and increasing the grid cell values by the value of one cell size (in meters) for each sea grid cell in the propagation direction until land was reached, and then starting over again from zero if there were more sea cells on the other side of the land cells (Fig 1a). An advantage of using a grid solution is that the cell values of adjacent cells can be used as input data, which was used for simulating the patterns of refraction and diffraction in this study. This is illustrated by an example for southerly wind (Fig 1b-c). Instead of adding the cell size to the cell value behind (the southern side in this example), the cells behind-to-the-right and behind-to-the-left were used (Formula 1, Fig 1b). When the adjacent grid cell on the left side of the current grid cell was *Land* then only cell values from behind and from behind-to-the-right were used and vice versa (Fig. 1c).

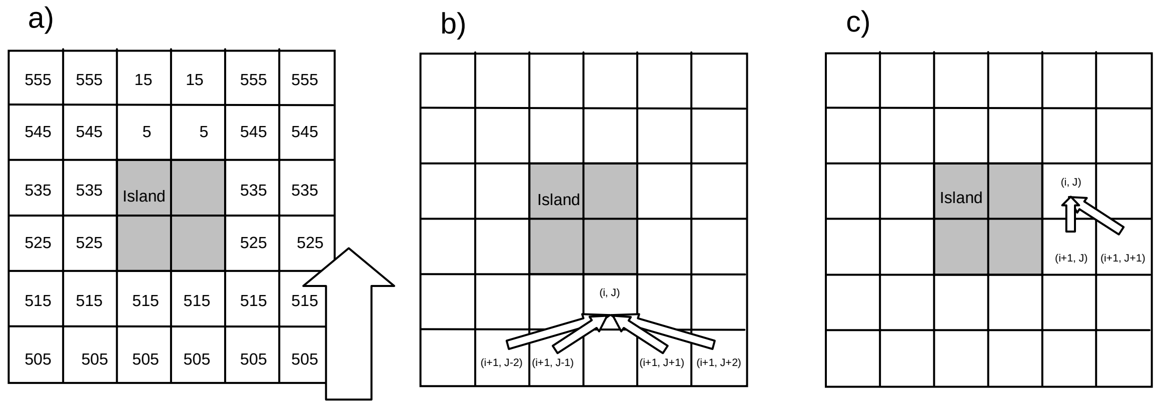


Figure 4. Example of calculation of fetch values, direction from south. a) The basic principle of increasing fetch values by increasing the cell size 10 m. b) Values from adjacent cells to the side of the source cell were used to simulate refraction/diffraction patterns, c) Calculations when an island limited the use of values from adjacent cells.

This method results in a pattern where the fetch values are evened 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 construction of the method,

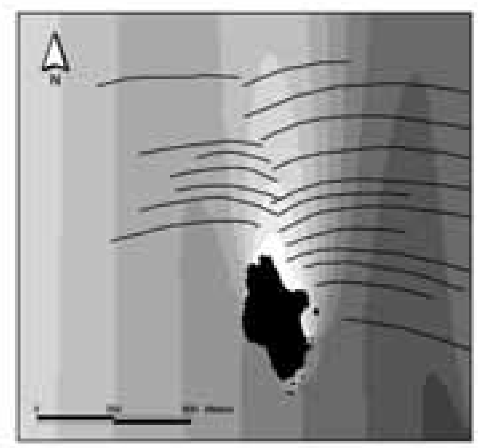


Figure 5. Aerial photographs of wave crests (black lines) were used to calibrate the refraction/diffraction simulation during construction of SWM.

The formula used for calculating a southerly wind/wave direction (corresponding to **Figure 4**), when no land pixels obstructed, was:

Formula 2.
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.

When there was a land pixel on the left (western) side the following formula was used:

Formula 3.
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 16 directions.

2.4 Wave exposure calculations

For each wind direction and corresponding fetch grid the adjusted fetch values of each gridcell was multiplied by the mean wind speed which resulted in 16 new grids. The mean value of all 16 grids was calculated in an overlay analysis. This could be summarized in the formula:

Formula 4.

