Harmonized measurements of spatial pattern and connectivity: application to forest habitats in the EBONE European Project

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Abstract

Within the EBONE European project ("European Biodiversity Observation NEtwork"), fine-grained maps of harmonized "General Habitat Categories" are available for sixty 1 km^2 samples located in Austria, Sweden and France. Three methods were proposed to map and assess automatically the spatial pattern and connectivity of habitats. They were demonstrated for forest phanerophytes habitats. Forest spatial pattern maps were obtained from mathematical morphology (GUIDOS freeware applying a 25 m edge size) to discriminate core forest, their boundaries, connectors between core areas and islets as small non-core elements. Landscape pattern mosaic maps were generated with a Landscape Mosaic Index to characterize the forest surroundings in a disk of 25 m radius. The two pattern maps were overlaid. A "Similarity" index was proposed to assess the pre-dominance of natural habitats (thus a similar/permeable forest – non forest interface) and of anthropogenic habitats (possibly fragmentation due to cultivated or artificial land use) in the context of the forest boundaries, connectors and islets. Forest interior areas were delineated with edge sizes depending on the similarity with their adjacent habitats. Finally, two forest connectivity indices (one with CONEFOR freeware) were computed for species with 500m dispersal capabilities on the basis of habitat availability, matrix permeability and inter-patch least-cost distances. The two indices were compared.

Keywords: spatial pattern, connectivity, forest habitat, European reporting

1. Introduction

The European EBONE project (**E**uropean **B**iodiversity **O**bservation **Ne**twork, http://www.ebone.wur.nl/UK) aims at European-wide habitat mapping, the delivery of habitat area estimates and the characterization of landscape level habitat pattern, fragmentation and connectivity as it is requested in the SEBI 2010 process (Streamlining European 2010 Biodiversity Indicators). Methodologies should be standardized and easily repeatable across scales, using existing capabilities from national/regional habitat monitoring programmes. Reporting is expected using the thirteen environmental zones from the European Environmental Stratification (Metzger *et al.*, 2005) based on climatic and topographic data at a 1 km^2 resolution. The EBONE in-situ database offers harmonized habitat field based maps (seamless vector layer with 400 m^2 Minimum Mapping Unit) over several 1km^2 samples thanks to the currently on-going conversion of national data into the common BioHab General Habitat Categories (GHCs, Bunce *et al.,* 2005 - figure 1). GHCs are organized in 5 super-categories *i.e.* whether the land surface element is 'Urban', 'Cultivated', 'Sparsely Vegetated' (vegetation cover below 30%),

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‘Herbaceous’, ‘Trees or Shrubs’. Each element is described according to 16 life forms based on plant structural characteristics like plant height and leaf retention division. For example, phanerophytes are classified as forest when above 5 m height.
For this study, available samples including forest phanerophytes were 16 in Sweden (NILS: National Inventory of Landscapes http://nils.slu.se), 39 in Austria (SINUS: Spatial INdices for land-Use Sustainability), and 11 in the French Provence Cote d’Azur (PACA) region (Figure1).

DESCRIPTION	CODES	Austria	France	Sweden
URBAN				
Artificial (buildings)	URB/ART	X		X
Non vegetated	URB/NON	X	X	
Vegetable gardens	URB/VEG	X	X	X
Herbaceous (garden, parks)	URB/GRA	X		X
Woddy (garden tree/shrubs)	URB/TRE			X
CULTIVATED				
Herbaceous crops	CUL/CRO	X	X	X
Bare ground	CUL/SPA		X	
Woody crops	CUL/WOC	X	X	
HERBACEOUS				
Leafy Hemicryptophytes	HER/LHE	X	X	X
Caespitose Hemicryptophytes	HER/CHE	X	X	
Cryptogams	HER/CRY			X
Helophytes	HER/HEL			X
Therophytes	HER/THE		X	
TREES/SHRUBS				
Shrubby chamaephytes	TRS/SCH			X
Low Phanerophytes evergreen	TRS/LPH		X	
Mid Phanerophytes	TRS/MPH		X	X
Tall Phanerophytes	TRS/TPH	X	X	
Forest Phanerophytes	TRS/FPH	X	X	X
SPARSELY VEGETATED				
Aquatic	SPV/AQU	X		X
Terrestrial	SPV/TER		X	X
UNCLASSIFIED	INA		X	

