

Forest structural connectivity analysis for the Nature Restoration Regulation

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1. Forest connectivity and the Nature Restoration Regulation



Indicators for forest ecosystems (European Commission, 24 June 2024)

- The Nature Restoration Regulation (NRR) will require EU member states to monitor several indicators* of forest biodiversity until they have reached *satisfactory levels* by 2050**
- **This includes forest connectivity, measured by forest area density (FAD)**



1. Standing deadwood
2. Lying deadwood 
3. Share of forests with uneven-aged structure
4. **Forest connectivity**
5. Common forest birds index (mandatory) 
6. Stock of organic carbon
7. Share of forest dominated by native tree species
8. Tree species diversity

**Note that not all indicators are mandatory*

***Positive trend required by 2030*



Calculating forest area density (FAD)

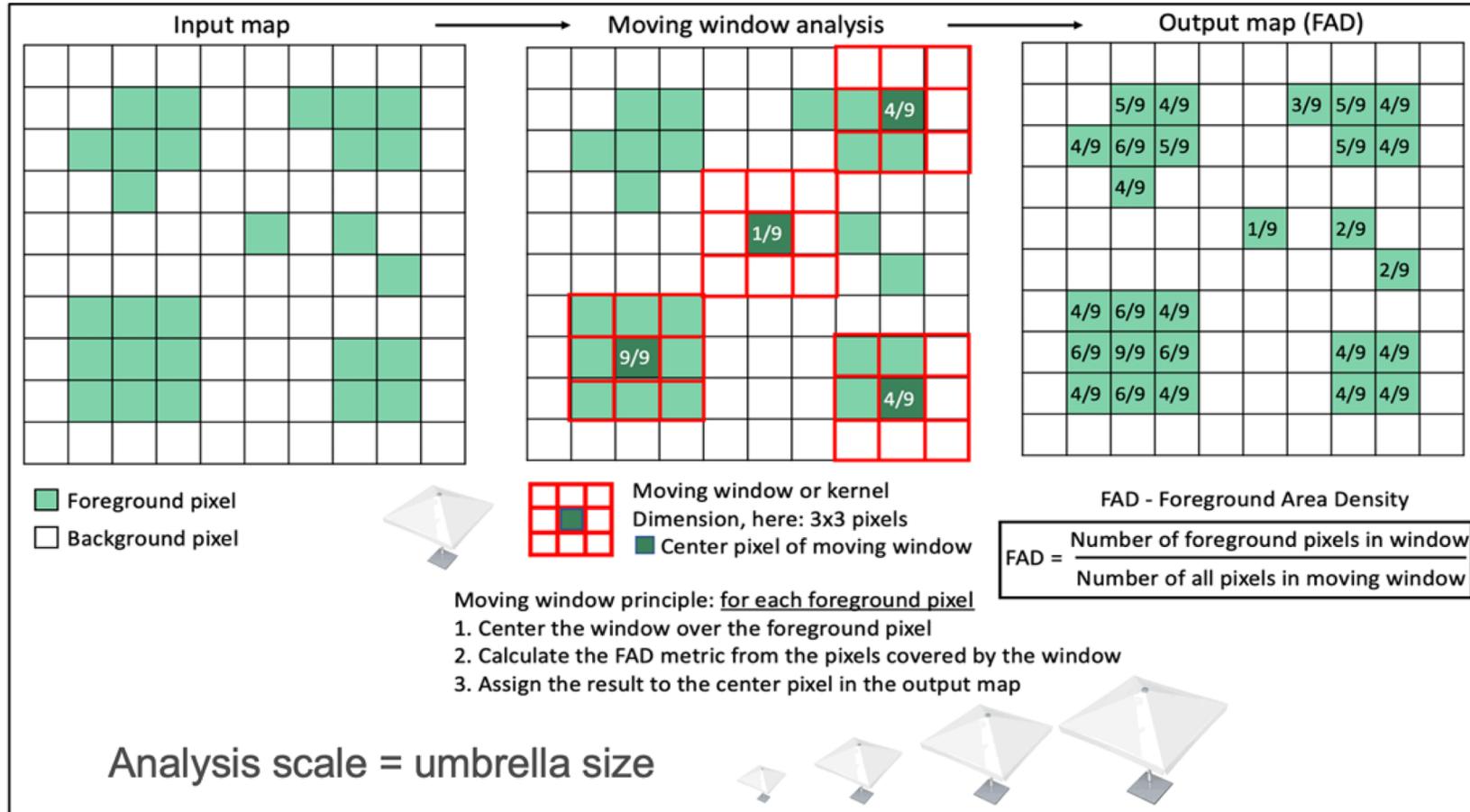
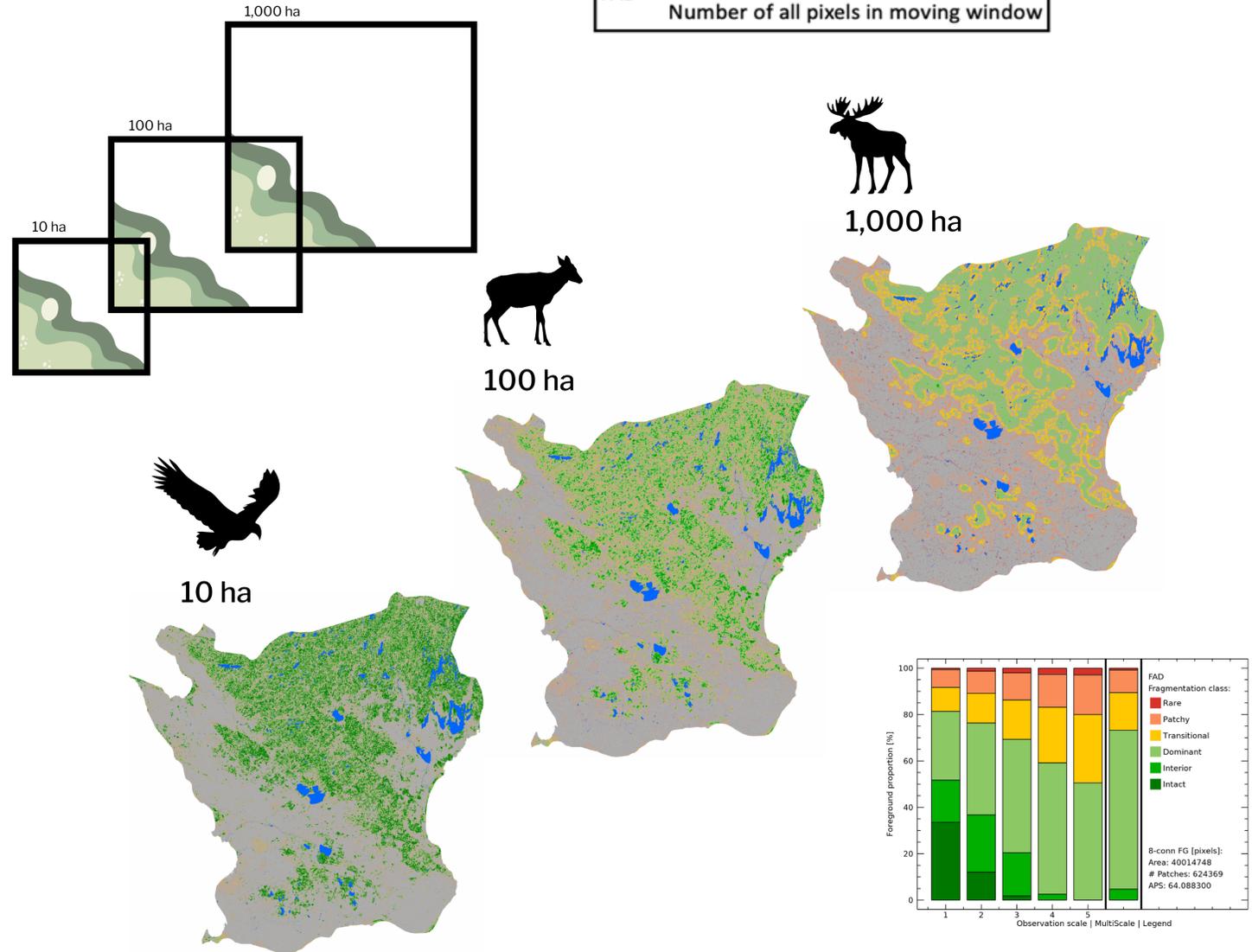


