



Avian Sensitivity Mapping and Wind Energy

GIS-based wind turbine micro-siting tool

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Roel May



INnovative Tools to reduce Avian Collisions with wind Turbines

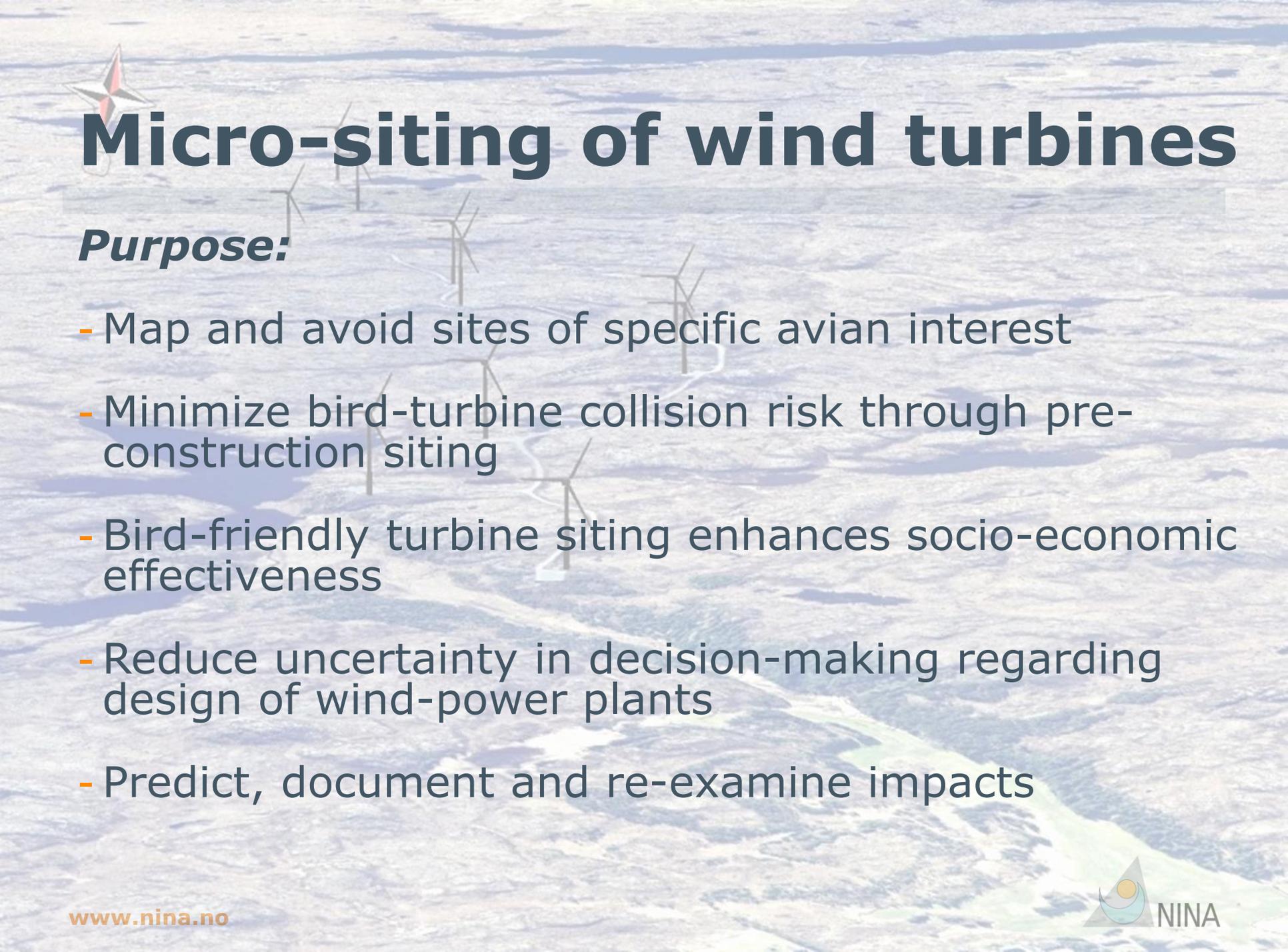


INTACT: R&D for green innovation

The primary objective is to develop measures and procedures to reduce the risk of bird – wind turbine collisions

The main focus of the research is to test promising deterrent measures at the Smøla wind-power plant and develop tools to facilitate this, and to test and refine micro-siting tools

- *Develop a standalone GIS-based micro-siting tool for identification of high-risk turbine locations (in red) for birds in relation to thermals, local topography and wind conditions*

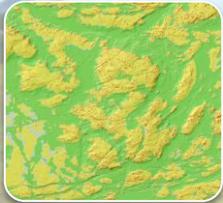


Micro-siting of wind turbines

Purpose:

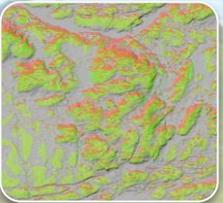
- Map and avoid sites of specific avian interest
- Minimize bird-turbine collision risk through pre-construction siting
- Bird-friendly turbine siting enhances socio-economic effectiveness
- Reduce uncertainty in decision-making regarding design of wind-power plants
- Predict, document and re-examine impacts

INTACT Wind-turbine Micro-siting Toolbox



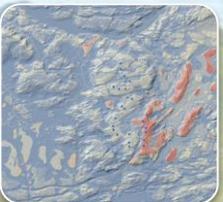
1. Landscape Orientation Toolbox

- Geomorphological classification (landscape metrics)
- Topographical and hydrological orientation



2. Updraft Estimation Toolbox

- Orographic updraft velocity based on DEM and proxy wind data
- Thermal updraft velocity based on LandSat 8 thermal band



3. Avian Site Risk Toolbox

- Weighing of maps from the two first toolboxes
- Calculate relative risk distribution for raptors

Bohrer G, et al. 2012. Estimating updraft velocity components over large spatial scales: contrasting migration strategies of golden eagles and turkey vultures. *Ecology Letters* 15: 96-103.

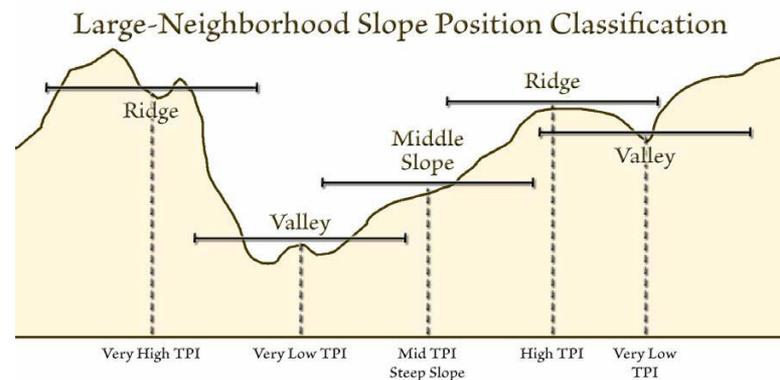
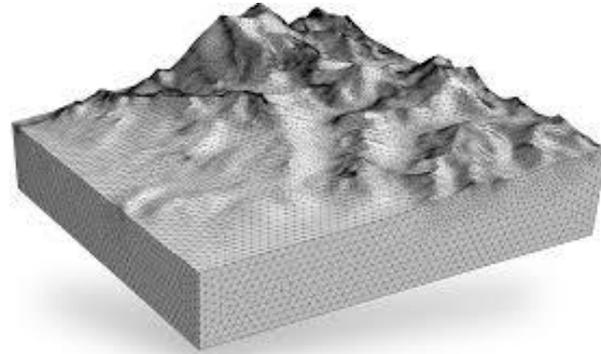
Pocewicz A, et al. 2013. *Mapping Migration: Important places for Wyoming's migratory birds*. Lander, Wyoming: The Nature Conservancy.