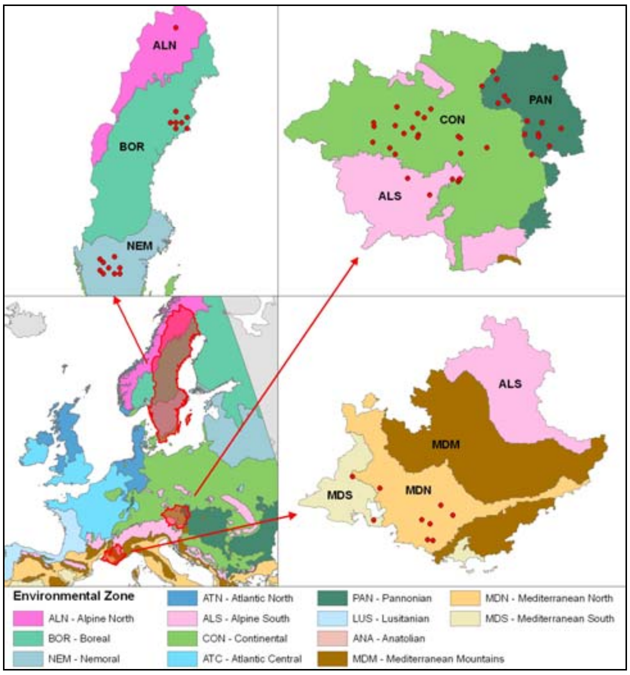

Figure 1: General Habitat Categories from the available 1km^2 samples per country (left) and localization of the samples (red dots) per environmental zones (right)

Available definitions of habitat pattern are first based on landscape structure and further refined by considering organisms’ behavioral responses to the landscape:

1. The landscape level spatial pattern of a habitat simply refers to the spatial arrangement or configuration of this habitat across the landscape.
2. Fragmentation refers to the entire process of habitat loss and isolation. Isolation means lack of connectivity and is more complicated than simple distance.
3. Connectivity refers to the “degree to which the landscape facilitates or impedes movement of organisms among resource patches”. It depends on habitat availability and spatial distribution, species’ dispersal abilities and response to the nature of the matrix.

From literature on forest fragmentation, interior forest habitats are remnant minus an edge of a certain width. They retain similar abiotic and biotic conditions to pre-fragmented conditions and do not experience strong influences from neighboring patches of other land cover categories. The width of recently exposed edges, measured by two tree heights, could range from 20 m to 160 m. Adjacent land cover types possibly influence the development of the forest edge communities and interior habitat. Depending on their similarity to the forest habitats, interfaces are more or less permeable. In temperate regions, shift in land uses at forest edges may be more important than direct forest loss. Forests fragmented by anthropogenic sources are intuitively more vulnerable to further fragmentation than forest fragmented by natural causes.

2. Methodology

Three available methods are tested to characterize spatial pattern and functional connectivity for a focal habitat class and demonstrated for the focal forest phanerophytes (FPH) habitat class.