Figure 1: Moving window analysis: a moving window of size $n \times n$ (here, 3×3) is centered over a given foreground pixel, the metric is calculated, and the resulting value is assigned to the same location in the output map. The central panel shows four example locations to illustrate the process.



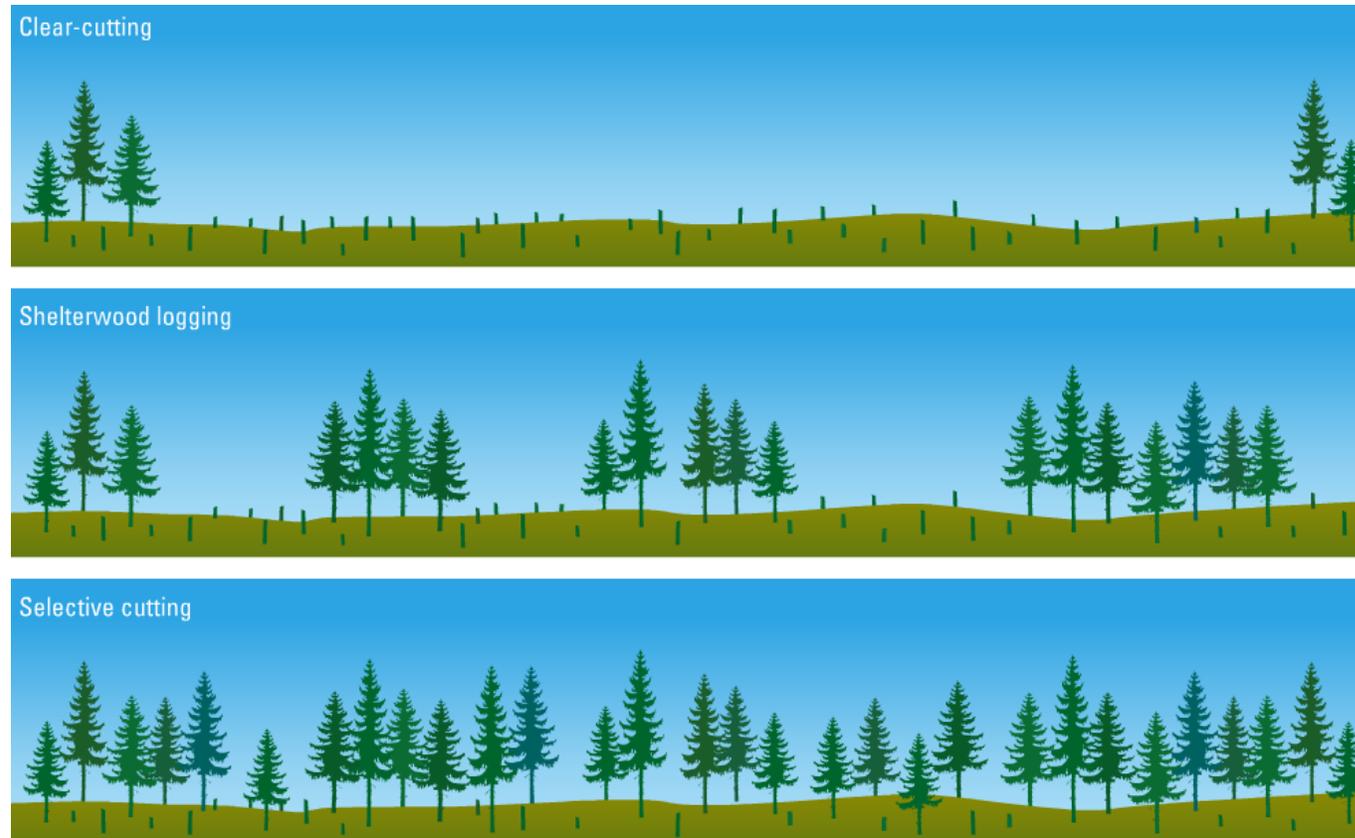
Importance of observation scale

- Average connectivity is reduced with increased observation scales
- To achieve a sufficient density of forest for a species with a range of 10 ha is much easier than a species with a range of 1,000 ha
- FAD is a scale-dependent measure; scale depends on the objective of the user



