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Used at varying spatial scales for harmonized reporting in the EBONE project

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Abstract

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This study is motivated by biodiversity related policy information needs on ecosystem fragmentation and connectivity. The aim is to propose standardized and repeatable methods to characterize ecosystem landscape structure in a harmonized way at varying spatial scales and thematic resolutions (habitat in situ versus land cover satellite based observations). Habitat landscape pattern was assessed in terms of configuration, interface mosaic context and structural/functional connectivity on the basis of three available conceptual models (morphological analysis, landscape composition moving window, network graph theory) that were customized, automated and partly combined. Input data were from the EBONE General Habitat Categories maps available over sixty 1 km^2 in-situ samples at fine scale (400 m^2 Minimum Mapping Unit). Demonstration focused on the focal forest phanerophyte habitat. Forest spatial pattern, edge interfaces and connectivity related maps and indices were obtained for all samples, and then reported per European Environmental Zones. A prototype web-based mapping client (http://forest.jrc.ec.europa.eu/ebone) was also developed to view and query the map layers and indices.
Finally, the same models and indices were applied to the satellite based European and regional land cover maps available at broad (25 ha MMU) and medium (1ha MMU) scales. Differences in patterns across the three scales were highlighted over the only common 1 km^2 analysis unit. Further, the satellite based patterns were reported at the more suitable fixed area grid of 25 km x 25 km. The overlay with the 1 km^2 in situ habitat pattern enabled to inform the macro-scale landscape structure context of the squares and compare with their micro-scale pattern.
Such study should be repeated to study spatio-temporal patterns relationships across scales once multi-temporal and larger in situ dataset will be available.

Keywords: habitat pattern, landscape mosaic, edge, connectivity, repeatable method, scale, web-based mapping

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Summary

This report presents the study conducted by the Joint Research Centre on measuring habitat pattern, fragmentation and connectivity. The study was framed in the European EBONE FP7 project ('European Biodiversity Observation Network'). It is of direct relevance to the biodiversity policy agendas where information is needed on among others, fragmentation and connectivity of ecosystem: the 2010 European Biodiversity Communication, target 5 of the 2011-2010 plan in the Convention of Biological Diversity, target 2 of the new European Biodiversity Strategy to 2020, indicator 4.7 in the Ministerial process on the Protection of Forests in Europe. The study aims at characterizing and measuring with standardized and repeatable methods across scales, ecosystem landscape structure (spatial pattern) and its connectivity, not its function or quality. Demonstration is focused on the forest ecosystem.

Data available were three-fold in spatial scales and associated thematic resolution: (1) the fine-grained EBONE 1 km squares database offering harmonized vector habitat maps (400 m^2 Minimum Mapping Unit (MMU)) thanks to the conversion of field based national data into a common format based on General Habitat Categories(GHCs) (Bunce et al., 2005), (2) Earth-Observation (EO) based land cover maps available at medium scale from regional/national survey (1 ha MMU) and from a European-wide forest product (25 m raster) and (3) EO based land cover maps available at broad-scale from the European CORINE Land Cover data (25 ha MMU). The 'General Habitat' maps available from EBONE partners over sixty 1 km^2 samples were located in the following countries and environmental regions from the Environmental Stratification of Europe (Metzger et al., 2005): part of Sweden in the Boreal and Nemoral regions, South-East France in the Mediterranean North and South regions and part of Austria in the Continental, Alpine South and Pannonian regions.

First, to guide the multi-source and multi-scale data integration, confusion matrices between the in-situ General Habitat Categories and the broad and medium scale EO based land cover classes were calculated for all 1 km^2 samples. Correspondences between classes were reported per Environmental Zones and for GHCs aggregated at top hierarchical level (urban, agricultural, forest, natural non-forested). Due to obvious differences in class definitions and scales, the correspondences between the GHCs in situ and EO based classes differed among environmental regions and were in general rather low. Consequently, it is advised to treat separately each of the three scales and data source in a pattern analysis. Each data will convey a scale specific and class specific message for a targeted ecosystem. The three messages may or not be correlated, still may provide complementary and new perspectives of the same ecosystem (forest habitat in the forest landscape for example).

Three fundamental components of habitat pattern - morphology, interface mosaic context and connectivity - were assessed on the basis of three available conceptual landscape models that were customised, automated and partly combined. Demonstration was focused on the in situ GHCs habitat samples and forest phanerophytes were selected as focal habitat for the study.
Forest habitat spatial pattern maps were obtained from mathematical morphology analysis (GUIDOS freeware applying a 25 m edge size) to discriminate core forest, their boundaries, connectors between core areas, branches like protrusion at edges and islets as small non-core elements. Landscape habitat pattern mosaic maps were generated with a landscape mosaic model to characterize the forest surroundings in terms of other natural/semi-natural non forested habitats, agricultural and urban habitats within a disk of 25 m radius. The two pattern maps were overlaid to assess the proportion of edge forest (boundaries, connectors, branches and/or islets) bordering natural habitats (thus a similar/permeable forest – non forest interface) and bordering anthropogenic habitats. The proposed 'Similarity' index summarizes edge interfaces and possibly

link to anthropogenic and natural fragmentation causes. Forest interior areas could be further delineated either with a fixed edge size (GUIDOS core forest) or with edge sizes depending on the similarity of adjacent habitats. Connectivity assessment was based on a third model accounting for habitat availability, matrix permeability and inter-patch distance computed as Euclidian and effective distances (respectively straight line or inter-patch least-cost). Two other connectivity indices were proposed for their sensitivity to the inter-patch matrix permeability. They were compared for species with 500 m dispersal capabilities. At last, spatial pattern, edge interfaces and connectivity measures obtained by applying the three models for all habitat samples were organized per European Environmental Zones.

The same three models were applied on the Earth Observation based land cover maps that were available at broader and medium scale (respectively 25 ha and 1 ha mapping units). Forest cover spatial pattern map, landscape mosaic pattern maps and forest landscape mosaic pattern maps were obtained. The share of the different pattern classes was provided for the French region. Mixed mosaic pattern classes were found relevant to identify broad and medium scale fragmentation processes. The study of connectivity was conducted on the French region and applied analysis units of 25 km x 25 km fixed area grid which best captures local landscape processes without losing too much information, still appropriate with 1ha and 25 ha MMU input maps.

At last, the study addressed the correspondence and the feasibility to integrate multi-scale and multi-source land cover and habitat based pattern estimates. Preliminary pattern results were given for the connectivity measures. Differences in connectivity across the three (in situ, satellite broad and medium) scales were highlighted over the only common 1 km^2 analysis unit. Further, the satellite based connectivity indices that were reported per fixed area grid of 25 km x 25 km, were used as a background layer for the overlay of the squares. Such overlay enabled to inform the macro-scale connectivity context of the squares and also to directly compare it with the micro-scale habitat pattern within the square.

This study proposed a standardised characterisation of pattern and automatic computation of pattern measures according to three models that were successfully applied at varying scales, thus enabling micro-scale habitat and macro-scale land cover analysis to be conducted for the same targeted ecosystem (in this case forest). Such exercise may prove beneficial to further study spatio-temporal pattern-process relationships across scales once multi-temporal and larger in situ dataset will be available.

Regarding dissemination and reporting of the results, a prototype web-based mapping client (http://forest.jrc.ec.europa.eu/ebone) was also developed to view and query the habitat map layers, the habitat pattern map layers and their associated area and pattern indices. The spatial layers and their associated data were prepared in a common ESRI Shapefile format for all samples. They were sent to the web client using the OGC WMS standard, which were published through MapServer.

1 Introduction

1.1 Study frame and objectives

This research on spatial pattern is framed within the European EBONE project (European Biodiversity Observation Network, http://www.ebone.wur.nl/UK/). EBONE, among other tasks, aims at European-wide habitat mapping for the delivery of habitat area estimates and the characterization of landscape level habitat pattern, fragmentation and connectivity. The project contributes to respond to information needs identified in the previous 2010 and the new 2011-2020 Biodiversity policy agendas: Indicator 13 of SEBI2010 process (Streamlining European 2010 Biodiversity Indicators (SEBI 2010 and 2007; EEA, 2009) carried out for the 2010 European Biodiversity Communication (EC, 2006), target 5 of the 2011-2020 strategic plan in the Convention of Biological Diversity (CBD, 2020), target 2 of the new European Biodiversity Strategy to 2020 (EC 2011), and the indicator 4.7 to assess the State of Europe's Forest (SoEF, 2007 and 2011).