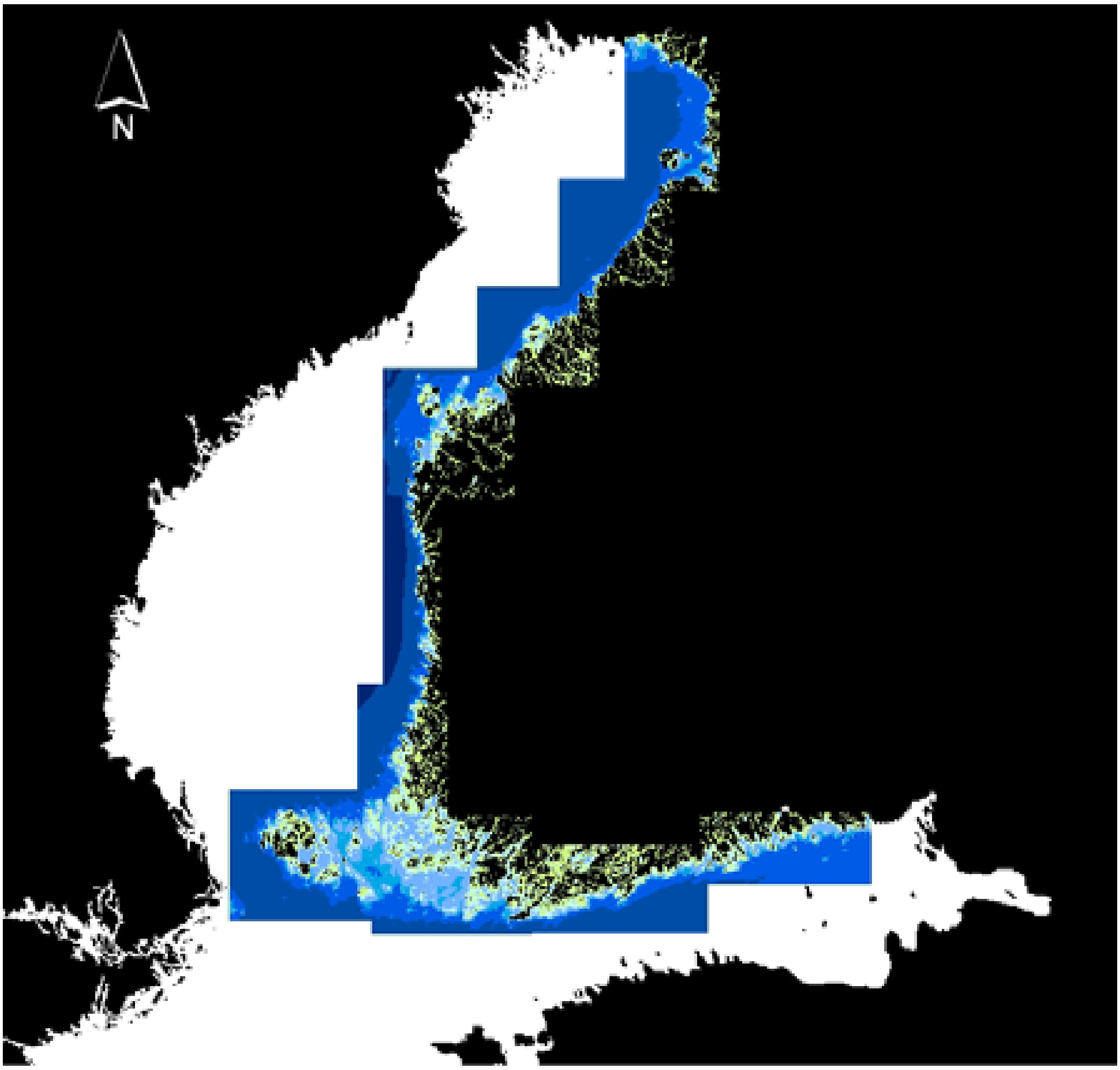
$$E_{SWM} = \frac{\sum_{i=1}^{16} (F_i * W_i)}{16}$$

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

This was repeated for each of the 10 sub areas (red rectangles figure 25 m grids) along the Finnish coast. The quality of the resulting wave exposure grids was controlled by comparing them with adjacent grids and with grids along the Swedish coast.

2.5 Merging wave exposure grids

The separate wave exposure grids are calculated from different wind data, which 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 differences between adjacent grids, the grids were merged and then clipped again. The grids were merged using the script Spatial.GridMosaic (ESRI 1998), which creates a seamless grid and smooth transition in overlapping areas. The merged grid was then clipped into 10 grids again to get grids of manageable sizes. **Figur 6** shows an overview of all wave exposure grids along the Norwegian coast. The colours indicate preliminary EUNIS classes according to the legend. The 10 separate grids are delivered digitally to SYKE, and shown in Appendix 1.



Figur 6. An overview of the Finnish coast showing the resulting 10 wave exposure grids. The colors indicate preliminary EUNIS classes according to the legend

3. Discussion

The resolution 25 m gridcell size was a compromise between the need for high resolution and manageable amounts of data. However, in an recent study by the Swedish National Board of Fishery 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 25 m resolution differed only little from finer resolution, but 50 m and coarser differed significantly (Göran Sundblad, pers. com.). The 25 m resolution seems then to bee an acceptable compromise even though studies of the most narrow bays might need a higher resolution.