Clear-cutting, shelterwood, and selective management regimes

- In Sweden, it is likely the NRR forest restoration measures will focus on promoting diversified forestry
- This may include a reduction in clear-cutting



Source: Clark, (2006)

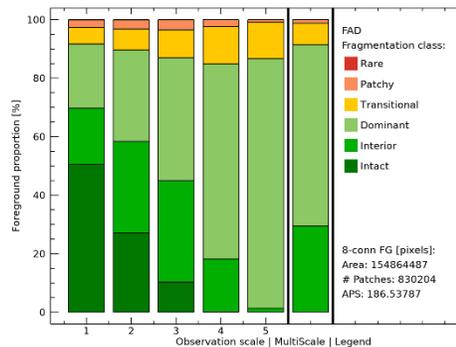
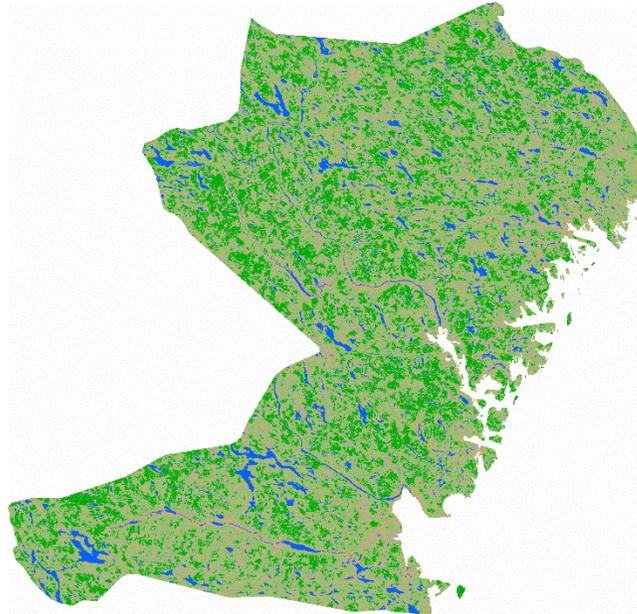
2. Simulating alternative management regimes

Research questions

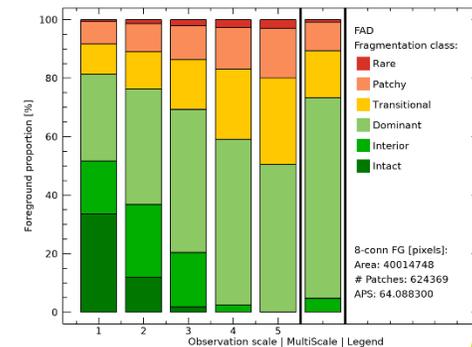
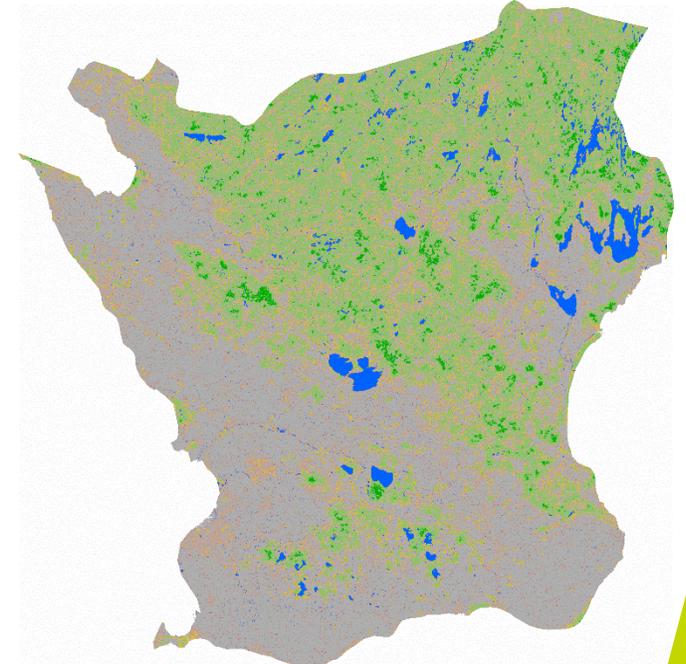
- How will future restoration under the NRR impact connectivity?
- How is FAD affected by different harvesting patterns?
- Will the impacts of restoration be different in already fragmented forest landscapes?