1. Landscape orientation

- During migration raptors prefer to follow topographical “leading lines” such as ridges, mountain ranges and main river systems
- Such orientation features depend on the geomorphometric complexity of the entire landscape at different scales in turn affecting how birds prefer to migrate across the landscape
- Classification of landscape features

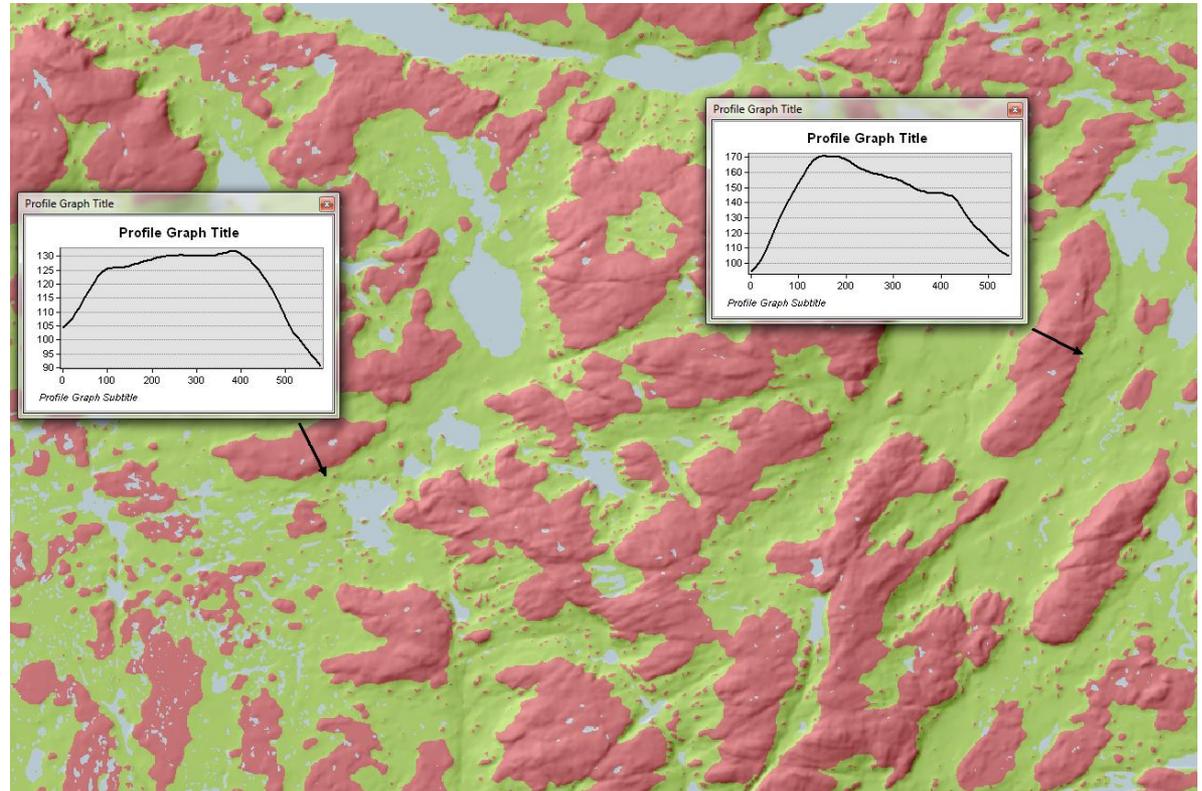
Landscape classification

- Topographical Position Index (TPI) compare pixel height with mean pixel height within a search window:
 - ▶ TPI < 0 (Valleys; concave)
 - ▶ TPI > 0 (Ridges; convex)
 - ▶ TPI = 0 (Plains and valley bottoms)
- Sensitive to geographical scale and DEM resolution (e.g. 3x3 or 60x60 pixels)
- Combining Slope and TPI (mean \pm SD) within at least two search windows can assist in the landscape classification



Landscape classification

- Canyons
- Mid-valleys
- Upland
- U-valleys
- Plains
- Open
- Mesas
- Local ridges
- Mid-ridges
- Ridges
- Water (mask)



Landscape orientation

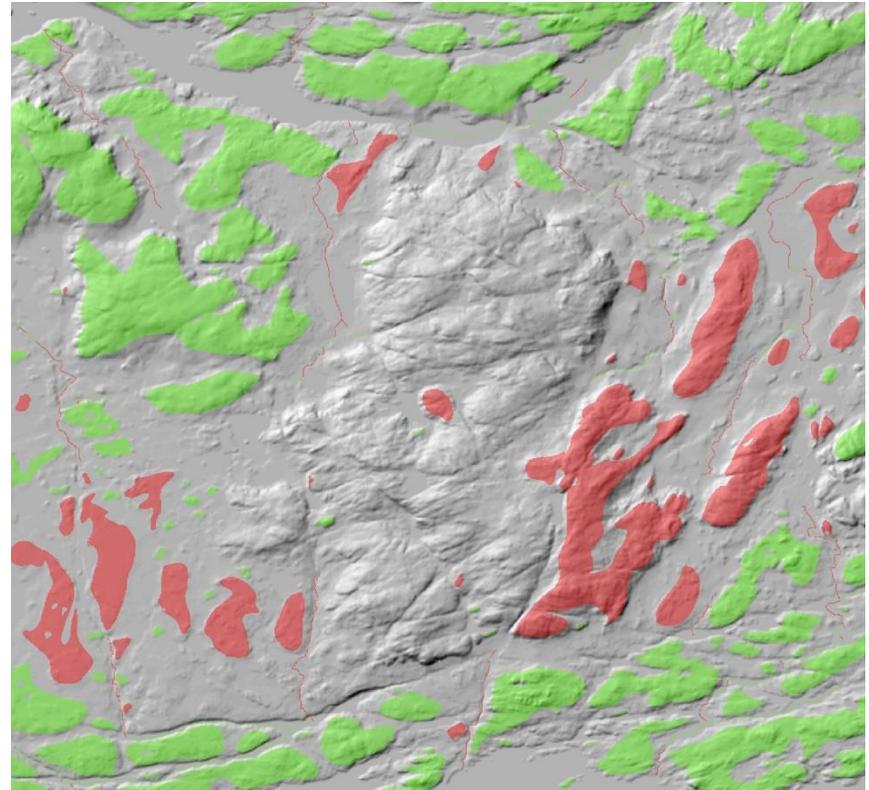
The tool estimates the azimuthal angles of ridges, mountain features and rivers

Measuring the azimuthal angles of some landscape features is complex because of their irregular shapes and non-linearity (e.g. valleys transitions and open plains)

Measuring angles of those geometrically complex features does not always give practical meaning with respect to bird migration preferences, and we have therefore used the features Long Axis to Short Axis ratio to select features that are mostly linear in nature

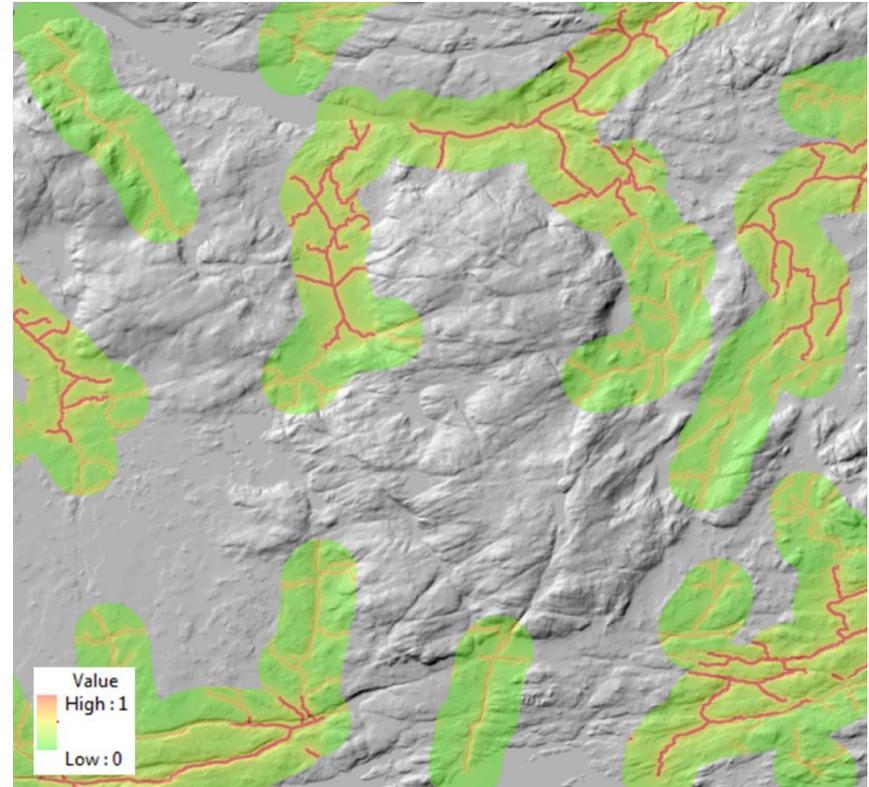
Landscape orientation

- **Minimum Bounding Geometry (MBG) for each landscape feature:**
 - ▶ measures azimuth orientation, width and length
- **MBG Axis ratio = MBG length / MBG width:**
 - ▶ non-linear features (ratio < 1.5) are removed
- **A Northness index is calculated as a measure on how the features are oriented north-south or east-west:**
 - ▶ East-West oriented features
 - ▶ North-South oriented features



Hydrological orientation

- **Norwegian river database (ELVIS)**
- **River order classification:**
 - ▶ Strahler stream order 3 (0.5)
 - ▶ Strahler stream order ≥ 4 (1.0)
- **Rivers ≥ 0.5 are buffered with 500m**
- **A Distance Decay model is used to measure how attractive rivers and the surrounding areas may be for migratory birds**