2.1 Morphological Spatial Pattern Analysis (MSPA)

The spatial pattern of a focal habitat class can be automatically characterized and mapped at pixel level thanks to mathematical morphology using the freeware called GUIDOS (Soille and Vogt, 2009). Seven mutually exclusive pattern classes are obtained by segmenting a binary raster map (1: foreground/focal class and 0: background):
1. ‘Core’: foreground pixels beyond a distance of a given size *s* to the background; *s* is the only entry parameter of the method; the input map is eroded with a Euclidian disk of radius equal to *s*.
2. ‘Islet’: foreground pixels that do not contain any core.
3. Boundary ‘Edge of core’: outer boundary pixels of a cluster of core pixels.
4. Boundary ‘Edge of perforation’: inner boundary pixels of a cluster of core pixels when perforated by background pixels (like ‘holes’ inside a foreground region)
5. Boundary ‘Branch’: foreground pixels with no core that is connected at one end only to a connector, an edge of core or an edge of perforation.
6,7. ‘Connector’: foreground pixels with no core that connects at least two different core units (bridge) or connects to the same core unit (loop).

2.2 Landscape mosaic index

The landscape context of a focal habitat class can be characterized in a Geographic Information System by applying a landscape mosaic index (Riitters *et al.*, 2009) on a 3-dimensional raster input map (for example, natural, agricultural and urban). Landscape pattern types are defined by placing a "window" on each pixel of the input map, calculating the proportion of the three classes within the window, and putting the result on a new map at the same location. This new map has fifteen landscape pattern categories (see Figure 2) and the landscape mosaic pattern map of the focal class is obtained by masking all non-focal classes. The “window” will be a Euclidian disk of radius *s*, like in the MSPA method, to further overlay the two pattern maps.

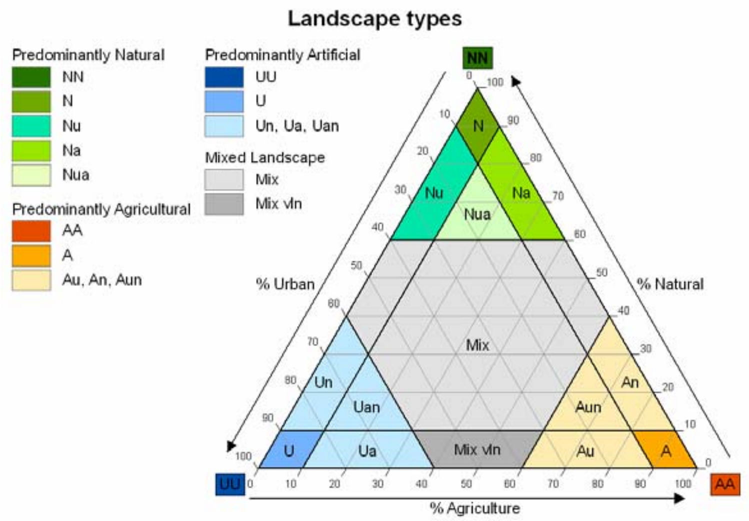

Figure 2: the fifteen landscape pattern types derived with the landscape mosaic index

The MSPA and the landscape mosaic pattern maps will then be overlaid to provide the landscape context composition in terms of mosaic pattern types for each non-core MSPA class (boundary, connector, and islet). A new “similarity” index (SI) is proposed to translate the anthropogenic or natural dominance in the surroundings. When the mosaic pattern is NN and the focal class forest, the context is similarly 100% natural, possibly permeable and most probably due to natural fragmentation causes. Anthropogenic fragmentation causes in predominant natural context are pointed at by using patterns N or (Nu, Nua, Na) in the formula.

$$SI(MosaicPattern)_{\text{MSPA Class}} = \frac{(MosaicPattern)_{\text{MSPAClass}}}{\text{MSPAClass}} \qquad (1)$$

"Interior" areas are delineated as core areas plus the NN part of the MSPA boundary edge.