Region	Forest cover (%)	Average FAD (%)
Skåne	36	67
Västernorrland	73	80

Västernorrland

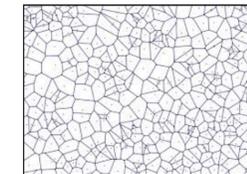
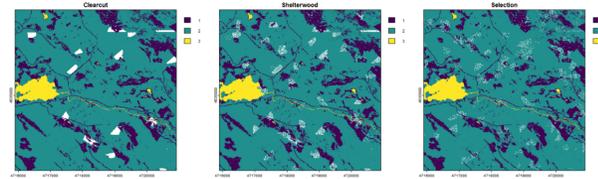
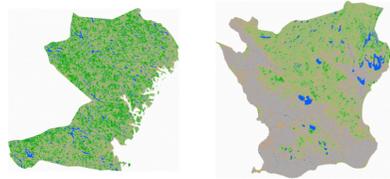


Skåne



Connectivity simulations workflow

2024  2030



Identify case study sites based on initial connectivity / fragmentation

Choose contrasting Swedish regions with high / low forest cover and FAD



Define management regimes to create 2030 scenarios

Parameters:
 Harvest target (6%, 1% per year)
 Distance constraint between stands (500m)
 Harvest % of stands (25 - 50%)
 Cluster size (0.1 - 2 ha)

Segmentation and sampling of stands from national land cover database

Forest cover derived from NMD (10 m resolution)
 Voronoi tessellation (segment size 4 ha)
 Random sampling to select stands
 Random sampling of clusters within stands
 Random sampling of subsequent stands to meet harvest target

Statistical analysis

Compare distribution of FAD and AVCON values
 Sensitivity to observation scale
 Differences across two case study sites

Assess connectivity change on simulations

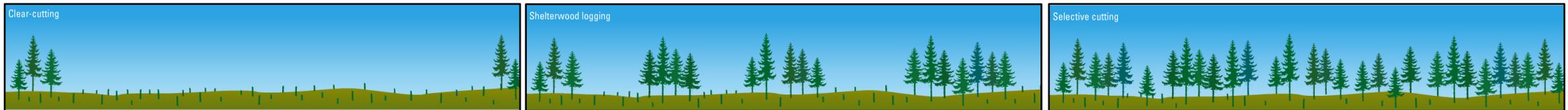
Use Guidos Toolbox to run fixed observation scale fragmentation analysis.
 24 scenarios for analysis



Remove cells until harvest target is met

Even-aged: remove entire stands
 Uneven-aged: remove clusters < 50 - 25% of stand, then remove clusters from neighboring stands at the same extend

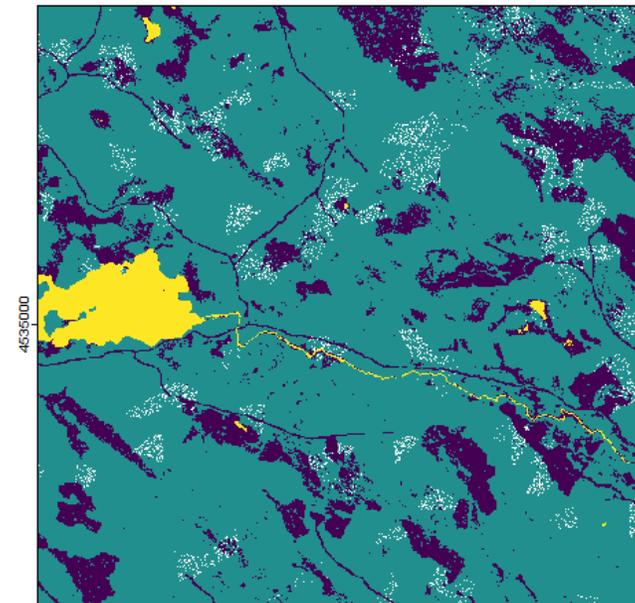
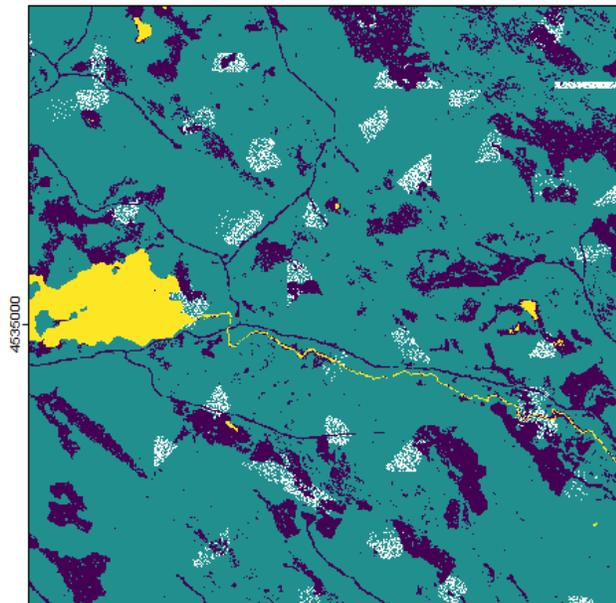
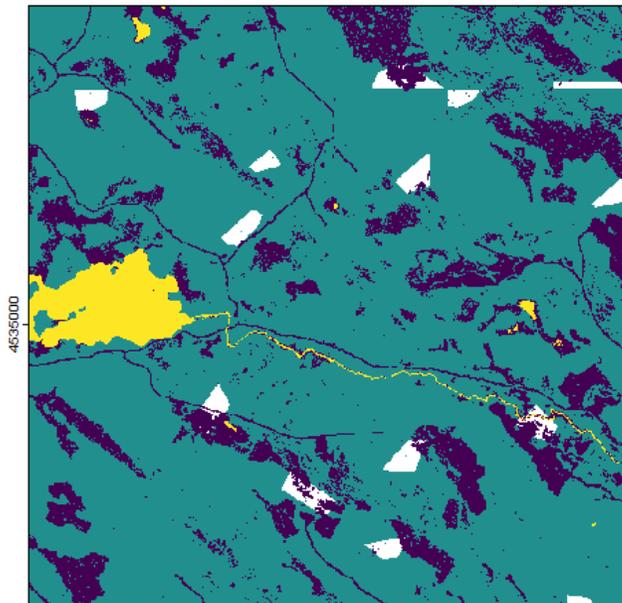
FAD in both Skane and Vasternorrland under different management