Landscape orientation interface

2.Landscape orientation

Select TPI map
%scratchworkspace%\Terrain structure.gdb\TPI_LANDFORMS_WATER

Select TPI Landform classes (optional)
"grid_code" = 7 OR "grid_code" = 8 OR "grid_code" = 9 OR "grid_code" = 10

Define filter area size (m2) (optional)
"Shape_Area" >= 5000

Define minimum area size (m2) for donut holes (optional)
5000 Square Meters

Set the axis-ratio to select mostly linear TPI features (optional)
"AXIS_RATIO" > 1.5

Select hydrology network
%scratchworkspace%\ELVIS_VKTOR.gdb\ELVIS_lin\Elvenett_lin

Classify rivers by Strahler categories (optional)
def Reclass(STRAHLER):
if (STRAHLER >= 4):
return 1
elif (STRAHLER == 3):
return 0.5
else:
return 0

Define a focal statistics (maximum function) neighborhood (optional)
Circle

Neighborhood Settings
Radius: 500.000000
Units: Cell Map

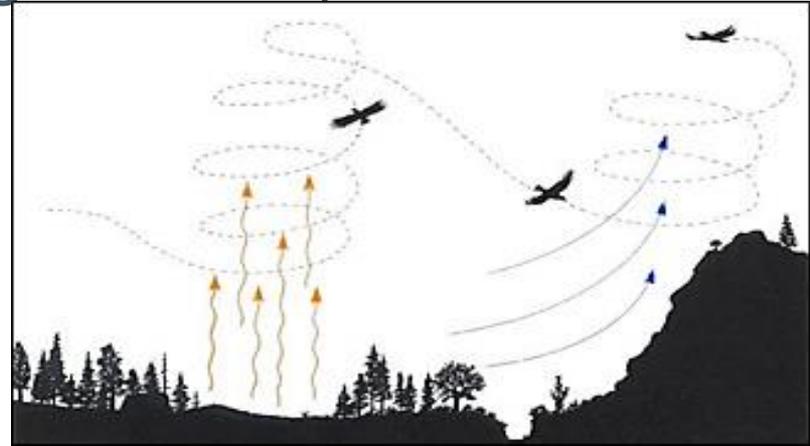
2.Landscape orientation

This tool estimates linearity and orientation of hydrology and elevated topography. It also estimates relative importance for areas within a given distance from rivers (based on a river distance decay dunction).

The flowchart on the right illustrates the tool's internal logic, starting with an 'Input' node, followed by a series of processing steps including 'Filter Area', 'Minimum Area', 'Axis Ratio', 'Hydrology Network', 'Strahler Classification', and 'Focal Statistics', leading to the final 'Output'.

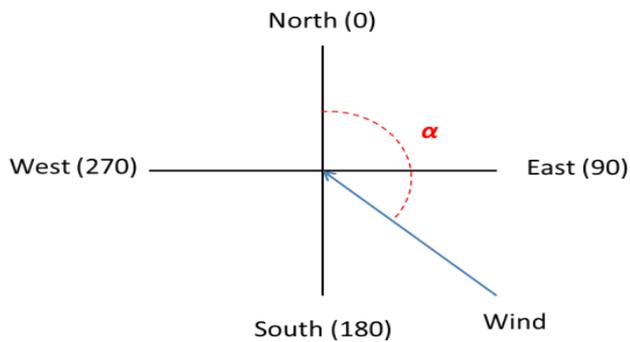
2. Updraft estimation

- Soaring birds are attracted to topography providing local updrafting winds to subsidize soaring and gliding flight activity
- Soaring birds do not maintain high altitudes during migration. Instead, they conserve energy by gaining lift from updrafts and gliding long distances, slowly losing altitude, to the next updraft
- Two types of lifting:
 - ▶ Orographic updrafts
 - ▶ Thermal updrafts



Orographic updraft model

Orographic updraft (w_0)

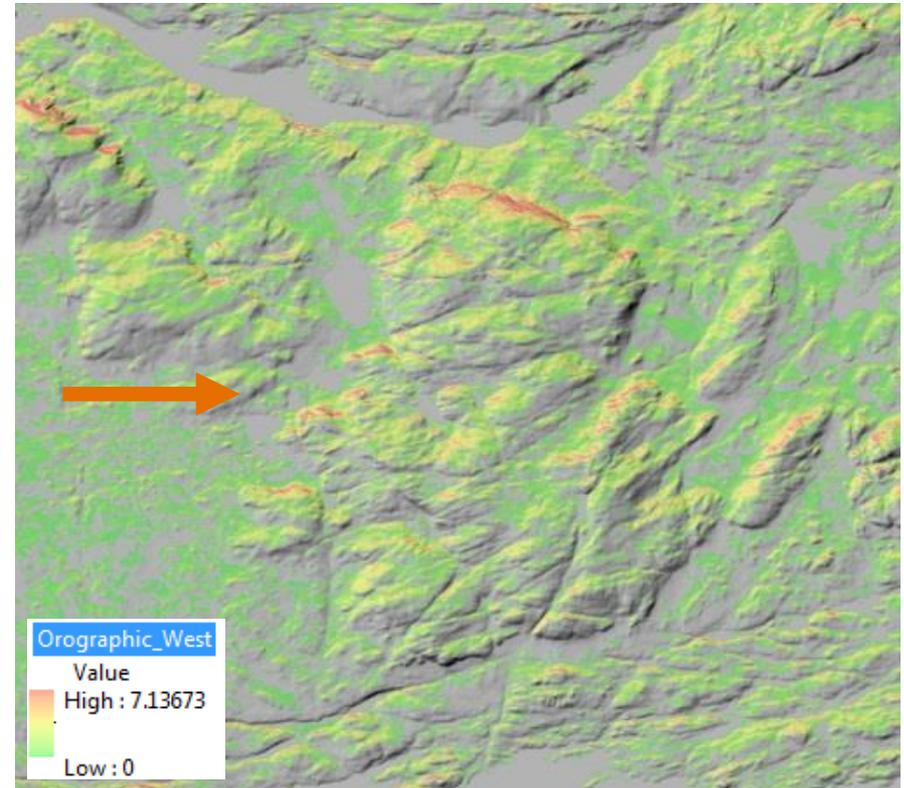


Orographic updraft coefficient (C_α)