2.3 Connectivity assessment

The Probability of Connectivity (PC) index for a focal class, calculated with the software Conefor Sensinode (Saura and Torne, 2009 at http://www.conefor.org), is based on topology (inter-patch distances), patch attributes like area and species specific dispersal ability. PC will be processed with the probability of dispersal, being a decreasing exponential function of the effective distance, matching to a 50% probability for a specific average dispersal distance. The effective distance is a value of movement cost through different habitats that is obtained through least-cost path algorithms, thus considering the landscape permeability between the focal patches. PC has a bounded range of variation from 0 to 1. The cost distance matching the 50% probability (p = 0.5, $\text{cost}_{d50\%}$) corresponds to the average dispersal distance ($d_{50\%}$) multiplied by the average friction per distance unit (avg_f). The average friction is set at half a logarithmic scale of frictions, being from 1 to 10,000 (avg_f = 100). PC is made comparable to the available habitat in the total landscape area, by computing its square root (RPC).

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i \cdot a_j \cdot p_{ij}}{A_L^{\,2}} \qquad (2)$$

$$RPC = \sqrt{PC} \qquad (2bis)$$

with:
$a_i\ a_j$ = area of patches
A_L = total landscape area
$p_{ij} = e^{\,k \cdot \text{cost}_{ij}}$

$$k = \frac{\ln(0.5)}{\text{cost}_{d\,50\%}}$$

$$\text{cost}_{d50\%} = \text{avg\_f} \cdot d_{50\%}$$

Another index, adapted from Hanski (1994), called Isolation Sensitive Index (IsoSi) is proposed. It is similar to PC but accounts for solely the arrival patch area size for each pair of patches. The landscape area (A_L) and the number of links (node to node) are used for normalization purposes.

$$IsoS_i = \frac{\sum_{i \neq j, i=1}^{n} a_i \cdot p_{ij}}{A_L \cdot (n-1)} \qquad (3)$$

with:
n = number of patches (nodes)

3. Result and discussion

3.1 Pattern characterization based on MSPA and landscape mosaic index

First, the GHCs vector maps of all available samples (figure 1) were rasterised at 1 m spatial resolution, re-classified into forest phanerophytes (FPH)-non forest and processed with GUIDOS using a narrow forest edge width (*s* equal to 25 m). The local morphology of the FPH habitat cover was mapped according to 4 main pattern classes (upper figure 3) and their forest area share (figure 4 left) was calculated: core, boundary (edges of core, perforation and branch), connector (bridge and loop) and islet.
Second, the GHCs 1 m raster maps were re-classified into natural (TRS, HER, SPV), cultivated (CUL) and urban (URB) habitat types (figure 1). The fifteen landscape pattern types were mapped by applying the mosaic index using a 25 m radius disk. The non-FPH classes were masked. The landscape context map of FPH habitats enables to visualize and characterize FPH interface zones (NN discriminated from Nu for example) (figure 3 bottom), and compute forest proportion of the 4 main landscape FPH pattern types for each available sample (figure 4, right):

- Two natural forest landscape patterns where FPH habitats have no (NN) or not significant (N) edge shared with cultivated and/or artificial habitats, interface zones are possibly permeable.
- Mixed natural forest landscape pattern (Nu, Nua, Na) where FPH habitats have possibly less permeable interfaces as being adjacent with cultivated and urban types of habitats
- "Some natural" forest landscape (all others) where FPH habitats are pre-dominantly embedded in non-natural context of cultivated and urban types of habitats.