This study overall aims at making progress on a European-wide harmonized, standardized and easily repeatable characterization of spatial pattern and connectivity. It also addresses the integration of in-situ and Earth Observation based data for this scale-dependent topic. Methodologies should use existing data and capabilities like in-situ habitat data from national/regional 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.

This study benefits from previous research on European-wide implementation of the two indicators EEA/SEBI2010 Indicator 'fragmentation and connectivity of ecosystem' and the Forest Europe 4.7 Indicator 'Landscape level forest spatial pattern' (SoEF, 2007 and 2011; Estreguil and Mouton, 2009). Estreguil and Mouton, 2009 and Saura et al., 2011 conducted a European-wide appraisal exercise based on Corine Land Cover data (CLC1990 and 2000), thus capturing structural landscape processes with a broad-scale of observation. Within EBONE, methodologies were upgraded allowing for a more detailed assessment of habitat pattern, fragmentation and connectivity. They were tested for the first time over fine-grained habitat maps. Furthermore, a multi-scale appraisal exercise of processes was conducted. The spatial measures proposed were applied at three scales of observation (fine-grained, medium and broad scales) on the basis of readily available harmonized habitat and land cover datasets in different European Environmental Zones. The results were compared across observation scales.

This report is structured into four Chapters:

- In the first Chapter, concepts like landscape level spatial pattern, fragmentation and connectivity are defined. Landscape pattern processes leading to change in biodiversity, and issues like interior habitat, edges, linear features and connecting features and matrix permeability are briefly reminded.
- The second Chapter describes the data available at three different scales.
- The third Chapter introduces the four methods (three main methods and one combination of two methods) selected to characterize spatial pattern, edge interfaces, mosaic pattern and connectivity. The spatial framework for reporting the measures is also introduced.
- The fourth Chapter provides the results of the study. First, confusion matrices show the correspondence of habitat and land cover databases. Second, the implementation of the methods is detailed at the habitat fine scale level using the 1km squares, the General Habitat Categories and the focal forest phanerophyte habitat. Pattern map products are presented. Pattern and connectivity assessment are then organized per Environmental Zones. The last part of the Chapter illustrates the

application of the three main methods on available Earth-Observation derived land cover maps at medium and broad scales and presents associated pattern and connectivity products. The multi-scale integration of land cover and habitat level pattern products and connectivity assessments is finally discussed.
- The last Chapter is about dissemination of the results and concludes this report. In particular, the prototype web map viewer that was developed in the frame of this study to report the habitat pattern data is briefly presented.

1.2 Definitions

1.2.1 Habitat versus land cover definitions

Bunce et al. (2008) argued on habitat definitions and proposed consistent ones in the context of the current needs for monitoring purposes. Habitats should be defined independently to the traditional vegetation classes and should incorporate structure. The development of the ecosystem concept was originally mainly based on vegetation. Indeed, detailed vegetation records are essential in determining habitat quality and condition (conservation status) (Haines-Young et al., 2000), but they are not required for monitoring habitat extent. In terms of significance for animal populations, vegetation structure is often more important than vegetation classes (Fox et al., 2003), also some widely recognized habitats are not directly linked to traditional vegetation associations (Rodwell et al., 2002). Existing European habitat classifications (e.g., the EUNIS system; Davies and Moss, 2002) have been based on species, geographical location, vegetation classes and environmental factors. These classifications have been successfully applied to produce general descriptions of the occurrence of classes in protected areas. However, they may not be appropriate for a monitoring exercise targeting the wider country side, because definitions of many of the terms used (e.g. montane and sub-Mediterranean) are not provided (Bunce et al., 2008) and the level of field information required is too high. Within EBONE, the BioHab General Habitat Categories (GHCs) from Bunce et al. (2005) are adopted. Habitat is defined as 'an element of the land surface that can be consistently defined spatially in the field in order to define the principal environments in which organisms live. GHCs are organized in five super-categories i.e. whether the element is 'Urban', a'Crop', 'Sparsely Vegetated' (vegetation cover below 30%), 'Trees or Shrubs', or 'Wetland'. Each element is then described according to sixteen life forms based on plant structural characteristics like plant height and leaf retention division (e.g. ten LF's for herbaceous and six LF's for shrubs and trees). In more details, plant life forms (Raunkiaer, 1934) are defined on the basis of the location of buds in the adverse season (precisely, based on the arrangement of perennating tissues of the plants growing under climatic conditions and their adaptations for surviving the unfavourable season - cold winter and summer drought). They are five principal life forms: phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes. They separate grassland, shrub and forest species. In EBONE, phanerophytes habitats are classified as low, medium, tall, or forest when trees are above 5 m height). GHCs include water bodies which extend to the Mean High Water (MHW) at the coast. It therefore excludes marine systems.

The land cover definitions and comments that are reported below are mainly from Herold et al. (2006 a,b) and Jansen et al. (2004 a,b). Land cover is defined as the observed (bio)-physical cover on the Earth's surface. It includes vegetation and man-made features as well as bare rock, bare soil and inland water surfaces. In situ and satellite land observations as well as different disciplines (geography, ecology, geology, forestry, land policy and planning, etc.) use and refer to land cover as the most obvious and detectable indicator of land surface characteristics. Land cover provides the most useful indicator of human interventions on the land. Land cover changes quickly over time and is a good proxy for dynamics of the Earth surface resulting from a variety of drivers and factors. Land-mapping activities can be understood as a process of information extraction governed by a process of generalization. This implicitly points to the loss of detail in the interpretation process to map specific land features. The degree of generalization and thus the efficiency of representing realty in two-dimensional form are directly linked to three major factors. The 'thematic' component refers to the land classification system and the adopted land cover classes. 'Cartographic' standards include the spatial reference system, and the minimum mapping unit (MMU) and the mapping scale. The 'interpretation' process is function of the characteristics of the source data, the timing, interpretation procedures, skills of the interpreter etc. These factors affect the mapping products, in terms of its content, quality, flexibility and efficiency for applications. At a certain level, land cover provides the common ground for many actors and disciplines. Technologies such as satellite Earth observation and geographical information systems (GIS) have vastly increased the availability of land cover information. These technologies, however, do not solve the problem of standardization and interoperability with other information.

This study is framed within a work-package of the EBONE project that aims at addressing the integration of in-situ land observations (typically sample based habitat maps) and satellite land observations (typically land cover maps available over large areas), for two purposes: (1) satellite based habitat mapping and (2) pattern mapping, fragmentation and connectivity assessment. This second sub-task is the focus in this report and relies on available maps. In order to guide the multi-source and multi-scale data integration exercise, the study will first address the confusion between the GHC habitat classes' in the habitat maps and the land cover classes in the land cover datasets available.

1.2.2 Landscape structure: pattern, fragmentation, connectivity

The characterization of habitat pattern is purely structural in a first instance and can then be refined with a more species-specific, thus functional, view:

- The landscape level spatial pattern of a habitat simply refers to the spatial arrangement or configuration of this habitat across the landscape.
- Fragmentation refers to the entire process of habitat loss and isolation. In terms of pattern, it means reduction in habitat amount, increase in number of patches, decrease in their size, and increase in isolation of patches (Fahrig, 2003). Isolation means lack (or loss) of connectivity and is more complicated than simple distance. Shift of land uses at the edges of certain habitat types also relate to fragmentation.
- Connectivity refers to the degree to which the landscape facilitates or impedes movement of organisms among resource patches" (Tailor et al., 1993) and depends on habitat availability (area), its spatial distribution or topology (inter-patch distance), dispersal ability of the species and their response to the nature of the matrix.

The EBONE project calls for standardized methods easily repeatable. Standardization, is a 'top down' process, and is therefore far more rigid than harmonization. Common definitions and standards are looked upon in the project to derive habitat and land cover relevant pattern and connectivity information from in-situ and satellite based maps.