$$C_\alpha = \sin(\text{slope}) * \cos(\text{wind direction} - \text{aspect})$$

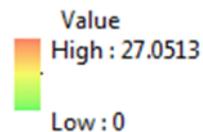
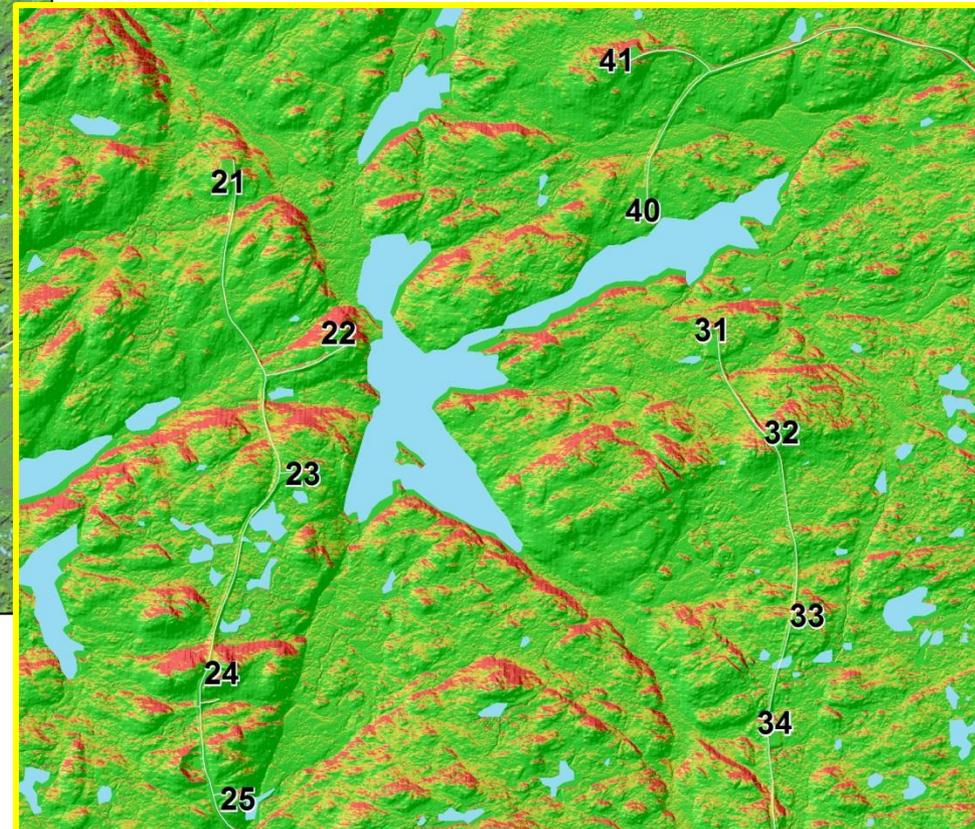
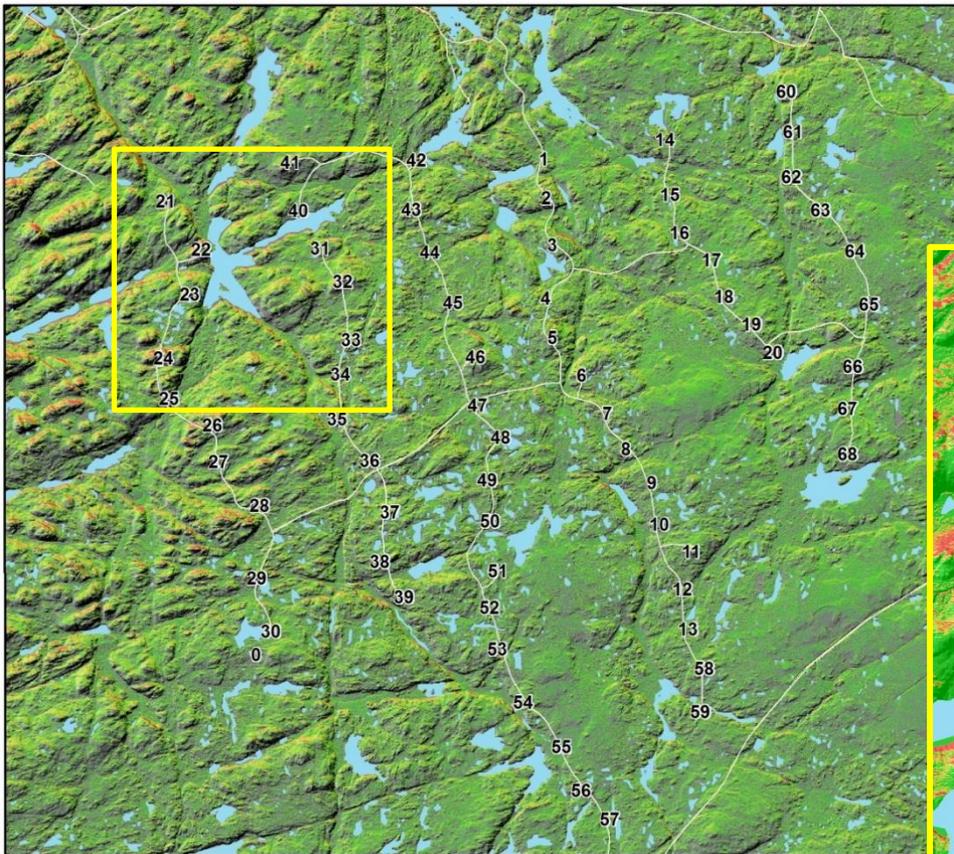
Orographic updraft velocity (w_0)

$$w_0 = v (\text{wind speed}) * C_\alpha (\text{updraft coefficient})$$

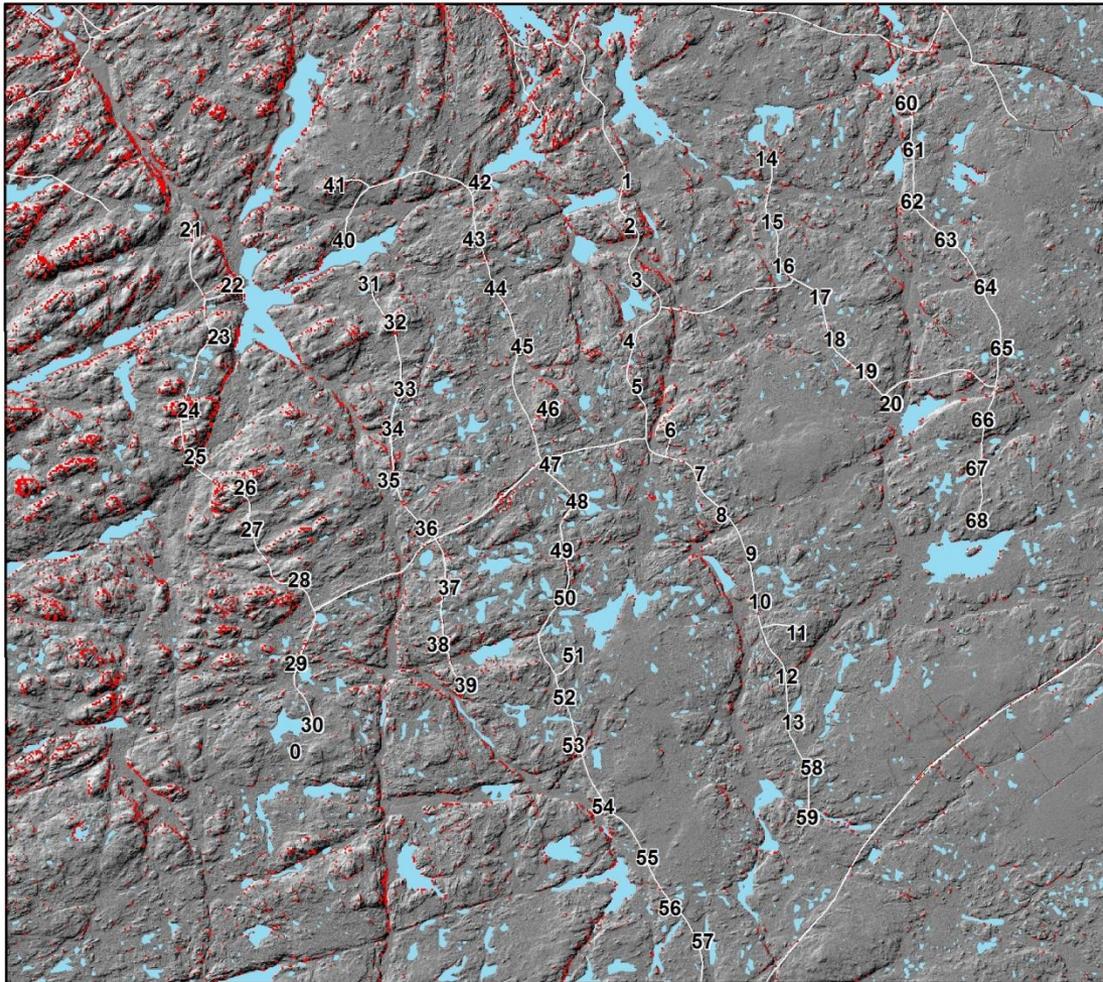


Orographic updraft model

Approximated orographic updraft wind velocity at the Smøla wind-power plant derived from northern wind at 28.4 m/s (full storm)



Orographic updraft model



To scope potential harmful turbine locations a proxy level of e.g. >10 m/s can be chosen, based on an aggregation of updrafts from all wind directions at 28.4 m/s

In reality, when based on species-specific updraft requirements and relevant flight strategy parameters (including topographic pathways and thermal updrafts), this could represent a realistic measure of potential harmful turbine locations in complex terrain

Orographic updraft interface

2.Calculate orographic updraft

Wind direction
North

Wind speed
Calm (0 - 0.2 m/s)

Orographic updraft
D:\Arbeid\INTACT\Orographic.gdb\Orographic

2.Calculate orographic updraft

This tool is developed in the R&D - project [INTACT \(INnovative Tools to reduce Avian Collisions with wind Turbines\)](#). The tool calculates estimated orographic updraft wind speed (also known as ridge lift) based on proxy wind direction and wind speed. Please note that Updrafts associated with turbulent eddies or lee waves are not included in this calculation. All negative values on the leeward side of the terrain are therefore set to 0. Please also note that in the current version of this tool calculated updrafts are not corrected for terrain channelling and wind sheltering.

- First terrain Slope and Aspect are calculated from a DEM.
- Secondly a Updraft Coefficient are calculated from the Slope and Aspect (in radians) and the wind direction using the equation $\text{Sin (Slope)} * \text{Cos (Wind direction - Aspect)}$.
- Third, the orographic updraft wind speed are then calculated using the equation $\text{Wind speed} * \text{Orographic Updraft Coefficient}$

Credits:

- Bohrer et al 2011. Estimating updraft velocity components over large spatial scales: contrasting migration strategies of golden eagles and turkey vultures.
- Brandes, D. & Ombalski, D.W. (2004). Modeling raptor migration pathways using a fluid-flow analogy.