Clearcut

Shelterwood

Selection



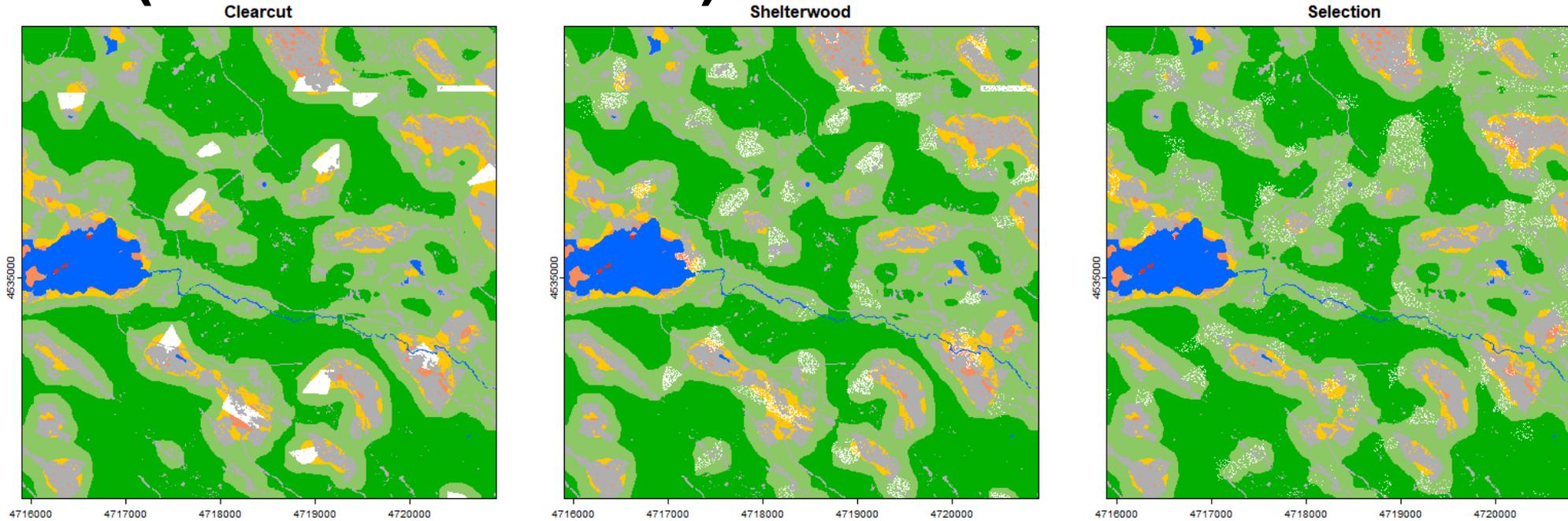
Harvest 100% of elected stands

Harvest 50% of elected stands

Harvest 25% of elected stands

Foreground cover	Color	FAD/FED/FAC	Connectivity	Fragmentation
1-Rare		$0\% \leq x < 10\%$	Very low	Very high
2-Patchy		$10\% \leq x < 40\%$	Low	High
3-Transitional		$40\% \leq x < 60\%$	Intermediate	Intermediate
4-Dominant		$60\% \leq x < 90\%$	High	Low
5-Interior		$90\% \leq x \leq 100\%$	Very high	Very low