1.2.3 Landscape structure and biodiversity

Major pattern related principles relevant for biodiversity and fragmentation (focus on forest fragmentation) are available in Estreguil and Mouton (2009) and in Kupfer et al. (2004 and 2006). They are briefly summarized below.

Interior and edge habitats are defined as follows:

- Interior habitats: The maintenance/restoration of interior habitat which are remnant minus an edge of a certain width. Interior areas of a forest patch retain similar abiotic and biotic conditions to prefragmented conditions and do not experience strong influences from neighboring patches of other land cover categories (Rutledge, 2003). Speaking very broadly, interior areas of forest patches potentially provide more suitable habitat '-and depending on their size may act as refuge areas- for interior species, i.e. species that can only tolerate forest conditions or are sensitive to edge effects. Interior and edge habitats are important to discriminate.

- Edge habitats: Because of their exposure to non-forested ecosystems, forest edges develop distinct environmental gradients that in turn lead to the development of unique forest edge communities dominated by a suite of species adapted to edge conditions (e.g., shade intolerant species). This is commonly referred to as the edge effect. New perforations in interior habitat patch potentially introduce edge effects (internal fragmentation process) into interior habitats. The penetration distance of non-forested species into forest is notoriously species-specific. A neighborhood approach to edge function must be used to at least characterize the adjacent land cover types possibly influencing the development of the forest edge communities that in turn, possibly influence processes within the interior habitat.
- The width of edge habitats: In forestry, the edge width is generally related to the height and structure of the forest. Franklin and Forman (1987) use a measure equivalent to two tree heights as a conservative rule-of-thumb to estimate the width of recently exposed forest edges; he mentioned sizes for wide edges (160 m, 120 m) and narrow edges (20 m). A 100 m edge width corresponds to edge effects for many interior species (Forman and Alexander, 1998; Harper et al., 2005; Laurance, 2008) and permeability distance for invasive species.

Over time, primary effects of fragmentation on species are: (1) sample effects due to the total loss of habitat patch, and (2) area effects due to the reduction of habitat patch size, 3) isolation effects due to increased functional distance between habitat units, and 4) edge effects due to newly created edge habitat (remnants subject to edge effects and the effects of edges on interiors).

- Sample and area effects relate more to the change of the landscape matrix and are primarily due to habitat loss, changes in spatial pattern and in habitat quality.
- Edge and isolation effects on species depend on the permeability of adjacent land cover types (the nature of the non-focal habitat matrix informs about functional distances between focal habitat units). Adjacent land cover types possibly influence the development of the forest edge communities that in turn, possibly influence processes within the interior habitat. Interfaces may be categorized as more or less permeable depending on the similarity of adjacent habitat types (Lidicker and Peterson, 1999). Generalist forest species will probably better accommodate a reduction in interior forest habitat when patches are embedded in natural non forested lands than in new urban or agricultural lands.
- Forest cuttings including temporarily un-stocked forest land are important for biodiversity: forest fragments in productive valley bottoms cleared for intensive agriculture, productive forest cuts for forestry, less productive forest removed for urban development.
- Most species of insects, mammals and birds are sensitive to fragments sizes of 1, 10 and 100 ha (Farina, 1998). Broadly speaking, removal of all size of core forest patch may be critical to some species.
- The fragmenting cause of a focal habitat is either anthropogenic or natural in origin and can be possibly identified by the habitat or land cover/use (pre-dominantly anthropogenic or natural) bordering the focal habitat. In temperate regions shift in land uses may be more important than direct forest loss and the vulnerability of a forest patch to further fragmentation could be looked upon based on edge (Wade et al., 2003).
- Connectivity particularly raises the important distinction between structural (connectivity is a function of landscape) and functional measures (function of landscape and organism) (Kindlmann and Burel, 2008). Structural connectivity refers to the degree of habitat connectedness while functional connectivity, while related to structural connectivity, refers more directly to species. Structural connectivity is essential for conservation management even if its functional aspect as pathways for dispersal and immigration

remains an open issue (Lambeck, 1997; Vos et al., 2001; Lindenmayer et al., 2002). Connectivity is crucial for the migration and survival of species, for the control of invasive species and diseases. The lack or loss of connectivity reduces the capability of organisms to move from one habitat patch to another and can interfere with pollination, seed dispersal, wildlife migration and breeding. For wildlife population survival and reduction of extinction risk, the habitat should be both abundant and well connected (Saura and Pascual-Hortal, 2007).

Spatial pattern processes relevant for biodiversity assessment tend to be local. Most studies on the ecological effects of pattern are thus conducted at landscape level and for management units (Kupfer, 2006). Even over large regions, fine scale data are thus needed to capture pattern processes that then, should be preferably aggregated over spatial units for reporting without losing too much information. Finally, Koper and Schmieglow (2006) show how habitat pattern and habitat amount are inextricably linked in assessments.

2 Data

Landscape structure analysis requires spatially continuous maps (Gustafson, 1998; Kupfer, 2006). Habitat fine grained maps are preferable to capture local processes but do not offer extensive coverage over large regions. Land cover data derived from remote sensing are more easily obtained over large regions but do not offer the thematic habitat level of detail. Different geographical extents and different thematic and spatial scales are already obvious from the harmonized maps available for this study.

2.1 Fine scale habitat maps (below 0.1 ha MMU, 1 km^2 samples)

The EBONE in situ 1 km^2 database offers harmonized habitat vector maps (400 m^2 MMU) thanks to the conversion of national data into the common General Habitat Categories (GHCs, Bunce et al., 2005). GHCs are organized in five super-categories ('Urban', 'Cultivated', 'Herbaceous' (vegetation cover below 30%), 'Trees/Shrubs', 'Wetland'). In the last three categories, they are five principal life forms: phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes. They separate grassland, shrub and forest species. Phanerophytes habitats are classified as low (0.3 - 0.6 m), medium (0.6 - 2 m), tall (2 - 5 m), or forest (above 5 m height). The samples including forest phanerophytes that were available for this study are presented in Table 1 and Figure 1. They were sixteen in the boreal and nemoral zones (Swedish National Inventory of Landscapes http://nils.slu.se), 39 in the continental, pannonian and alpine south zones (SINUS project: Austrian Spatial INdices for land-Use Sustainability), and eleven in the Mediterranean Provence and Cote d'Azur (PACA) region in France (from EBONE work-package 6 provided by P. Roche). More details on data sources and conversion to GHCs can be found in Bunce et al., 2009.

Table 1
General Habitat Categories from the available 1 km² samples per country.

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) gardens	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	TPS/LPH		X	
Mid Phanerophytes	TRS/MPH		X	X
Tall Phanerophytes	TPS/TPH	X	X	
Forest Phanerophytes	TPS/FPH	X	X	X
SPARSELY VEGETATED				
Aquatic	SPV/AQU	X		X
Terrestrial	SPV/TER		X	X
UNCLASSIFIED	INA		X	

2.2 Medium scale maps (approx. 1 ha MMU, regional coverage)

Regional land cover maps based on the CORINE nomenclature were available at medium scale (usually 1 ha) for the French PACA region (CRIGE-PACA, 2006 and Annex 1). In addition, the Pan-European-wide forest cover map of year 2000 (FMap2000, Pekkarinen et al., 2008) was available. It was automatically derived from Landsat ETM+ (30 m re-sampled to 25 m) scene by scene processing and mosaicking. It provides a geometrically accurate forest mask (point level agreement over 80% and close to 90% in central-European conditions). Forest areas are occupied by forest and woodlands with a vegetation pattern composed of native or exotic coniferous and/or broadleaved trees. Forest definition is based on CLC nomenclature; it is a forest cover class rather than a forest use class. Forest excludes woodlands with trees smaller than 5 m height, forest nurseries and regeneration with canopy closure less than 30%, burnt areas and forest roads. Transitional woodlands may be included due to high tree density.