4. References

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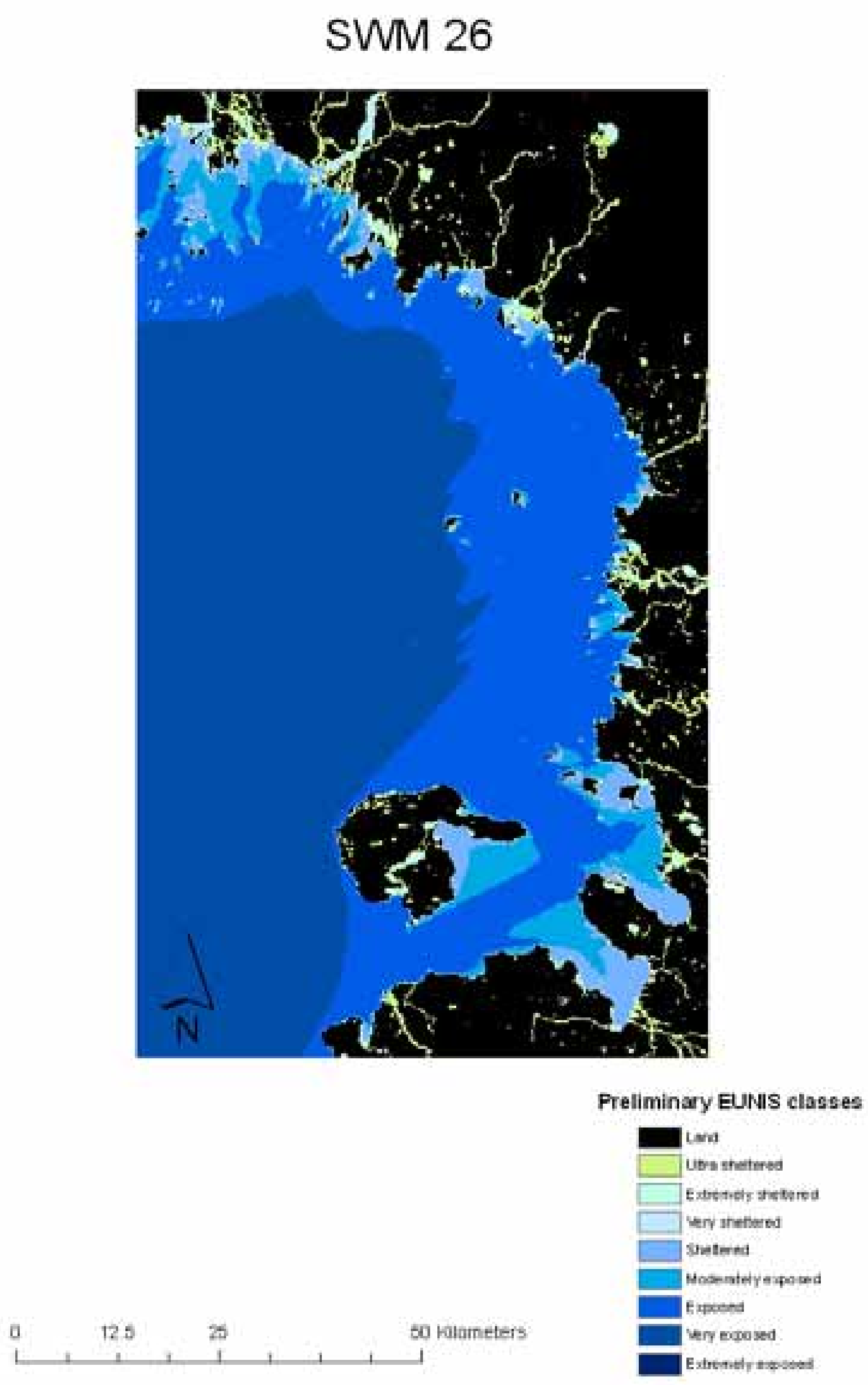
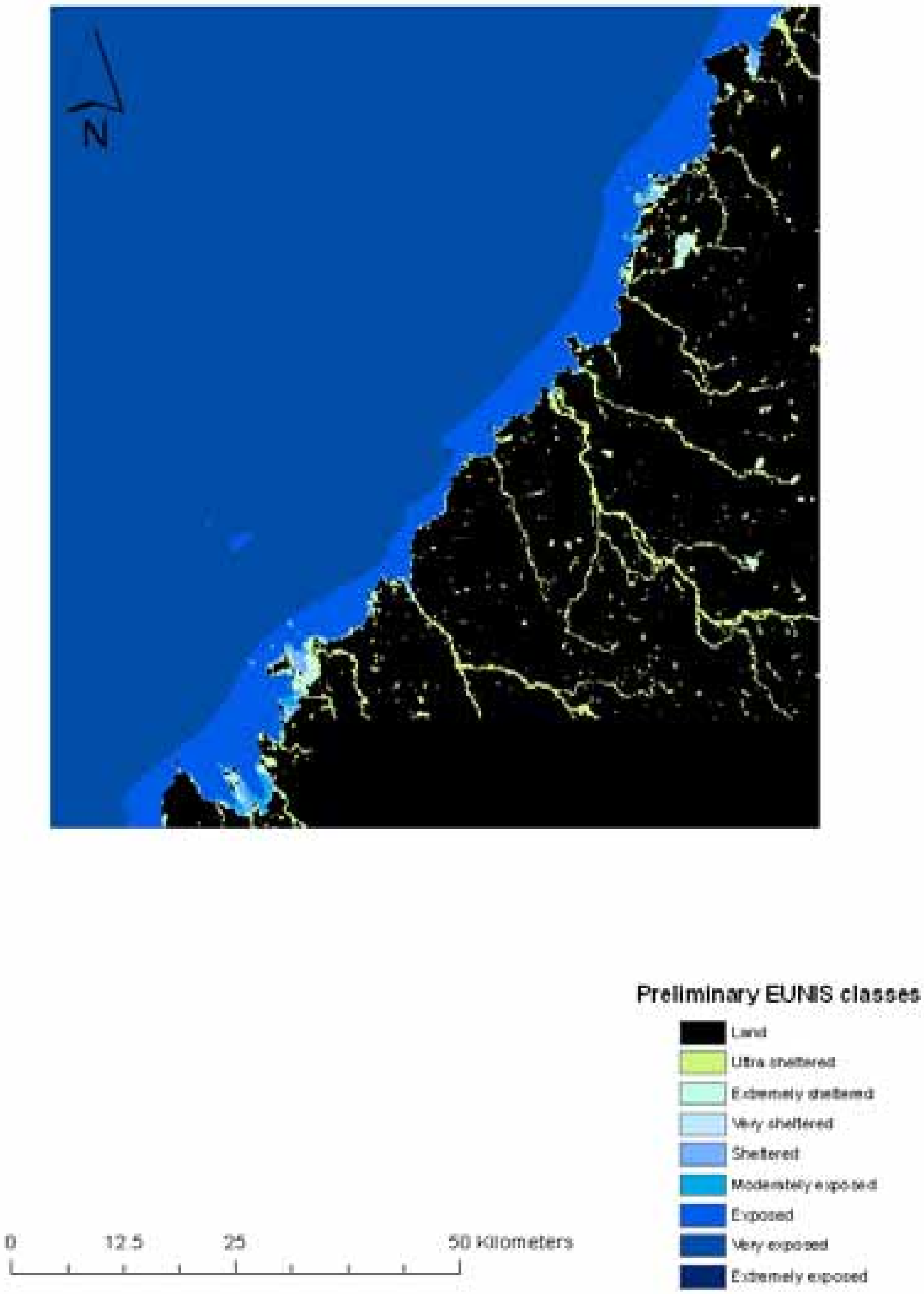
5. Appendix 1. Wave exposure grids