FAD (obs. scale 10 ha) in Västernorrland



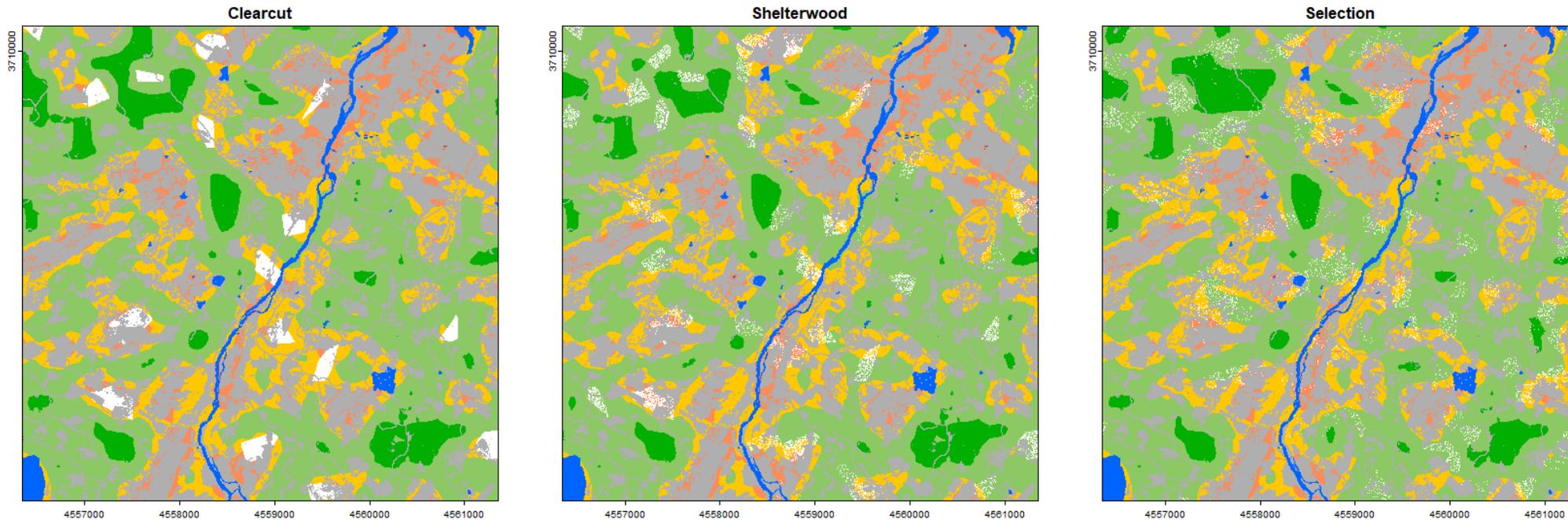
Key takeaways?

- Scattered harvest slightly reduces structural connectivity
- FAD favours large concentrated blocks to maintain interior
- At regional scales little difference in FAD between clear-cut and shelterwood

Baseline	Clear-cutting	Shelterwood	Selection
80.4%	78.9%	78.4%	78.2%
Average connectivity loss: -2.02%			

Foreground cover	Color	FAD/FED/FAC	Connectivity	Fragmentation
1-Rare		$0\% \leq x < 10\%$	Very low	Very high
2-Patchy		$10\% \leq x < 40\%$	Low	High
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5-Interior		$90\% \leq x \leq 100\%$	Very high	Very low

FAD (obs. scale 10 ha) in Skåne



Key takeaways?

- Effects are less dramatic in already fragmented landscapes
- Less interior forest (high connectivity areas) being impacted

Baseline	Clear-cutting	Shelterwood	Selection
66.3%	65.2%	64.8%	64.5%
Average connectivity loss: -1.48%			

Foreground cover	Color	FAD/FED/FAC	Connectivity	Fragmentation
1-Rare	■	$0\% \leq x < 10\%$	Very low	Very high
2-Patchy	■	$10\% \leq x < 40\%$	Low	High
3-Transitional	■	$40\% \leq x < 60\%$	Intermediate	Intermediate
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5-Interior	■	$90\% \leq x \leq 100\%$	Very high	Very low

Connectivity losses across management regimes

- Losses are greater in more intact landscapes
- Selection forestry consistently shows largest FAD decline
- Using more area for management results in more gaps, and thus greater loss of interior forest
- This stabilises at larger scales, where 90 – 100% connectivity is harder to achieve