2.3 Broad scale maps (25 ha MMU, European wide coverage)

The European-wide harmonized CORINE Land Cover data for years 2000 (CLC2000), 1990 and 2006 are based on high resolution Landsat imagery. 44 land cover classes (Bossard et al., 2000) are mapped at broad scale (seamless vector layer with 25 ha MMU, also available in raster format by resampling to 100 m). Land cover data from the CORINE Land Cover provide a big picture view of the landscape, classifying tracts of land based on the distribution of dominant cover types. The time span of Landsat imagery is about one year, the geometric accuracy is below 25 m, the thematic accuracy is 85% at CLC level 3 products in 2000 (CLC, 2006).

2.4 Data in Environmental Zones

Table 2 summarizes per environmental region the data available (number of in-situ samples for which fine grained habitat maps are available, broad and medium scale Earth Observation based land cover maps).

All assessments will be reported per environmental regions using the environmental stratification from Metzger et al., 2005 (Figure 1). This classification system has been derived from statistical analysis of climatic and topographic data at a 1 km^2 resolution. Thirteen Environmental Zones have been established, linked hierarchically to 84 environmental strata. Strata will not be considered for reporting at this stage because the number of samples is too low.

In EBONE, this stratification will be used to derive the minimum of 1400 samples required for the surveillance and monitoring the General Habitat Categories to an acceptable statistical accuracy in Europe. Such a sampling design will further enable data from the sample kilometer squares to be integrated at the stratum level. At the end of the EBONE project, this stratification system will thus hold information for all the 1 km squared samples in Europe and will be used to display the spatial information of any parameter and indicator (for example pattern and connectivity indices) either at the kilometer square level (e.g, altitude), or at the environmental strata or region. The hypothesis is that when field data is available, they could be linked to land cover map to develop sophisticated estimates of the distribution of the main habitats in Europe and monitor changes in habitats, their patterns and land uses.

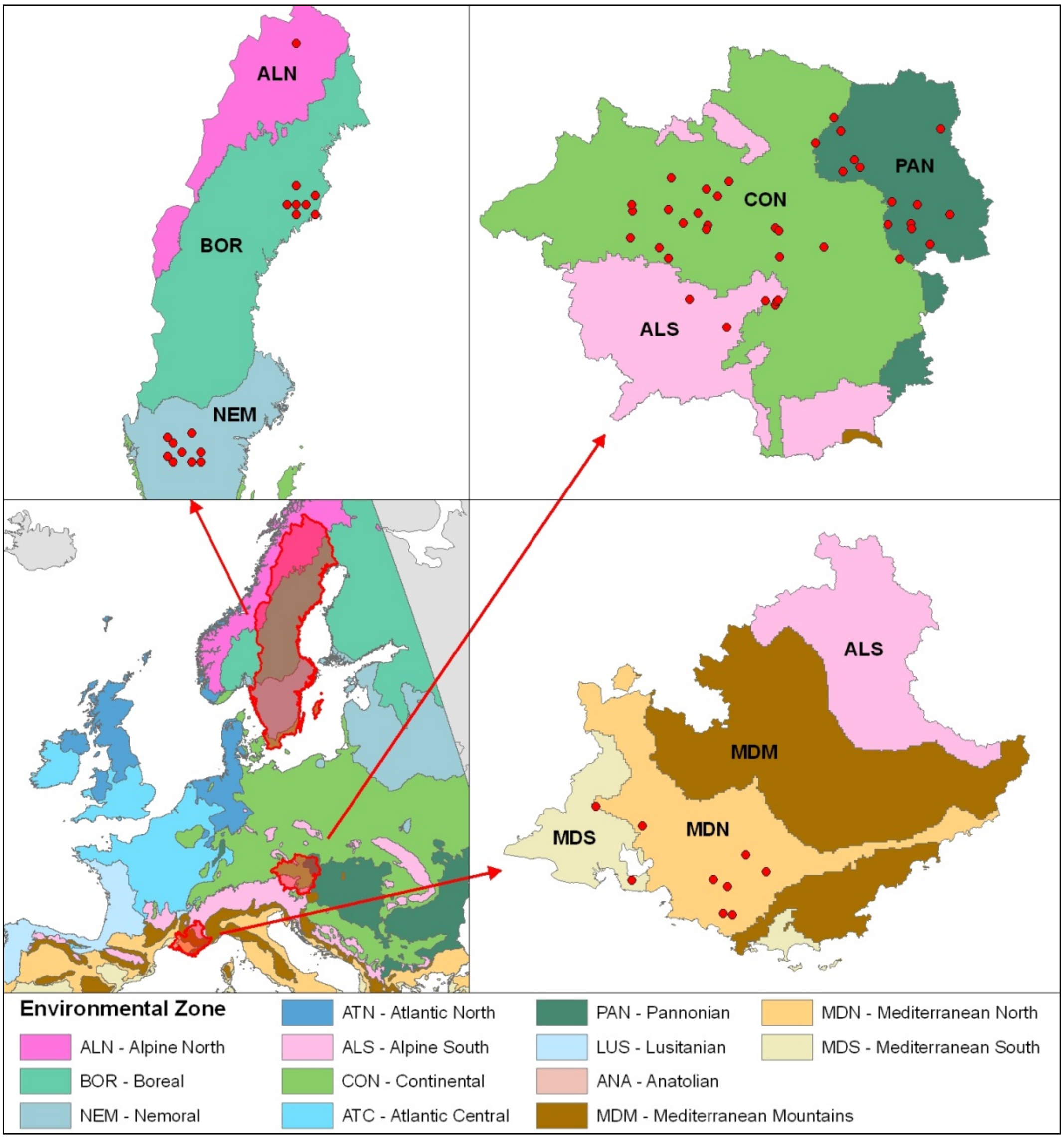


Figure 1
Localization of the samples (red dots) per environmental zones.

Table 2
Summary table of datasets per environmental regions (Metzger et al., 2005)

Environmental region	Country	Number habitat samples	LAND COVER MAPS				
			Medium scale			Broad scale	
			Fmap 2000	PACA 2006	National	CLC 2006	CLC 2000
Boreal	Sweden	7	X		X	X	X
Nemoral	Sweden	9	X		X	X	X
Med. North	France	8	X	X		X	X
Med. South	France	1	X	X		X	X
Continental	Austria	24	X			X	X
Alpine South	Austria	3	X			X	X
Pannonian	Austria	12	X			X	X

3 Methods

3.1 Correspondence between land cover and habitat maps

Confusion matrices were produced to assess the correspondence of the thematic and spatial resolutions of the land cover and habitat datasets. GHCs habitat maps were overlapped with CLC layer in order to depict which CLC land cover classes were intercepted by GHCs habitats categories. Both classifications were harmonized by aggregating the classes to four principle classes - Urban, Agriculture, Forest, and Natural non-forested - as shown in Table 3.

Table 3
Correspondence between GHCs habitat and CLC land cover with aggregation into four main classes.

CLASS	CLC II LEVEL DESCRIPTION AND CODE		GHCs CODE
URBAN (URB)	Urban fabric	11	URB/ART
	Industrial, commercial and transport units	12	URB/NON
	Mine, dump and construction sites	13	URB/VEG
	Artificial, non-agricultural vegetated areas	14	URB/GRA
			URB/TRE
AGRICULTURE (AGR)	Arable land	21	CUL/CRO
	Permanent crops	22	CUL/SPA
	Pastures	23	CUL/WOC
	Heterogeneous agricultural areas	24	
FOREST (FOR)	Forests	31	TPS/TPH
			TPS/FPH
NATURAL NON-FORESTED (NNF)	Scrub and/or herbaceous vegetation associations	32	TRS/SCH
	Open spaces with little or no vegetation	33	TPS/LPH
			TRS/MPH
			SPV/AQU
			SPV/TER
			HER/LHE
			HER/CHE
			HER/CRY
			HER/HEL
			HER/THE

Similarly, the correspondence (confusion matrix) was produced to assess the match between GHCs habitat maps and the Forest Map 2000 layer. In this case, the GHCs categories were aggregated into two classes - Forest and Non-forest - as available in the Forest Map classification. Four available methods to characterize key structural (spatial pattern) and functional (connectivity) measures were implemented: Morphological Spatial Pattern Analysis; Landscape mosaic model, combination of both; and connectivity model. From these, a range of indicators measures were derived and tested for the focal forest phanerophytes (FPH) habitat class.