SWM 25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50 Kilometers
Preliminary EUNIS classes
Land
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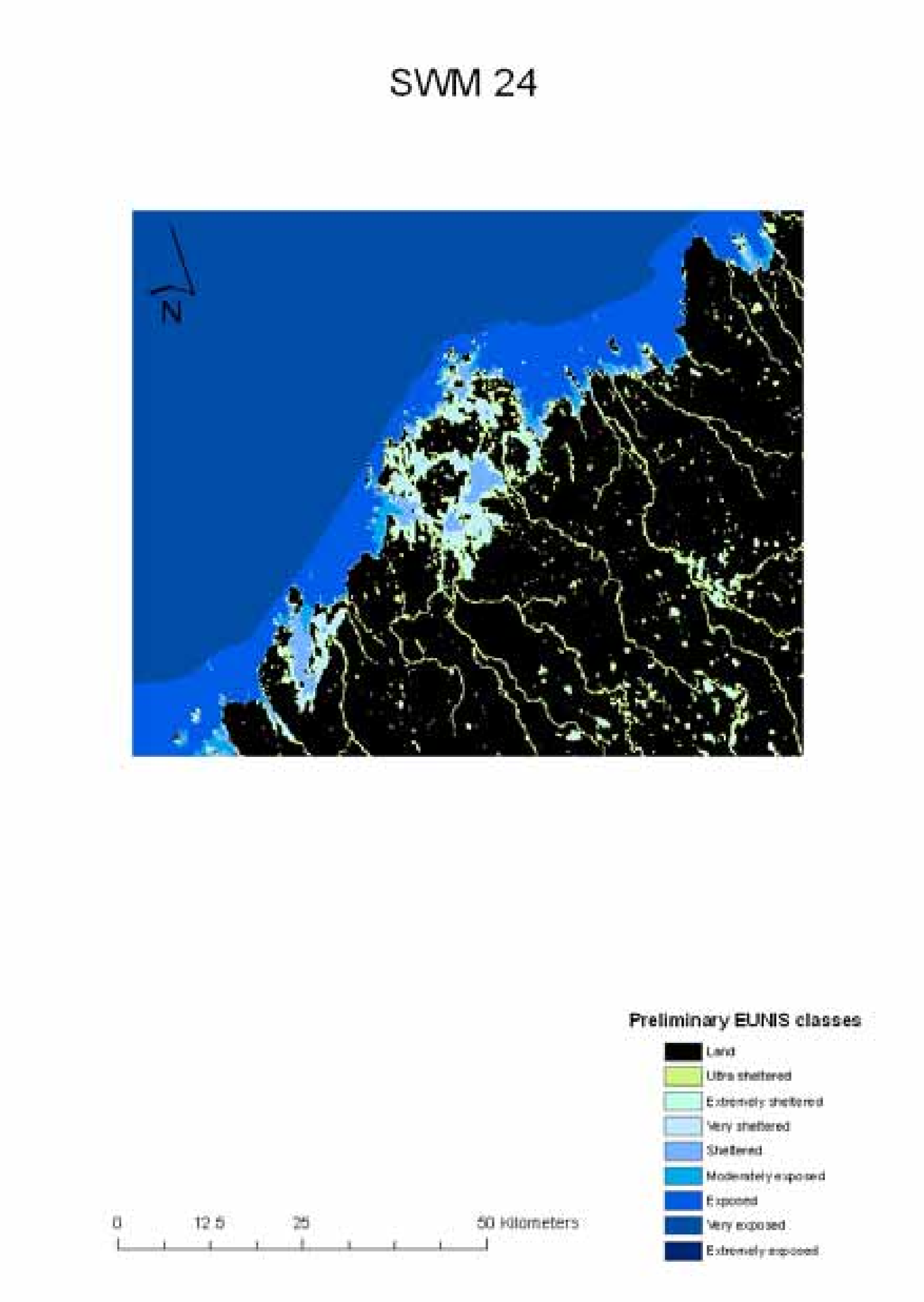
Extremely sheltered
Very sheltered
Sheltered
Moderately exposed
Exposed
Very exposed
Extremely exposed