Toolbox developed by: Frank Hanssen, NINA July 2014



OK Cancel Environments... << Hide Help Tool Help

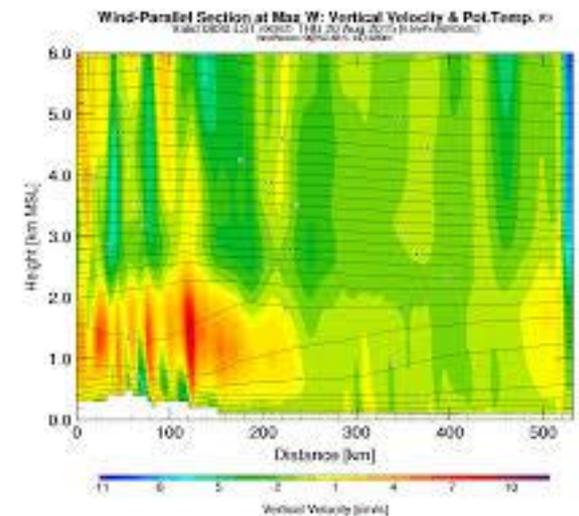
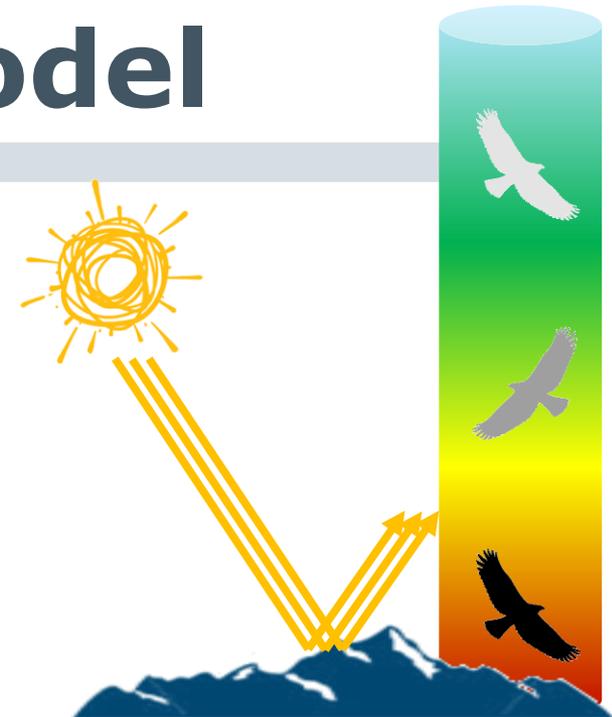
Thermal updraft model

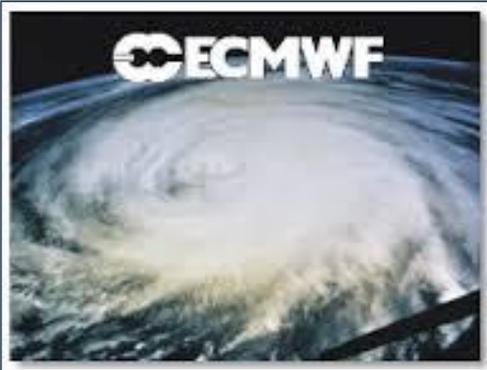
Thermal updraft velocity

$$W^* = [gzH / \theta]^{1/3}$$

- g is the gravitational acceleration
- θ is the potential temperature
- H is the surface sensible heat flux; determined by the *Land Surface Temperature*
- z is a bird's flight height within the atmospheric boundary layer

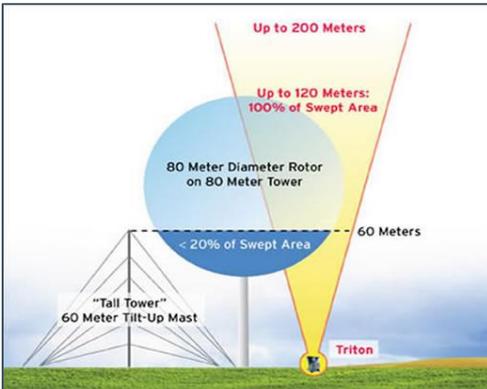
Thermal soaring flight is not possible when W^* is negative (surface cooling during nights, after rainfalls or when the surface is covered by snow/ice)





Weather Forecast models:

- Most usual to use for thermal updraft estimation
- Not applicable for micro-siting due to low resolution
~ 2.5 km (met.no) and 12.5 km (ECMWF)



SOnic Detection And Ranging (SODAR)

- Atmospheric turbulence
- Wind speeds in altitudinal layers
- Thermo-dynamics i lower parts of the atmosphere
- SODAR has limited coverage and is very costly



LandSat8 thermal sensor:

- Heat surface energy
- High resolution (30-100 meter)
- Cover the same are app. every 16 day
- 1 scene covers 170 km x 185 km
- Free access to data from NASA
- Sensor is sensitive to clouds

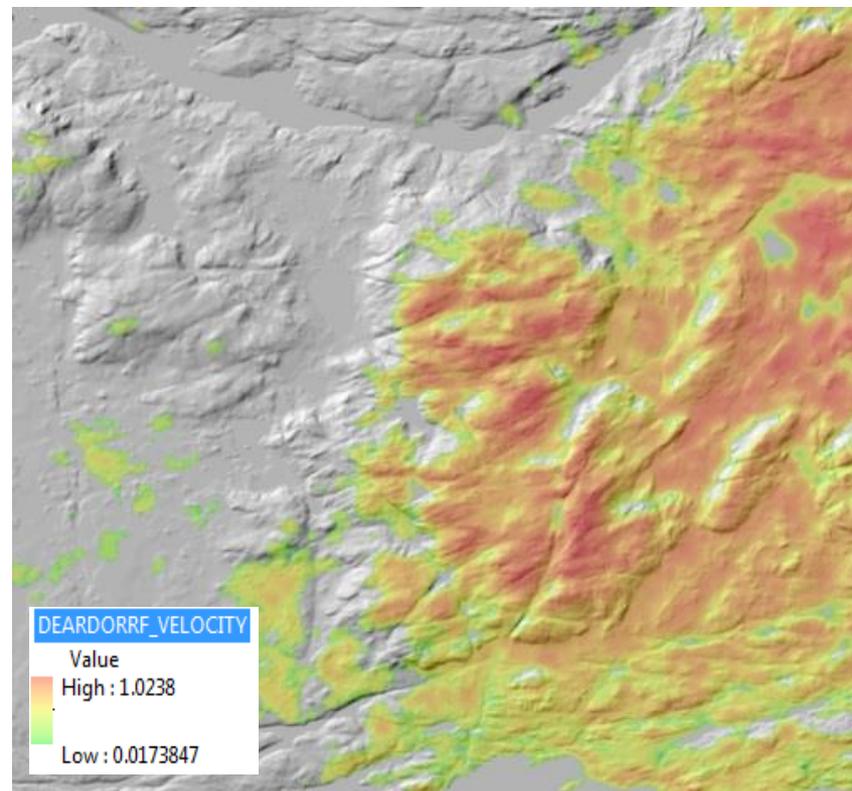
Thermal updraft model

Input parameters:

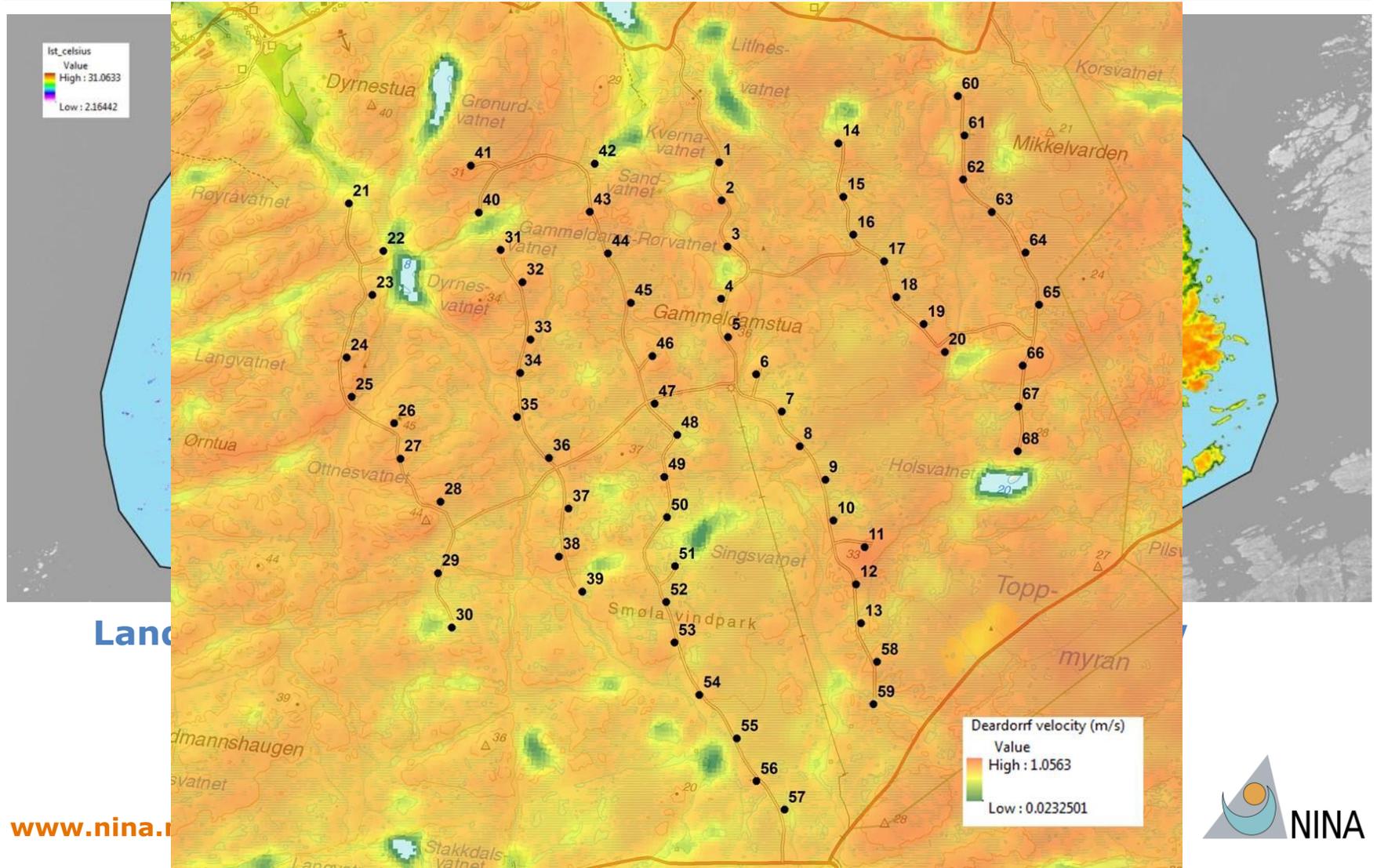
- Region of interest
- Water mask
- LandSat Band 5 (NIR)
- LandSat Band 4 (Red)
- LandSat Band 10 (TIR)
- Flight height
- Horizontal wind direction
- Meteorological constants

Calculations:

- Solar radiation
- Surface-air heat exchange
- NDVI (absorbed radiation)
- Land surface temperature



Thermal updraft model



Thermal updraft model

Birds have different morphology and behavioural characteristics which influence species-specific flight strategies, and the species' capability to exploit orographic and thermal updrafts as they traverse the landscape

To determine bird-specific requirements for taking advantage of thermal updrafts in soaring flight activities we utilized the Flight program developed by Pennycuick (2008)

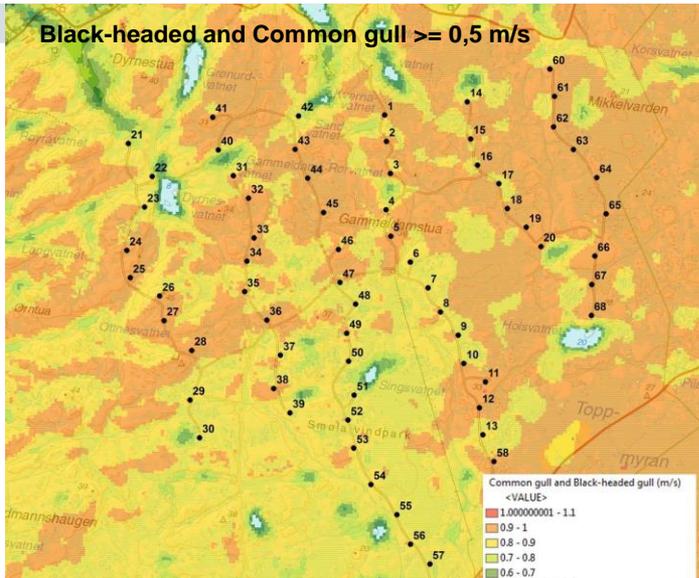
Minimum sink (V_{ms}) and **Best glide (V_{bg})** defines the minimum and maximum requirement thermal updraft speeds needed to avoid sinking downwards in uplifting air currents. All speeds above V_{ms} makes it possible to climb upwards on an updraft

Examples:

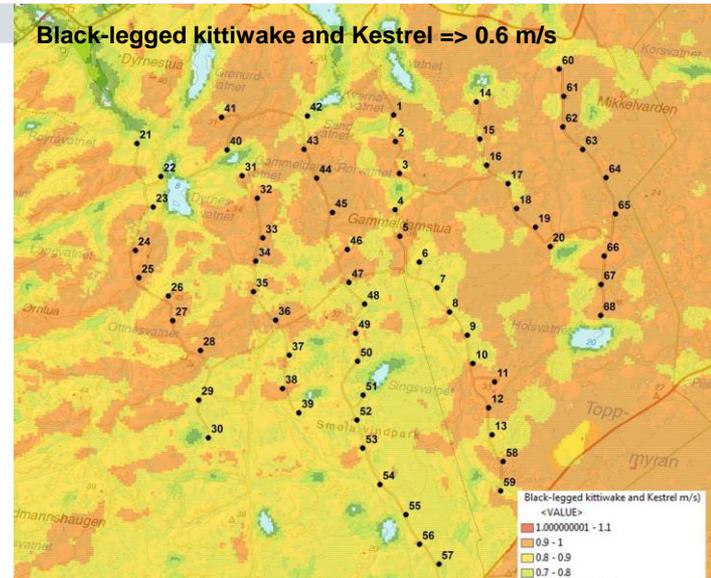
- Common gull and Black-headed gull: 0.4-0.5 m/s
- Black-legged kittiwake and Kestrel: 0.5-0.6 m/s
- White-tailed eagle and Great black-backed gull: 0.6-0.7 m/s
- Carrion crow: 0.7-0.9 m/s
- Willow ptarmigan: 14.2-16.5 m/s

Thermal updraft model

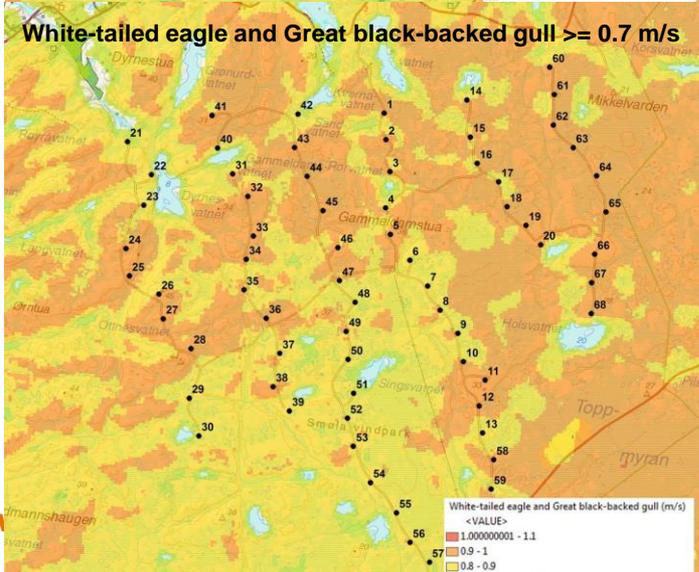
Black-headed and Common gull $\geq 0,5$ m/s



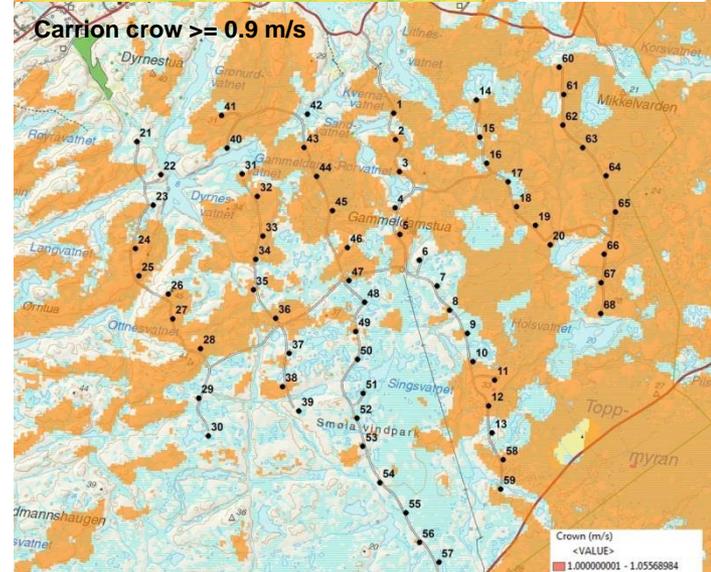
Black-legged kittiwake and Kestrel $\Rightarrow 0.6$ m/s