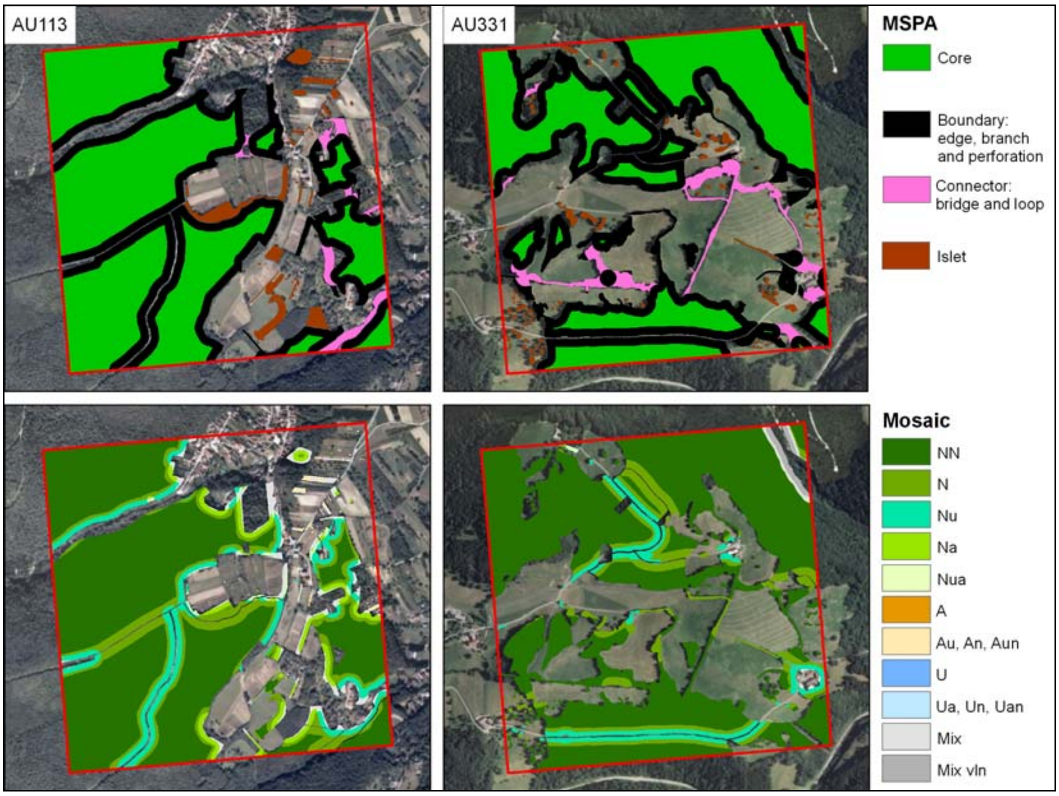

Figure 3: Example of two samples in Austria: Forest MSPA (upper) and landscape mosaic (bottom) maps

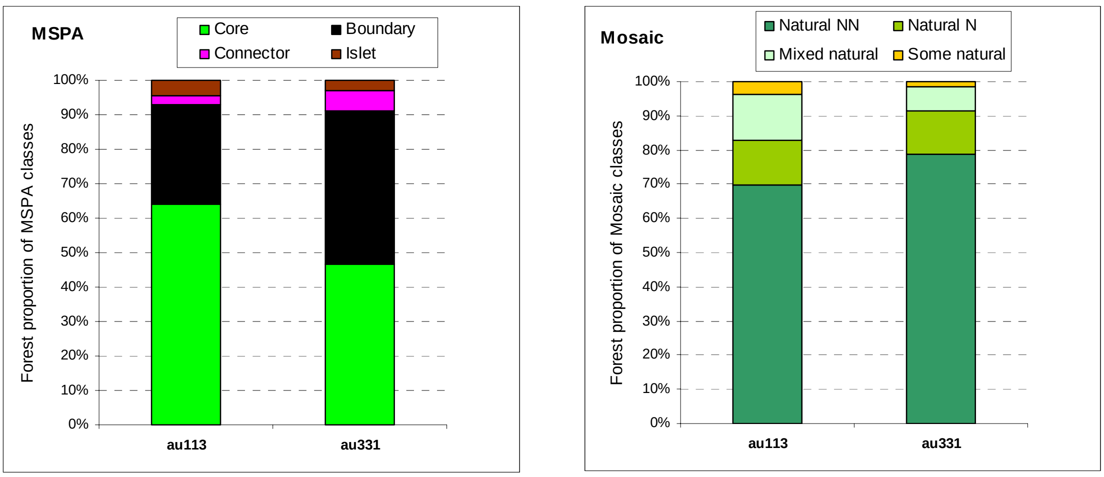

Figure 4: MSPA and landscape mosaic class proportion for the same two samples in Austria