SWM 24
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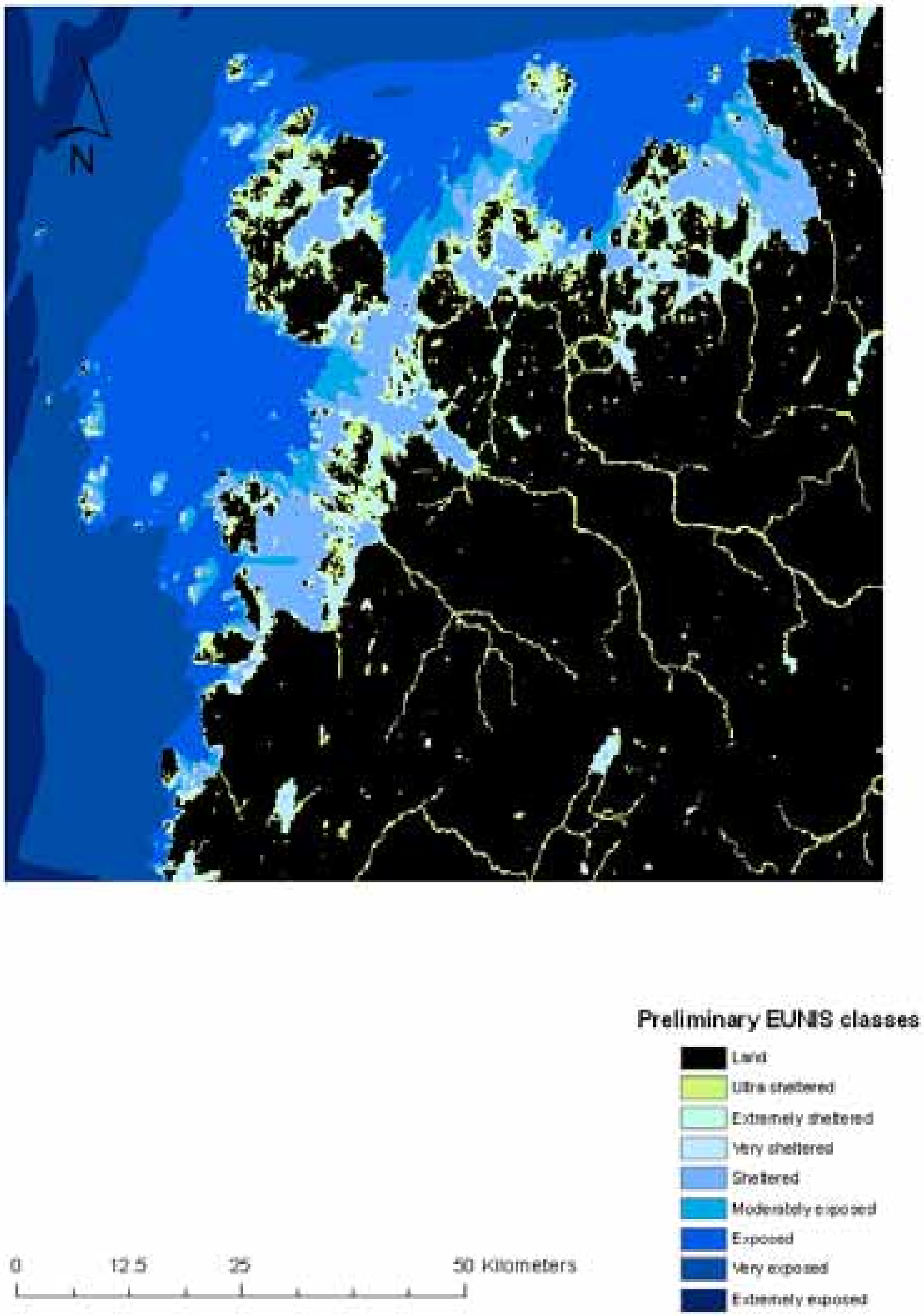
SWM 23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