White-tailed eagle and Great black-backed gull ≥ 0.7 m/s



Carrion crow ≥ 0.9 m/s



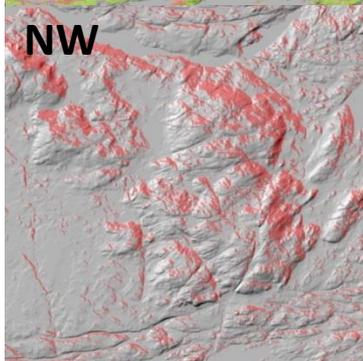
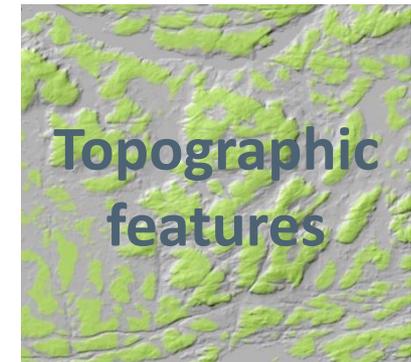
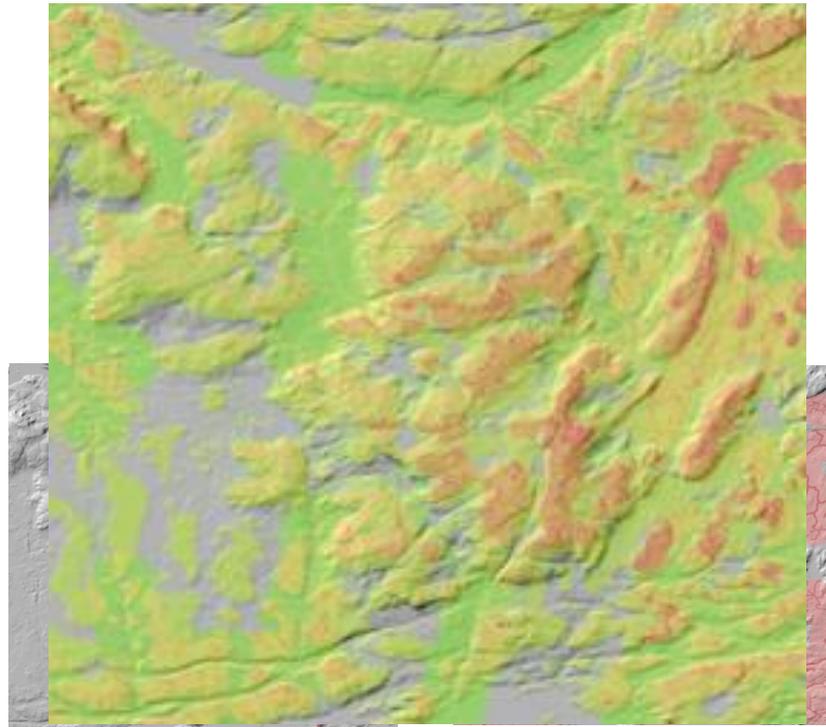
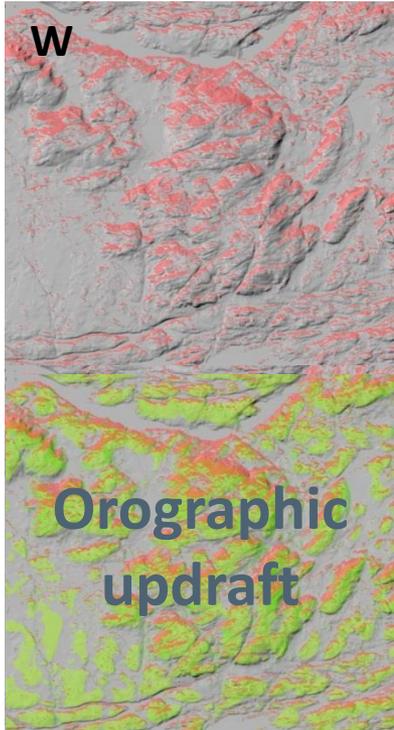
3. Integration: Avian site risk

$$MIS_e = \sum_{i=1}^n w_i * (f_{ci} * m_i)$$

[Pocewicz et al. 2013]

Factor/Modifier	Value and description
Orographic updrafts (Factor) <ul style="list-style-type: none"> - Areas in prevailing wind direction (e.g. West) - Areas in prevailing wind direction +/- 45 degrees (e.g. NW and SW) - All other areas 	1: High importance 0.5: Medium importance 0: No importance
Thermal updraft (Factor) <ul style="list-style-type: none"> - Areas with thermal updraft velocity >= 0.7 m/s - Areas with thermal updraft velocity < 0.7 m/s 	1: High importance 0: No importance
Stream distance decay function (Factor) <ul style="list-style-type: none"> - Distance decay value >= 0.5 - Distance decay value > 0 & < 0.5 - Distance decay value = 0 	1: High importance 0.5 Medium importance 0: No importance
Topography (Factor) <ul style="list-style-type: none"> - Elevated topography (Ridges/Mesas) - All other terrain (plains, valleys, fjords etc.) 	1: High importance 0: No importance
Topographical/Hydrological orientation (Modifier) <ul style="list-style-type: none"> - Northness index = 2 (North-South) - Northness index = 1 (East-West) 	2: Factor increased 1: Factor maintained

Integration: Avian site risk



Weighted Sum

Click error and warning icons for more information

Input rasters

Raster	Field	Weight
Thermal_Closed_Corrected	VALUE	1
TOPOGRAPHY_FACTOR	VALUE	1
Reclass_River_Factor_0	VALUE	1
Orographic_Updraft_Factor	VALUE	1

Output raster

D:\Arbeid\UNTACT\Relative importance of migration concentration.gdb\WeightedSum

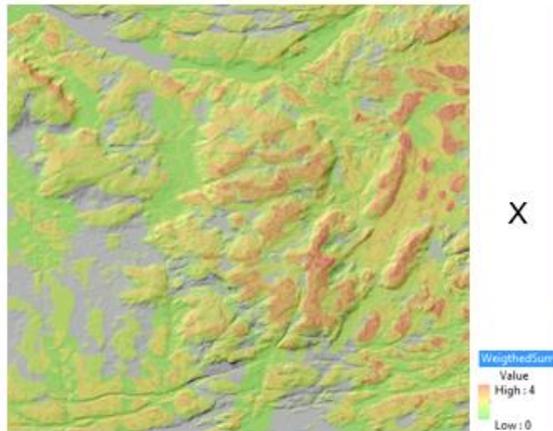
Weighted Sum

Overlays several rasters, multiplying each by their given weight and summing them together.