3.2 Morphological spatial pattern analysis (GUIDOS - MSPA)

According to literature (Kupfer, 2006; Betts, 2000), pattern and fragmentation has been mainly measured with traditional patch based metrics (mean and number of patch size, distance) over a systematic fixed area grid from freeware such as Fragstats (McGarigal et al., 2002) or with area density scaling measures from the 'amount-adjacency' model based on image convolution (Riitters et al., 2002). More recently, a new method based on mathematical morphology (Soille and Vogt, 2009) was developed to classify and map locally at pixel-level six mutually exclusive land-cover pattern classes ('core', 'perforated,' 'edge,' 'islet', 'connector', and 'branch') from any binary data (i.e. black and white images). It provides more precise spatial and thematic classification than the amount-adjacency model and at any scale (Vogt et al., 2007ab). This method provides a standard and unambiguous pixel-level spatial pattern classification for a focal class and is relevant to our purpose. Its main limitation is the over-simplification of the landscape in a binary model.

The freeware called GUIDOS (Soille and Vogt, 2009) enables the automatic implementation of spatial pattern mapping based on mathematical morphology analysis (Figure 2) through the application named MSPA. This application segments a binary raster map (foreground/focal class set to 2, background set to 1, missing/ignored class set to 0) through a series of morphological transformations. It was run to produce the seven mutually exclusive spatial pattern classes for the foreground/focal forest phanerophytes (FPH) class (Figure 2):
1. *Core:* foreground pixels beyond a distance of a given edge size parameter *s* to the background, and obtained by erosion of input map 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).*

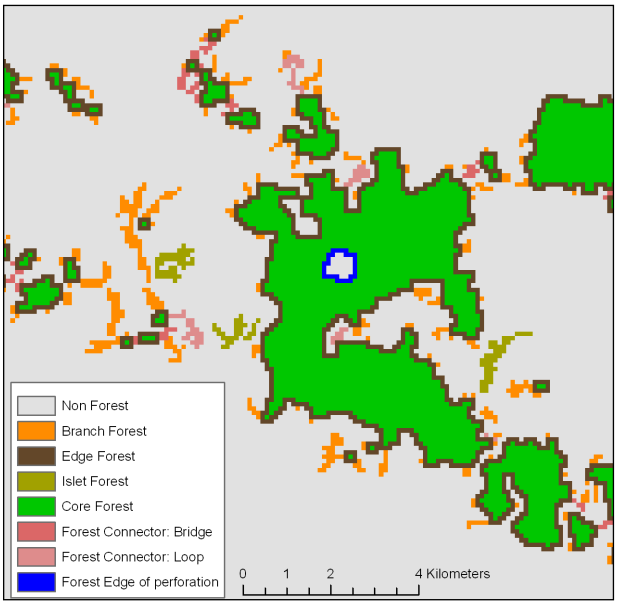


Figure 2
Forest spatial pattern classes derived from morphological analysis at pixel level.

The edge size, *'s'* the only entry parameter requested by the method, is fixed by the operator and represents the distance to the borderline that enables the delineation of the interior part of the focal class' patches. Traditional measures can be derived, such as average core patch size and frequency of core units per ranges of patch sizes (<1 ha, 1-5 ha, >5 ha) that are relevant for species with specific area ranges requirements.

Depending on the user interest and focus, the GUIDOS/MSPA pattern classes can be aggregated in main 'MORPH' pattern categories in different ways. The share of each MORPH pattern category in the focal habitat is relevant such as for example:

- The habitat proportion in core quantifies the proportion of interior habitat.
- The habitat proportion in edges, edges of perforation, branches and connectors quantify the proportion of all edge habitats. Edge habitats are potentially located in the perimeter of core patches (perforation, branch, edge classes) and/or in the connectors between core patches (loop and bridge). Alternatively, the user may prefer discriminate connectors and branches features.
- The habitat proportion of connector *per se* quantifies habitat areas connecting different core patches while the habitat proportion in branches relate more to protrusion at edges (for example encroachment of woodlands in pastures due to land abandonment). Connectors and branches may also be merged since they are both linear features that are important to identify along for example agricultural fields.
- The habitat proportion of islets quantifies areas of small and/or elongated and thin non-core fragments. Islets are potentially vulnerable to disappearance due to their shape and size, and potentially offer stepping stones for the dispersal of focal habitat-dependent species between core patches.

In this study two different aggregations of pattern classes will be demonstrated. The first aggregation will result in the following MORPH classes: Interior Forest (IF): *core* ; Boundary (BO): *edge* and *edge of perforation,* Branch (BR): *branch* ; Connector (CO): *bridge* and *loop* ; Islet (IS): *islet.* The second aggregation will differ from this one in merging the *branch* with *edge* and *edge of perforation* to make the MORPH Boundary (BO) class.

3.3 Landscape mosaic model

The second pattern approach is based on the landscape mosaic index (Wickham and Norton, 1994, Riitters et al., 2000 and 2009) and provides Landscape Pattern Types. The landscape context of a focal habitat class is characterized from a 3-dimensional raster input map (for example, three classes such as 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 of the central pixel. This new map has fifteen landscape pattern categories (see Table 4 and Figure 3) and the landscape mosaic pattern map of the focal class is obtained by masking all non-focal classes (Figure 4).

This method has the advantage to function in a tri-polar space. The derived pixel-level map of landscape mosaics can help to visualize 'interface zones' (e.g., the 'forest-artificial interface') and other spatial gradients of land cover composition (Figure 4). In this study, the 'window' was an Euclidian disk of radius s, like in the GUIDOS/MSPA method, which enabled the combination of the two pattern maps (see next section).

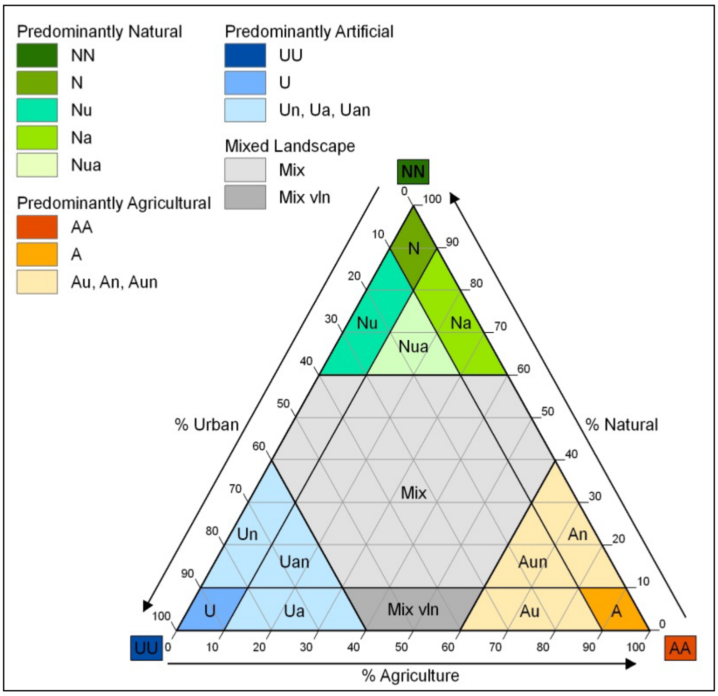


Figure 3

The fifteen landscape pattern types derived with the landscape mosaic index.

Table 4

Landscape types definition with proportions of land cover classes.

CLASS	TYPE		Urban %	Agriculture %	Natural %
Predominantly Urban	1	U	[80 -100]	[0 -10]	[0 – 10]
	2	Ua	[60 – 90[	]10 – 40]	[0 – 10]
	3	Uan	[60 -80[	]10 – 30]	]10 – 30]
	4	Un	[60 – 90[	[0 – 10]	]10 – 40]
Predominantly Agriculture	5	A	[0 – 10]	[80 -100]	[0 – 10]
	6	Au	]10 – 40]	[60 – 90[	[0 – 10]
	7	Aun	]10 – 30]	[60 -80[	]10 – 30]
	8	An	[0 – 10]	[60 – 90[	]10 – 40]
Predominantly Natural	9	NN	0	0	100
	10	N	[0 – 10]	[0 -10]	]80 -100[
	11	Na	[0 – 10]	]10 – 40]	[60 – 90[
	12	Nua	]10 – 30]	]10 – 30]	[60 -80[
	13	Nu	]10 – 40]	[0 – 10]	[60 – 90[
Mixed Landscape	14	Mix	[0 – 60[	[0 – 60[	[10-60[
	15	Mix vln	]30 – 60[	]30 – 60[	[0-10[

Figure 4

Processing steps in the landscape mosaic index (top: left, orthophoto and sample Au333 Austria; right, aggregation of GHCs into three landscape classes; (bottom: left, landscape types from mosaic process; right, landscape types extracted for forest land).