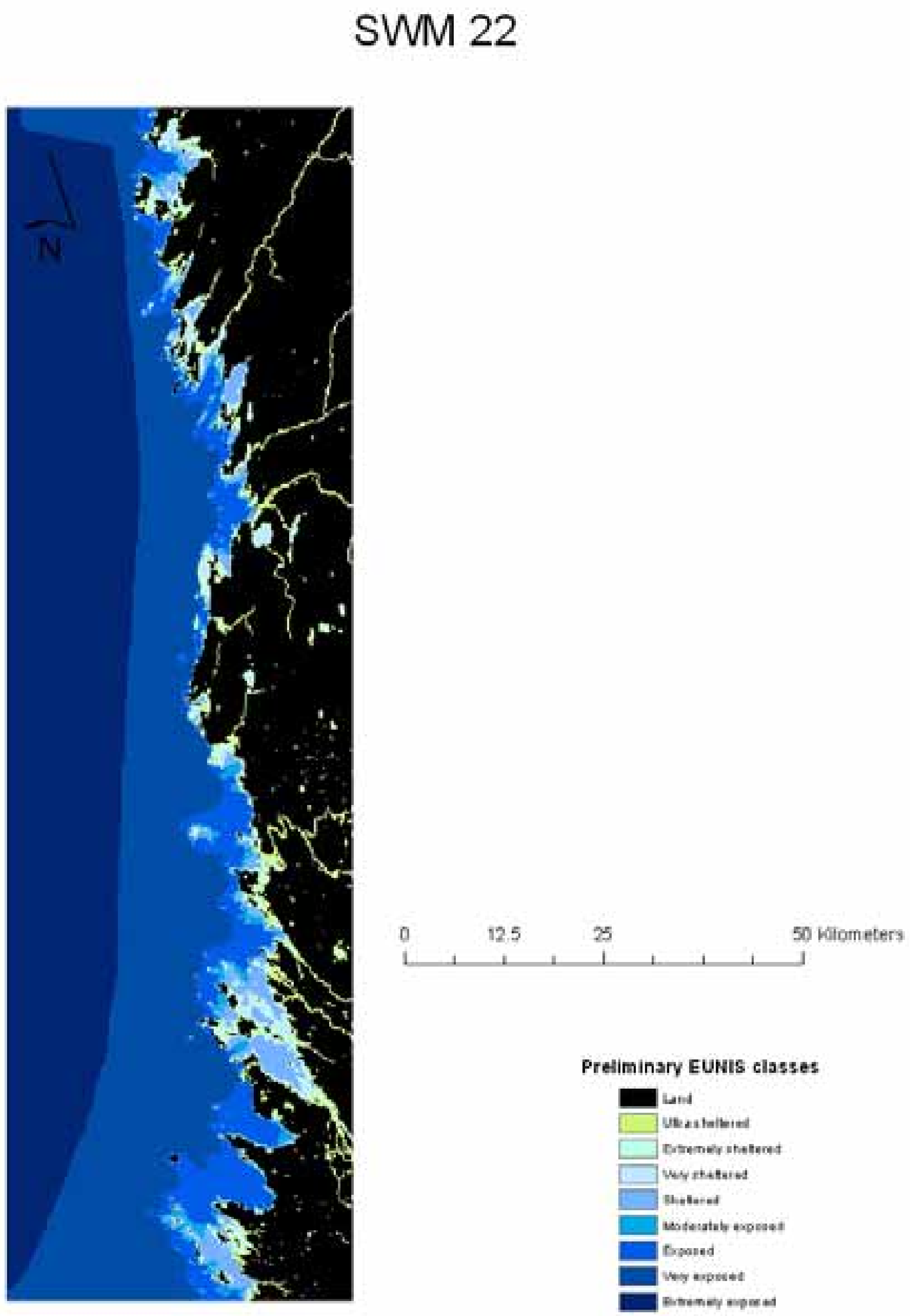
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SWM 20
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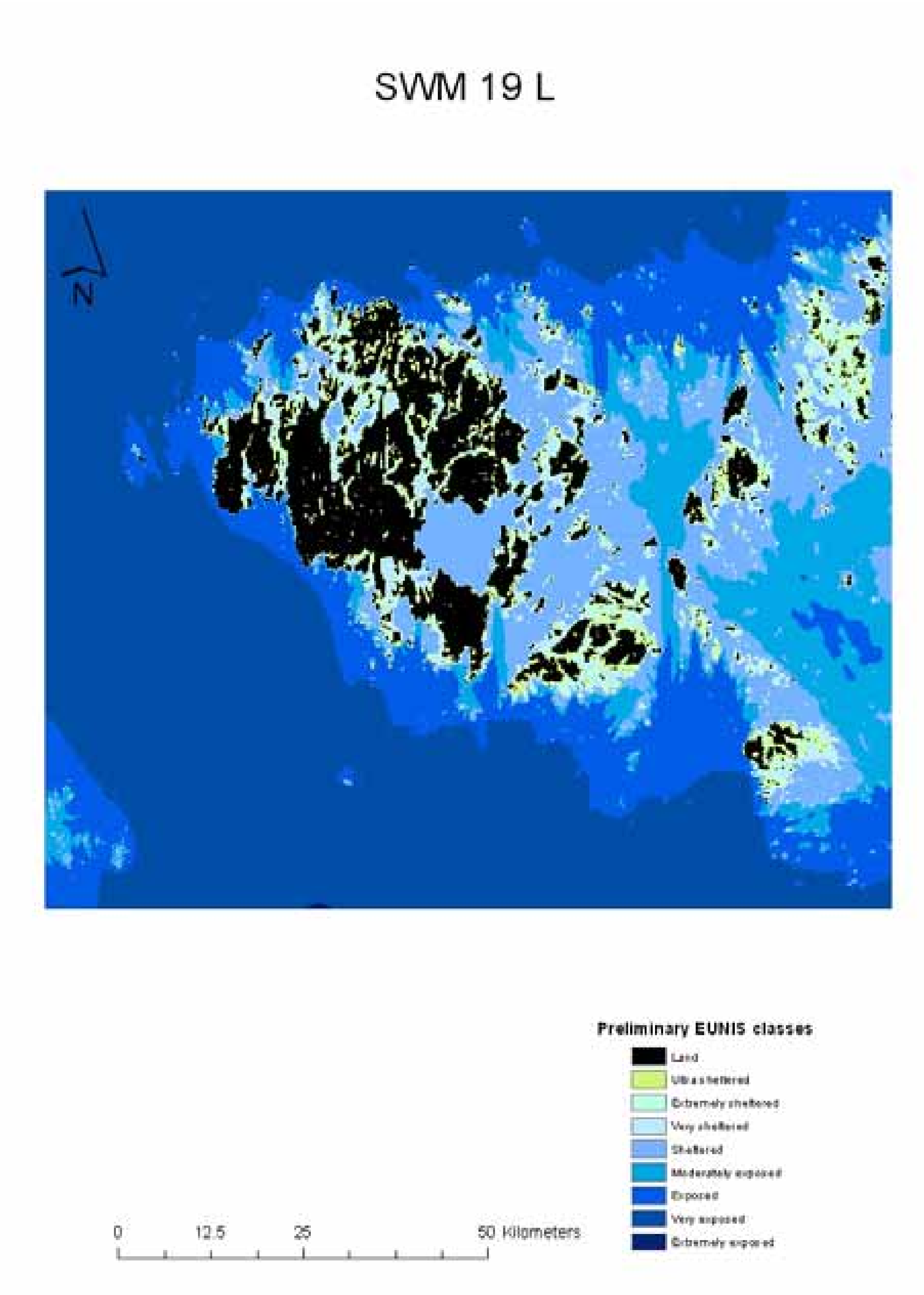