Statistical analysis

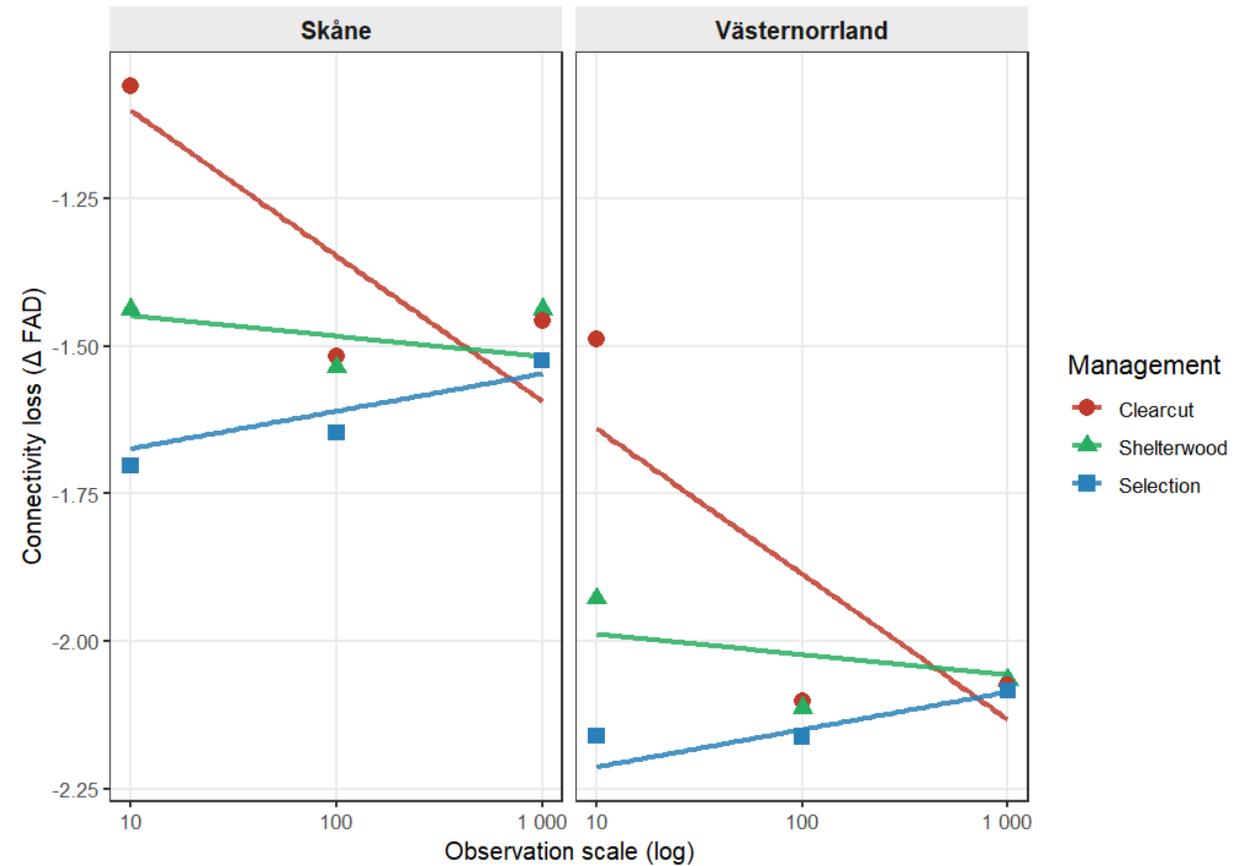
- Selection and shelterwood result in significantly greater losses than clear-cutting at fine observation scales (i.e., 10 ha)
- Alternate management regimes less sensitive to scale: potential reason that harvest clusters are more even across the landscape
- Management regimes converge at larger scales, with differences in FAD loss diminishing — consistent with large-scale losses being driven primarily by interior forest reduction

Table 1 (right) . Log-linear model coefficients for FAD connectivity loss
 Response variable: FAD gain/loss relative to baseline. Predictors: management type, $\log_{10}(\text{scale})$, region, and management $\times \log(\text{scale})$ interaction. $R^2 = 0.923$, adjusted $R^2 = 0.881$, $F(6,11) = 22.05$, $p < 0.001$.

Significance codes: *** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$ · $p < 0.1$. Bold values indicate significance at $p < 0.05$.

FAD connectivity loss by management type and observation scale

Lines show log-linear model fits; steeper slopes indicate greater scale sensitivity

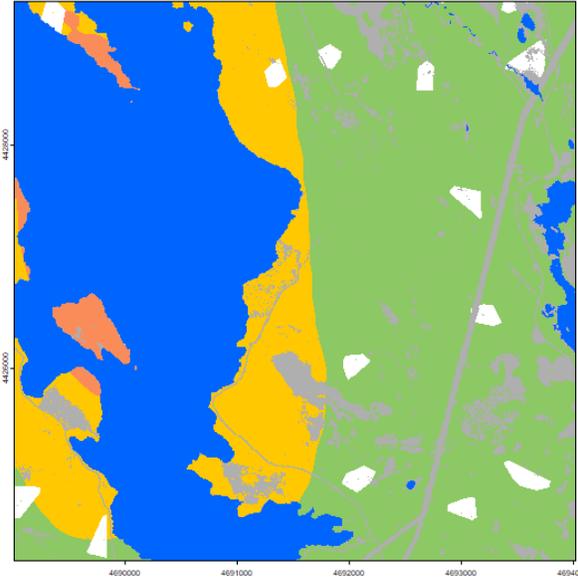
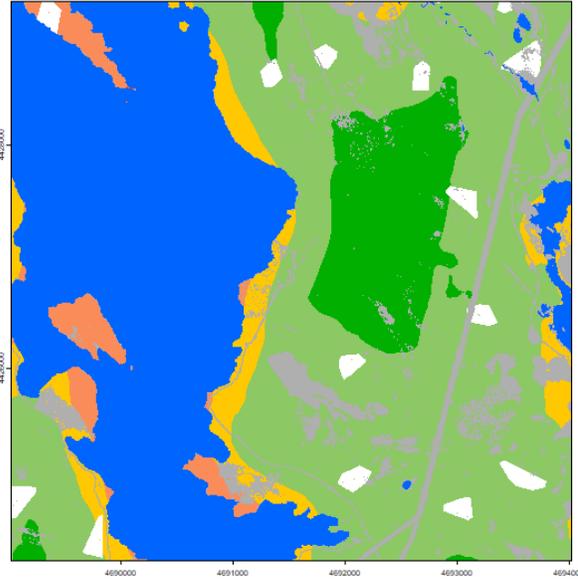
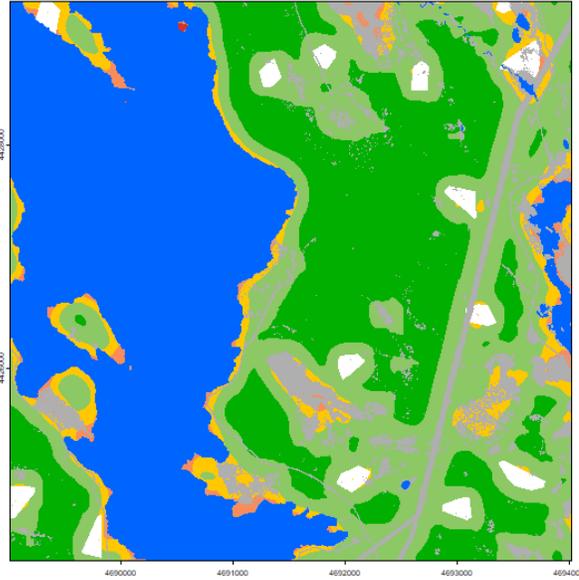