The fifteen pattern mosaic types can be further organized in three main categories: predominantly natural, predominantly agricultural, and predominantly artificial. In each category, the proportion of mixed class is relevant to identify fragmentation processes. For example the Mixed Natural landscape pattern type (MN) is the sum of Nu, Nua and Na and identifies the land area where intermingling of artificial and agriculture occurs into predominantly natural land.

Landscape pattern types extracted for a focal class (forest) can be aggregated into four main mosaic types to create the mosaic habitat pattern map (MOSAIC classes):

- In the predominant natural context category (Nx), the 'core natural' pattern type (NN) are areas where the forest habitats suffer no direct edge effects from cultivated and/or urban habitats, and are always adjacent to natural/semi-natural habitats. Interface zones are likely permeable for species. Fragmentation processes when any, is probably from natural causes, otherwise due to temporarily unstocked forest areas.
- In the predominant natural context category (Nx), the 'mainly natural' (N) patterns type are forest areas bordering mainly natural habitats (80%) while the 'mixed natural' pattern types (MN = Na + Nu + Nua) are forest areas still in natural context but with a more significant share of adjacent cultivated and urban habitats. Typically MN forest pattern types points at anthropogenic fragmentation processes and are probably more at risk of further degradation.
- In other than predominant natural contexts (Ux, Ax, Mix), the 'some natural' forest pattern type (SN = sum of all the other types) are forest habitats predominantly embedded in non-natural landscape context (i.e. forest patch in agricultural landscape), and that more likely suffer strong edge effects from cultivated and/or urban types of habitats.

The habitat shares in each mosaic pattern types are reported, as well the natural/semi natural habitats in the landscape (NP).

3.4 Combining morphological and landscape mosaic pattern

The combination of the morphological based model and the landscape mosaic models consist in overlapping their respective pattern maps for a focal class, the edge size *s* used in GUIDOS and the radius *s* of the disk in the mosaic model must be the same. By doing so, the landscape mosaic context of each MORPH habitat pattern class ($MORPH_{Mosaic}$) is mapped at pixel level and further accounted in measures.

Combining the MSPA and the mosaic pattern maps enables to amend the concept of the 'interior' areas of the focal class. While MORPH core areas applied a fixed edge width, the new interior forest (IF*) class is obtained by the MORPH Core class enlarged by the NN part of the MORPH boundary class (BO_{NN}) (in other words the "Core-NN). IF* gives the core forest area but applies no edge size when the adjacent habitat is similar to the focal class (likely more permeable interface when forest is adjacent to 'natural' habitats). The forest proportion of the interior areas (IFP*) is calculated.
Further, the combination of these two models enables to account for the context of each non-core MORPH pattern classes (for example BO, BR, CO, IS). A new 'similarity' index (SI) is proposed to translate the landscape mosaic context (MOSAIC equal to NN, N, MN, or SN) of each specific MORPH habitat pattern class.

$$\mathrm{SI\_MORPHClass}_{\mathrm{Mosaic}} = \frac{\mathrm{MORPHClass}_{\mathrm{Mosaic}}}{\mathrm{MORPHClass}}$$

For forest edges as delineated by the MORPH BO class, SI-BO_{NN} gives the NN proportion in the MORPH boundary class, i.e. the proportion of forest edges bordering only natural habitats; SI-BO_{MN} provides the proportion of forest edges in a less natural context (Mixed Natural) most probably pointing at anthropogenic fragmentation causes at edges. Similarly, SI-IS_{NN}, SI-CO_{NN} SI-LI_{NN} are calculated.

3.5 Connectivity model

The freeware Conefor Sensinode 2.2 (Saura and Torne, 2009 at www.conefor.org) computes the Probability of Connectivity (PC) index for a focal class in a given landscape, based on topology (inter-patch distances), patch attributes like area and species specific dispersal ability (Figure 5). The index combines landscape graph theory, a probabilistic connection model and the habitat availability concept. A landscape graph is made up of a set of nodes (i.e. forest patches) and links between nodes. In this model, each link between every two patches is characterized by a probability of dispersal, obtained as a function of distance (a decreasing exponential function of either the Euclidean (straight-line) edge-to-edge distance or the effective distance, matching to a 50% probability for a specific average dispersal distance).

In the PC connectivity index formulas (Table 5), a_i and a_j are the areas of habitat patches i and j. A_L is the maximum landscape attribute and corresponds to the total landscape area (i.e. area of the study region, comprising both habitat and non-habitat patches). The strength of each link is characterized by p_{ij}, which is the probability of direct dispersal between patches *i* and *j* (without passing through any other intermediate habitat patch) (Figure 6). The product probability of a path (where a path is a sequence of patches in which no patch is visited more than once) is the product of all the values of p_{ij} for all the links in that path. p^*_{ij} is the maximum product probability of all the possible paths between patches *i* and *j* (including direct dispersal between the two patches) (Figure 6). If patches *i* and *j* are close enough or have a strong direct connection, the maximum probability path will simply be the direct movement between patches *i* and *j* ($p^*_{ij} = p_{ij}$). If patches *i* and *j* are more distant or have a weak direct connection, the 'best' (maximum probability) path will probably consist of several steps through intermediate stepping stone patches yielding $p^*_{ij} > p_{ij}$. When two patches are completely isolated from each other, then $p^*_{ij} = 0$. When $i = j$ then $p^*_{ij} = 1$ (a patch can always be reached from itself); this relates to the habitat availability concept that applies to PC, in which a patch itself is considered as a space where connectivity exists.

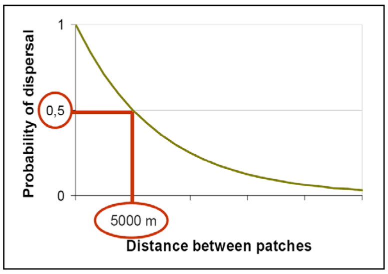


Figure 5

A logarithmic function of Dispersal Probability with a d50% = 5 km.

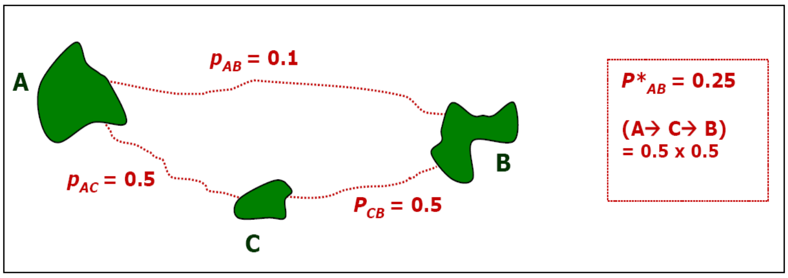


Figure 6

Difference between Probability of Connectivity P_{AB} and Maximum Probability of Connectivity P^*_{AB} (Saura and Torne, 2009).

In this study, a 500 m and a 250 m average dispersal abilities were arbitrarily taken for demonstration. We tested two types of distance to characterize the connections between nodes, as suggested in Saura and Torne (2008). Euclidian distances and homogeneous matrix were used to compare connectivity across scales (cf Section 4.5) because one dataset was solely binary (non-forest class not detailed). Euclidean (straight-line) distances are appropriate for those species that are not much affected by the land cover types (matrix) between the forest habitat patches (e.g. some bird species), for landscapes with a more or less homogeneous matrix, or simply as a first level of analysis that can be refined later with some more detailed considerations. Analysis of connectivity was otherwise done using effective distances i.e. by considering the permeability of the landscape between the forest patches and least-cost models. Estimating effective (minimum-cost) distances has the advantage to take into account the variable movement abilities and mortality risk of a species through different land cover types. The effective distance represents a value of movement cost through different habitats that is obtained from least-cost path algorithms (ESRI ArcGIS 'Cost Distance' and

'Path Distance'), thus considering proxies of landscape permeability between the focal patches. Costs of movement (friction f) were assigned to every habitat types using a logarithmic increment values from forest/trees tall types of habitats (FPH and TPH were allocated lowest friction 1) to urban habitats (highest friction 10.000). The cost distance matching the 50% probability ($cost_{d50\%}$) corresponds to the average dispersal distance ($d_{50\%}$ = 500 m, alternatively 250 m) 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).