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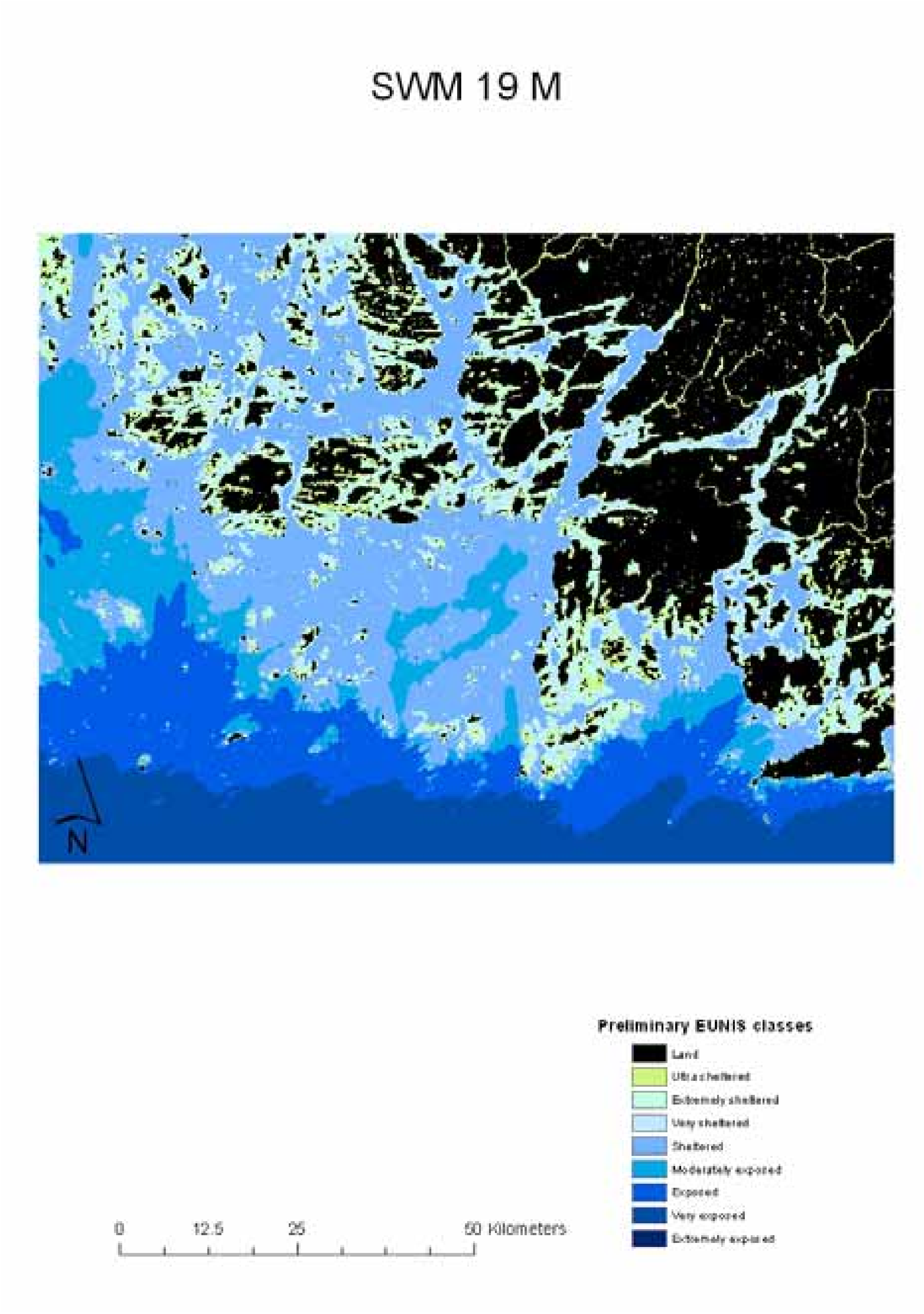
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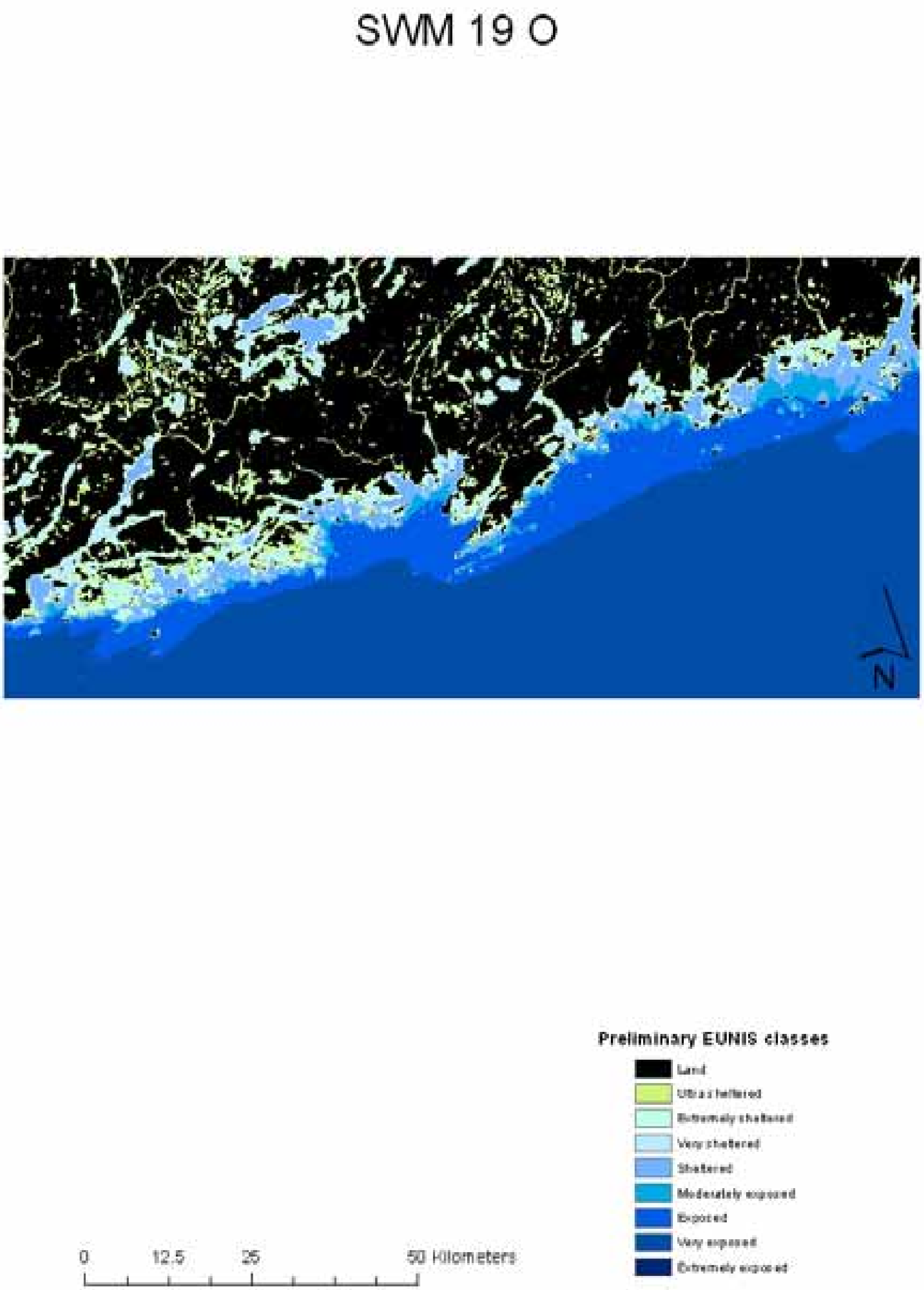