Term	Estimate	Std. Error	t value	p value	Sig.
(Intercept)	-0.854	0.128	-6.658	< 0.001	***
Management: shelterwood	-0.561	0.177	-3.162	0.009	**
Management: selection	-0.884	0.177	-4.985	< 0.001	***
log(scale)	-0.246	0.058	-4.247	0.001	**
Region: Västernorrland	-0.539	0.055	-9.861	< 0.001	***
Shelterwood \times log(scale)	0.212	0.082	2.582	0.025	*
Selection \times log(scale)	0.310	0.082	3.778	0.003	**

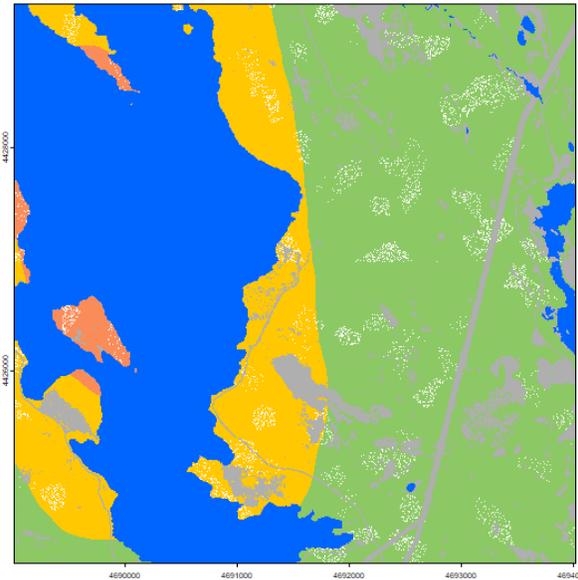
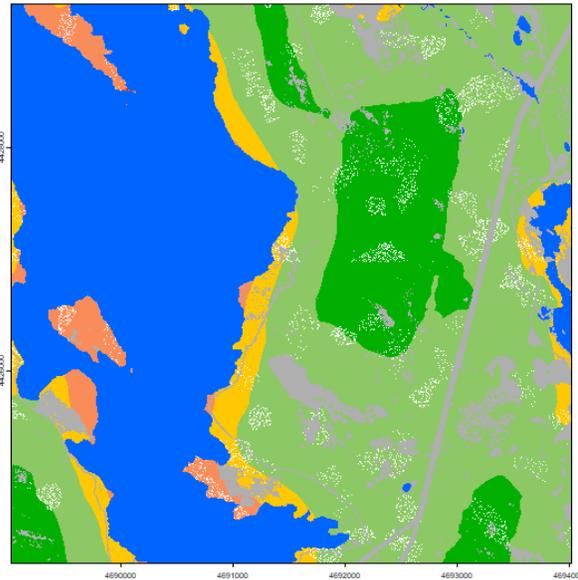
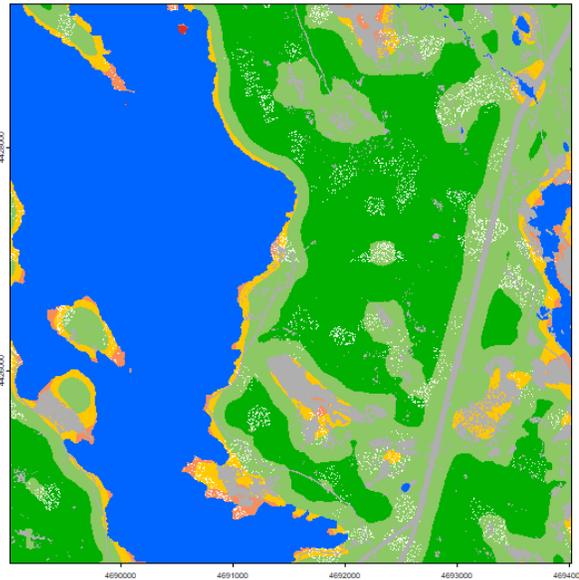
Observation Scale



CC



SF



Highlights of results

- Future restoration measures under the NRR may have a negative effect on structural connectivity
- More scattered harvesting patterns reduce interior parts of the forest and create more edge areas compared with homogenous clearcuts
- These effects are greater in more connected forest landscapes (where there is more interior forest)
- However, at larger observation scales, this levels out, and there is little difference in FAD between management regimes.



4. Concluding thoughts

TRANSFORMIT



Integrating societal demands with biodiversity conservation



The NRR will require EU Member states to **monitor connectivity** based on FAD

If based on observed forest land cover, **this will be sensitive to different forest management regimes** over short (6 year) timescales



FAD favours large, intact blocks of forest, so spreading harvest across too large an area may reduce connectivity



However, **at the large scales** required for EU-wide reporting, differences between management regimes are minimal



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