As for the equivalent connected area (ECA) index in Saura et al. (2011), the square root of the PC (RPC in Table 5) was selected due to its more reasonable and usable range of variation (from 0 to the total forest proportion FP), and to an easier and straightforward interpretation with respect to the forest area proportion. The 'distance' between RPC and the forest proportion (FP) in the landscape depends on how large are the patches, how far they are one another and how much the non-forest landscape matrix in between patches is natural/semi-natural. In two landscapes with equal forest area proportion (FP), the more connected forest landscape will be the one with RPC closest to FP, i.e. with larger and more effectively connected patches.

Further, our concern was about the sensitivity of the connectivity index to the landscape matrix permeability. Indeed in RPC, for each pair of patches, the weight for areas (intra-patch) is important in comparison to the small value of the p_{ij} component. Thus, another available connectivity index adapted from Hanski (1994), called Isolation Sensitive Index (IsoSi), and similar to PC, is tested. It accounts for solely the arrival patch area size for each pair of patches, thus put less emphasis on intra-patch connectivity and render it more sensitive to the inter-patch landscape matrix permeability and possible barrier effects and more focused on the probability of species movement. The landscape area (A_L) and the number of links (node to node) are used for normalization purposes.

A third new index of connectivity, untitled the Average of Probability of Connectivity (APC), was also proposed by removing areas in the PC formula and thus by accounting only for the probability of dispersal between patches. It is then normalized with the square of the patch number. This new index integrates the configuration of patches but not their areas, and focuses on species' movement in the non-forested landscape matrix thus its likely permeability.

Table 5
List of standard measures derived from the connectivity model.

	Attributes and input values	Description [unit]
$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i \cdot a_j \cdot p_{ij}}{A_L^2}$	a_i a_j	area of patches i and j [m2]
	n	number of patches (nodes)
$RPC = \sqrt{PC}$	$cost_{ij}$	least cost path from i to j
$IsoS_i = \frac{\sum_{i \neq j, i=1}^{n} a_i \cdot p_{ij}}{A_L \cdot (n-1)}$	p_{ij} = e $_k$ • $cost_{ij}$	probability of dispersal
	$cost_{d50\%}$	constant of probability exponential function
	d50% = 500	dispersal distance [m]
$APC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} p_{ij}}{n^2}$	avg_f = 100	average dispersal distance
	costd50% = avg_f • d50% = 50.000	cost distance at 50% probability
	A_L = 1.000.000	total landscape area [m2]

3.6 List of indicator measures

The indicator measures which were tested for the focal FPH habitat are summarized in Table 6. Their compilation required the following input data:

- the binary (FPH-non FPH) raster mask, the raster morphological spatial pattern map derived from the MSPA application of GUIDOS, using a fixed edge size *s* (cfr. Section III.2),
- the habitat raster map reclassified into three main classes, the landscape mosaic pattern types maps derived from the landscape mosaic model applied with a fixed neighborhood window size (cfr. Section III.3), and the landscape mosaic patterns types maps of the focal FPH habitat,
- the input vector habitat map, the connectivity measures per spatial analysis units based on the Probability of Connectivity index (PC) and the Isolation Sensitive Index ($IsoS_i$), obtained with least cost distances for a fixed average species dispersal distance and friction values assigned for each habitat classes in the landscape (cfr. Section III.5).

Spatial analysis units to report pattern and connectivity measures were arbitrarily bounded to the 1 km^2 habitat sample for the local habitat scale based on the fine scale habitat maps. In addition for regional scale assessments that are typically conducted with medium and broad scale data, the concern was to capture local processes without losing too much information; thus analysis units were fixed at 25 x 25 km^2 cell size. The 1 km^2 grid was too small to grab processes from medium and broad scale data and the 25 x 25 km^2 cell size was found a good compromise between processing capacity and time constraints. Reporting was then done per Environmental Zones.

Table 6
List of measures based on the three models.

HABITAT PATTERN MEASURE	FORMULA (input: habitat FPH, s = 25 m)
Cover of the focal habitat in landscape (sample) Focal habitat proportion in landscape (sample) Natural/semi-natural habitat share in sample Dominant landscape mosaic type of sample	FC FP NP MMOSAIC (15 classes)
Habitat share in each MORPH morphological class (Core, Boundaries, Branch, Connectors, Islets) Linear features	MORPH-P=MORPH/FC (with MORPH as IF, BO, BR, CO, IS) LI = BR+CO
Habitat share in each landscape mosaic context MOSAIC pattern type ('core natural NN, 'mainly natural N, 'mixed natural MN, or 'some natural SN)	MOSAIC-P=MOSAIC/FC (with MOSAIC as NN, N, MN or SN)
Habitat in interior part of patches	
Habitat proportion in interior part (habitat beyond a fixed distance to border (MORPH Core with a fixed edge width))	IFP = IF/ FC
Habitat proportion in interior part or/and adjacent to natural land (habitat beyond a fixed distance to border when bordering cultivated and/or urban habitats, no edge width applied when adjacent to natural land)	$IF^* = IF + BO_{NN}$ $IFP^* = IF^* / FC$
Habitat in boundaries/edges of patches with an 'interior' part	
Habitat proportion in boundaries (fixed edge width)	BOP= BO/FC
Proportion of boundaries along natural habitats Proportion of boundaries along anthropogenic habitats	$SI\text{-}BO_{NN}$, $SI\text{-}BO_{N}$ $SI\text{-}BO_{MN}$, $SI\text{-}BO_{SN}$
Habitat in linear features as connectors and branches	
Habitat proportion in connectors and branches	COP=CO/FC; BRP=BR/FC

HABITAT PATTERN MEASURE	FORMULA (input: habitat FPH, s = 25 m)
Habitat proportion in linear features	LIP = LI / FC
Proportion of connectors (BR, LI) along natural habitats Proportion of connectors (BR, LI) along anthropogenic habitats	$SI\text{-}CO_{NN}$, $SI\text{-}CO_{N}$ (or SI-BR, SI-LI) $SI\text{-}CO_{MN}$, $SI\text{-}CO_{SN}$ (or SI-BR, SI-LI)
Habitat in islets	
Habitat proportion in islets	ISP = IS / FC
Proportion of islets along natural habitats Proportion of islets along anthropogenic habitats	$SI\text{-}IS_{NN}$, $SI\text{-}IS_{N}$ $SI\text{-}IS_{MN}$, $SI\text{-}IS_{SN}$
Habitat connectivity for low dispersal ability	**Species dispersal d= 500m, 250m**
Habitat connectivity (area and connectivity sensitive index) (patch area, inter-patch distance, matrix permeability)	PC, RPC
Habitat connectivity (isolation sensitive index) (arrival patch area, inter-patch distance, matrix permeability)	IsoSi
Habitat connectivity (landscape permeability sensitive index) (inter-patch distance, matrix permeability)	APC

4 Results

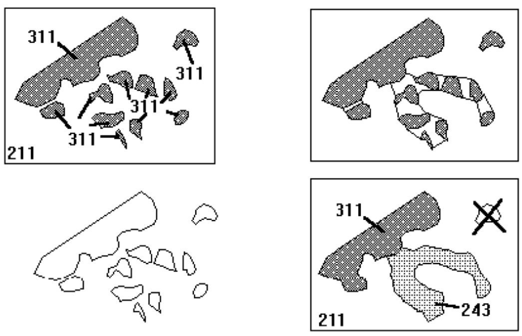
4.1 Correspondence between habitat and land cover datasets

4.1.1 Foreword on thematic and spatial correspondence

There are obvious differences in forest definition from the four different maps available although each map applied the commonly used classifiers:

- vegetation life form (trees, shrubs, herbaceous vegetation, non-vegetated);
- leaf type (needle-leaf, broad-leaf) and leaf longevity (deciduous, evergreen);
- non-vegetated covers (bare soil/rock, built up, snow, ice, water);
- density of each land category in percent cover.