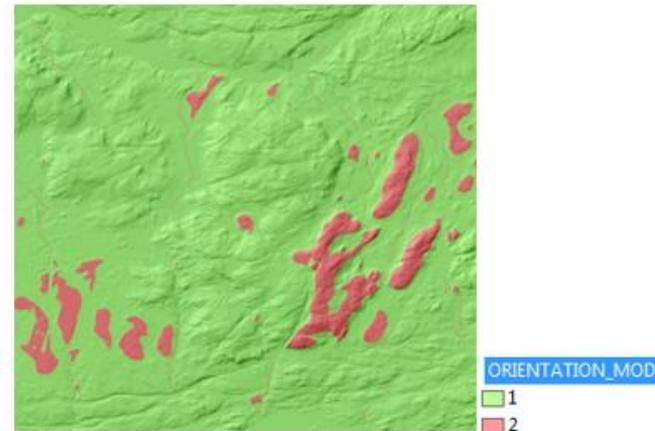
OK Cancel Apply << Hide Help Tool Help

Integration: Avian site risk

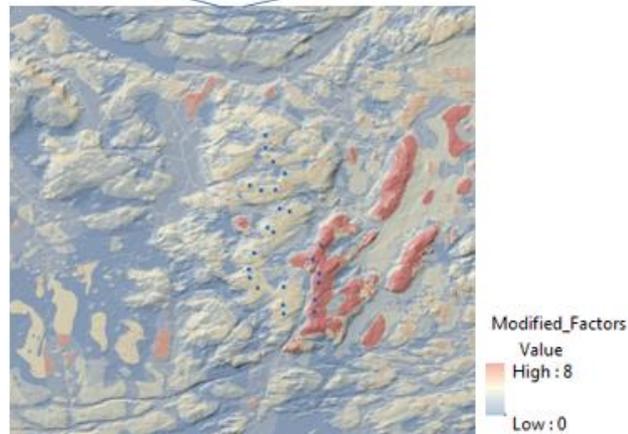
Risk assessment



Orientation modifier

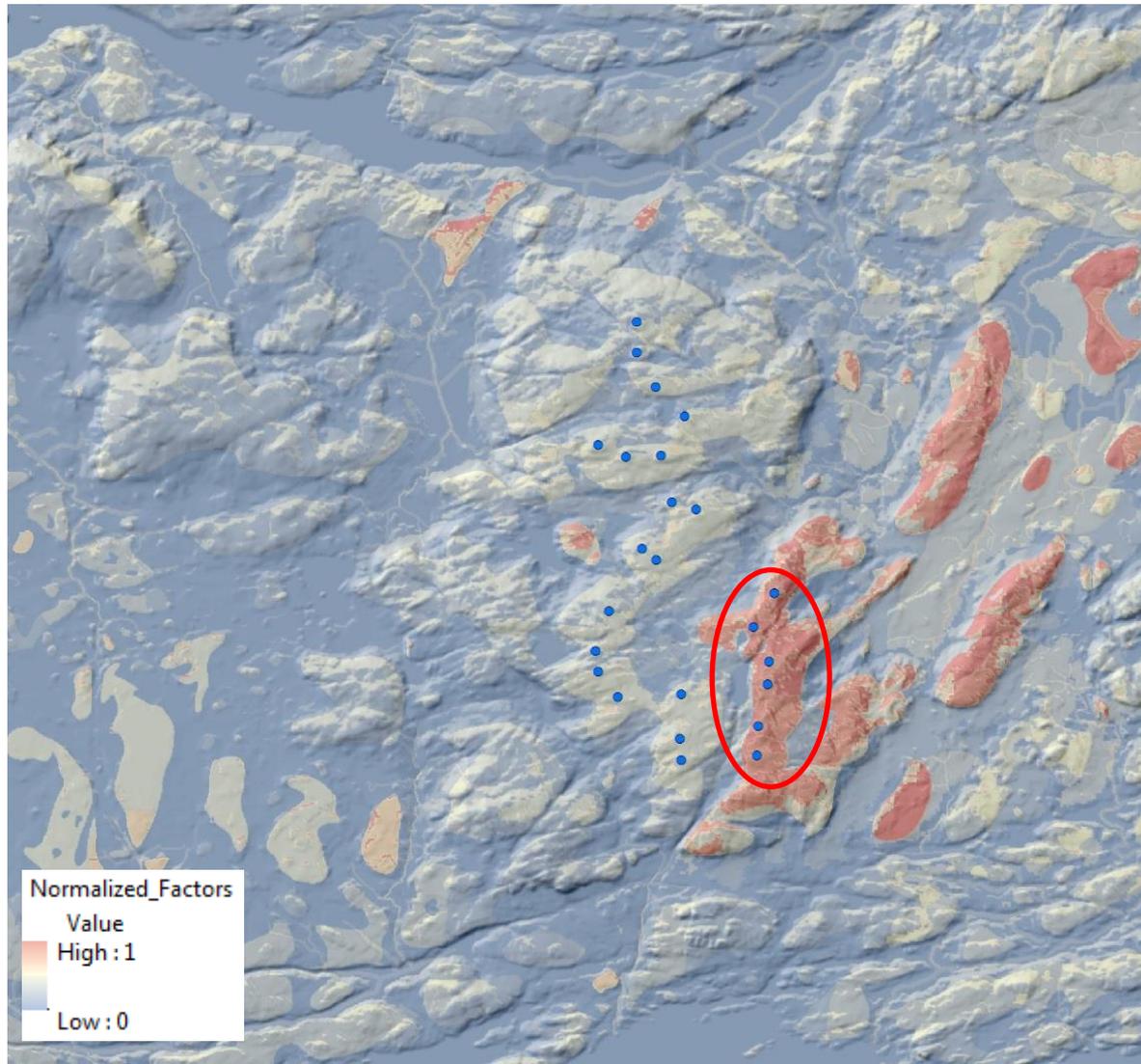


X



Modified risk assessment

Integration: Avian site risk



Normalised risk map

$$\frac{Factor - Factor_{Min}}{Factor_{Max}}$$

Map shows relative risk distribution for raptors in the Hitra wind-power plant

Avian site risk interface

Distribution of raptor migratory stopovers

Wind speed
Moderate breeze (5.6 - 8.0 m/s)

Main wind direction
West

Main wind direction minus 45 degrees
Northwest

Main wind direction plus 45 degrees
Southwest

Select LandSat TIR band
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Select LandSat NIR Band
D:\Arbeid\INTACT\LIST\LandSat8\Hitra\LC82000162014258LGN00_B5.TIF

Select LandSat Red band
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Select water mask (optional)
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Select analysis mask
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Define raptor flight height
70

Indicate horizontal wind speed at 2 meters altitude
5.4

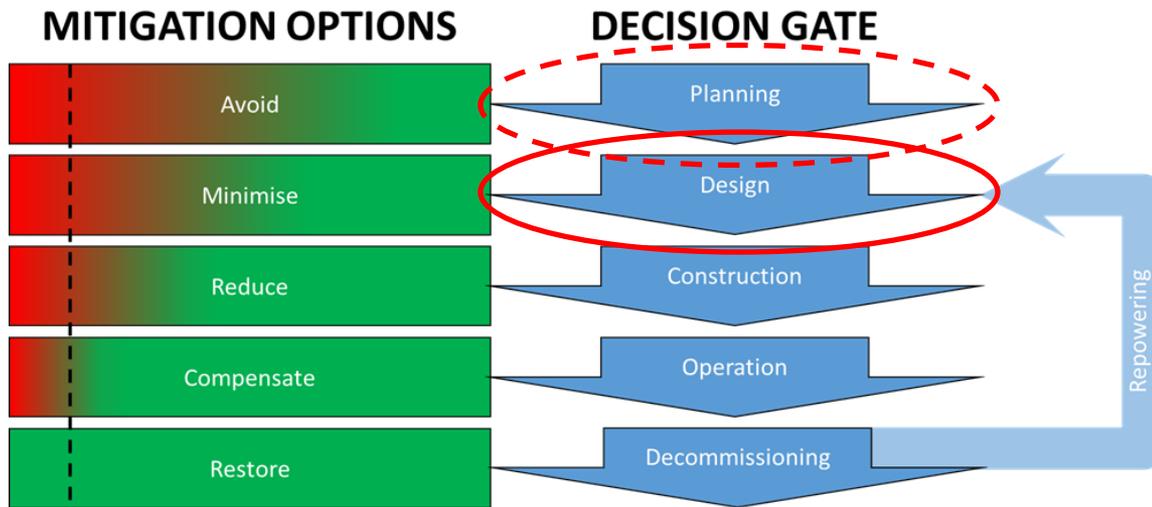
Distribution of raptor migratory stopovers

The diagram shows a network of nodes and connections. Nodes are represented by circles in blue, green, and yellow. Connections are represented by lines. The network is complex, with many nodes and a central hub-and-spoke structure.

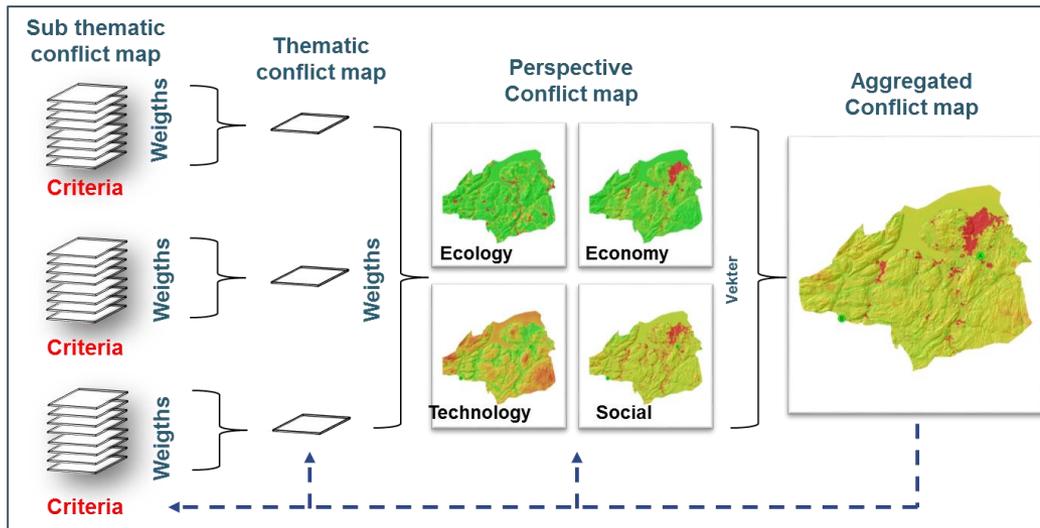
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Implementation



- Pre-construction wind farm design
- Repowering
- Scoping process
 - Consensus-based Siting (ConSite)



Questions?

Cooperation and expertise for a sustainable future

Three overlapping wavy lines in teal, green, and orange, curving across the slide.

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