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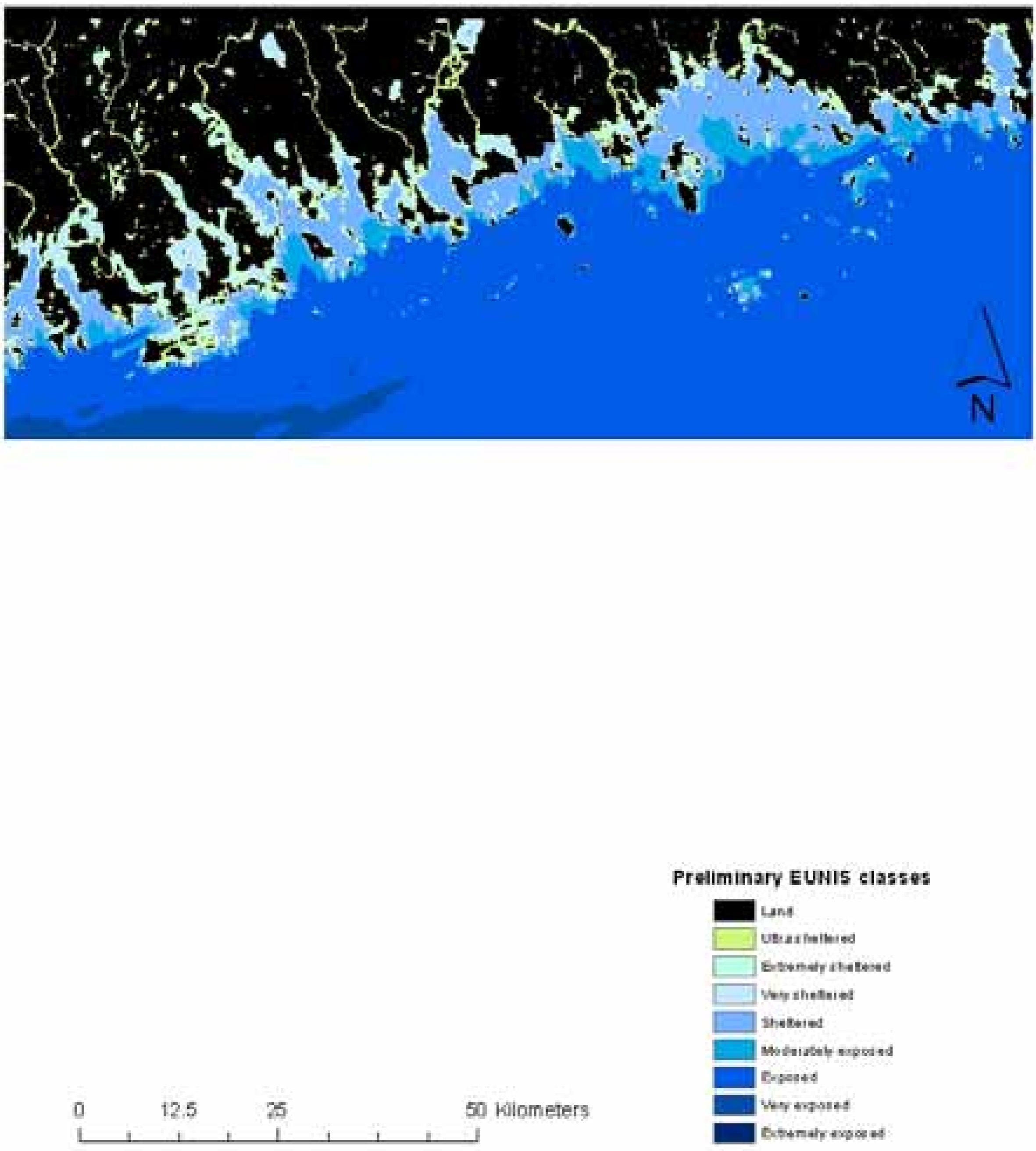
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