The MSPA and the mosaic pattern maps were overlaid to compute the Similarity Index for non-core MSPA classes, and delineate "interior" forest areas which edge width depends on adjacent habitats. Forest proportion of "interior" and core areas can be compared in table 1 for two samples with different permeable boundary contexts as illustrated by the proportion of NN in the boundary MSPA class ($SI\ (NN)_{Boundary}$). Also, boundaries are more exposed to anthropogenic fragmentation in pre-dominant natural context ($SI(NuaNaNu)_{Boundary}$) in the less permeable Au113.

Table 1: Forest (FPH) proportion of "interior" and Core area, and the Similarity Index applied to boundaries in two samples in Austria (Continental zone).

Samples Id	Core FPH	Interior FPH	$SI\ (NN)_{Boundary}$	$SI\ (NuaNaNu)_{Boundary}$	$SI\ (\text{some nat.})_{Boundary}$
Au113	40.1%	43.5%	18.6%	36.7%	6.4%
Au331	26.5%	41.3%	58.9%	13.7%	3.6%

3.2 Connectivity

Connectivity indices PC, RPC and IsoSi were calculated for species dispersing at 500 m average dispersal distance. Costs of movement (friction) were assigned to every habitat types using a logarithmic increment values from FPH (lowest friction 1) to urban habitats (highest friction 10.000). The parameter $cost_{d50\%}$ was 50.000. RPC and IsoSi behaved differently (see Table 2 with the sample Au113 with fewer nodes and a less permeable context than the sample Au331).

Table 2: Connectivity indices in two different spatial configurations and permeability contexts

Samples Id	FPH area %	Nodes number	PC	RPC	IsoSi
Au113	63 %	33	35 %	59 %	50%
Au331	57 %	85	31 %	56 %	55%

IsoSi is more sensitive to the inter-patch landscape matrix permeability, possible barrier effects and is thus more focused on the probability of species movement. This was expected since the weight for areas (intra-patch) is the same than p_{ij} while it is double in the PC (and RPC) index. In contrast, PC (and RPC) reacts better to habitat availability (its intra and inter-connectivity). Are the two indices necessary to correctly describe landscape connectivity and its permeability? How sensitive a connectivity index should be to the matrix permeability? More research needed.

4. Conclusions

For all sample, harmonized pattern and connectivity maps and tabular data were organized per environmental zone. They will be incorporated into the EBONE data management structure prototype to be ready at the end of the project (2012). The methods here proposed are currently repeated over the available Earth Observation based land cover maps to prepare the integration of EO based and *in situ* habitat pattern assessment in the view of extending the geographical extent of habitat pattern/connectivity information available for biodiversity assessment (Estreguil and Mouton 2009).

References

Bunce, B. et al, 2005. A standardized procedure for surveillance and monitoring European habitats and provision of spatial data. *Landscape Ecology*, 23:11–25

Estreguil C. and Mouton C., 2009. Measuring and reporting on forest landscape pattern, fragmentation and connectivity in Europe: methodology and indicator layers. *Office for Official Publications of the European Communities*, EUR23841EN.

Metzger M.J., et al 2005. A climatic stratification of the environment of Europe. *Global Ecology and Biogeography*. 14: 549-563.

Riitters K.H., Wickham J.D. and Wade T.G., 2009. An indicator of forest dynamics using a shifting landscape mosaic. *Ecological Indicators* 9:107-117

Saura, S., Torne´J. , 2009. Conefor Sensinode 2.2: A software package for quantifying the importance of habitat patches for landscape connectivity, *Environ. Model. Softw.* (2008), doi:10.1016/j.envsoft.2008.05.005.

Soille and Vogt, 2009. Morphological segmentation of binary patterns. *Patterns Recognition Letters*. doi:10.1016/j.patrec.2008.10.015