The forest land cover type describes land that is dominated by trees. As a rule in CORINE Land Cover nomenclature, a canopy closure or aerial crown density of at least 30% is required before a tract of land will be classified as forestland cover type, the minimum mapping unit is 25 ha and the trees height is at least 5 m. The minimum mapping unit of 25 ha conceals heterogeneity of mapped land cover types (for example the class 'land principally occupied by agriculture with natural vegetation in it', see Figure 7) and the rule on the minimum size of linear features (above 100 m) lead to a loss of information. As a result, forest areas may be underestimated (Uuttera et al., 2003) with Corine Land Cover based maps. Forest pattern processes are only broadly described depending on the compactness of the forest cover. Similarly at medium scale, the JRC forest map or the regional CLC based map apply the same forest nomenclature but the former has a 25 m raster resolution (625 m^2) and the latter a 1 ha minimum mapping unit.



Loss of forest patches due to the 25 MMU and the 300 m distance rule for aggregating units below 25 ha (forest parcel into CL211: arable land). (CLC311: coniferous forest, CLC243: agricultural land interspersed with natural vegetation) (Bossard et al., 2000)

Figure 7
Loss of forest patches at broad scale CLC map.

The standing forest classes (broadleaves, coniferous, mixed) include young plantations when at least 500 stems by hectare are reached. It does not include other wooded land, young plantations less than 500 stems/ha, clear cuts, burned areas, or forest nurseries. Forest habitat data contain detailed field-based information about the extent, composition, and structure of forests at scales as fine as the stand level and the individual tree. Although the forest land cover data and the forest habitat data are correlated, one should not expect them to be equivalent or be alarmed by differences.

Forest land cover data is not equivalent to land use where forest logging is usually not considered a forest loss, but just a temporary change in land cover. Under this point of view, the CLC and the forest GHCs habitat definitions are very different from the international forest standard definition (FAO FRA 2005). They give an interesting and useful monitoring perspective from an ecological point of view on the contrary to forest use data. Forest land temporarily unstocked is a non-forest class in our dataset at the three different scales (fine, medium, broad). Forest fragmentation, caused by forest harvesting, have a very dynamic and cyclic nature that may be beneficial to some species and highly detrimental to others (land mechanically disturbed after clear cut may be replanted or left to natural regeneration). Transitional woodland is mapped in all EBONE datasets but successional stages of phanerophytes are only documented with the GHC habitat data.

To capture more permanent forest fragmentation types due to land development (urban sprawl and transport infrastructure), GHC habitat maps should include roads to be more relevant for road ecological issues. Land cover products should also be complemented by road vector database to properly address similar issues at broad scale.

4.1.2 Confusion matrices

Confusion matrices show clearly the scale issues when data with different spatial resolutions are overlapped. Table 7 was generated by the overlap of GHC and CLC2006 (1 ha MMU) layers in the PACA region. CLC 1ha has no artificial cover (URB), due to the absence of large urban elements, while sparse buildings or unpaved roads are classified on the GHCs layer. Due to different definitions and scales of observation, the confusion of forest (FOR) and natural non-forested (NNF) is significant in the Mediterranean North Environmental Zone, leading low overall correspondence. The agreement between agricultural lands and cultivated habitats is rather good.

Table 7
Confusion matrices between GHCs habitats and CLC 1ha, year 2006.

ENV. ZONES	GHC	CLC 1ha				Correspondence Rate
		URB	AGR	FOR	NNF	
MDN	URB	0.0%	9.1%	1.8%	3.4%	
	AGR	0.0%	82.6%	0.8%	4.1%	
	FOR	0.0%	4.7%	65.8%	43.9%	
	NNF	0.0%	3.6%	31.6%	48.6%	**55.5%**
MDS	URB	0.0%	4.4%	1.7%	0.9%	
	AGR	0.0%	56.9%	1.0%	5.5%	
	FOR	0.0%	38.3%	73.1%	4.1%	
	NNF	0.0%	0.5%	24.1%	89.6%	**75.7%**

The confusion matrices generated from the GHC and 25m European wide Forest map layers provide higher correspondence rates for the same region (Table 8), still some non-forested categories (i.e. MPH, LPH) are classified as forest habitat patches in the European wide forest.

Table 8
Confusion matrices between GHCs habitats and Forest map 25m, year 2000.

ENV. ZONES	GHC	Forest Map 2000		Correspondence Rate
		F	NF	
MDN	F	70.5%	27.2%	
	NF	29.5%	72.8%	**71.5%**
MDS	F	63.1%	35.9%	
	NF	36.9%	64.1%	**63.5%**

Confusion matrices generated from the overlap of GHC and CLC2000 map (25 ha MMU) over the Austrian study area are shown on Table 9, where two major mismatches are noticeable. The high percentages of AGR class for CLC classified as NNF for GHC in the Continental and Alpine South Zones (mountainous areas) is probably explained by the fact that pastures, are an agricultural land use in CLC (2.3.1 code) while they are natural herbaceous habitat (HER) in the GHCs classification. The time difference between CLC2000 and the recent GHCs habitat map may explain the second mismatch where large areas of shrub recently turned to forest in the Alpine South Zones (high NNF percentage in the forest GHCs category).

Table 9
Confusion matrices between GHCs habitats and CLC 25 ha, year 2000.

ENV. ZONES	GHCs	CLC 25 ha				Correspondence Rate
		URB	AGR	FOR	NNF	
ALP	URB	0.0%	6.3%	3.2%	6.3%	
	AGR	0.0%	0.5%	0.0%	0.1%	
	FOR	0.0%	20.0%	88.7%	84.0%	
	NNF	0.0%	73.2%	8.1%	9.7%	38.6%
CON	URB	56.5%	7.1%	3.4%	1.8%	
	AGR	8.1%	45.9%	1.9%	3.9%	
	FOR	5.4%	11.1%	76.6%	9.6%	
	NNF	30.1%	35.8%	18.0%	84.7%	55.6%
PAN	URB	73.2%	6.5%	1.4%	0.0%	
	AGR	20.5%	67.3%	7.5%	0.0%	
	FOR	4.8%	14.4%	83.2%	0.0%	
	NNF	1.4%	11.8%	8.0%	0.0%	68.7%

The GHC-FM2000 confusion matrices provide higher correspondences than the GHCs-CLC25ha ones (Table 10), although some FM2000 patches are found in GHC pastures (HER) in the mountainous environmental zones (ALP and CON).

Table 10
Confusion matrices between GHCs habitats and Forest map 25 m, year 2000.

ENV. ZONES	GHC	Forest Map 2000		Correspondence Rate
		F	NF	
ALP	F	71.5%	21.0%	
	NF	28.5%	79.0%	74.2%
CON	F	63.3%	8.5%	
	NF	36.7%	91.5%	81.1%
PAN	F	82.7%	8.5%	
	NF	17.3%	91.5%	90.2%

Confusion matrices between GHCs and CLC (1 ha MMU) in Sweden also outline major disagreements. A high percentage of CLC artificial land classes are in the Natural Non Forested (NNF) GHCs habitats and not in the urban habitats classes for Boreal zone (Table 11). The CLC map classified those large areas as artificial vegetated areas, while the GHCs habitat separates vegetation from artificial covers thanks to its higher resolution. Furthermore, more than half of the CLC forest is NNF GHCs in the Nemoral and Boreal zones (large shrubs areas classified as forests in CLC).

Table 11
Confusion matrices between GHCs habitats and CLC 1ha.

ENV. ZONES	GHCs	CLC 1ha				Accuracy Rate
		URB	AGR	FOR	NNF	
BOR	URB	9.5%	6.8%	2.3%	1.2%	
	AGR	0.0%	61.2%	0.5%	0.2%	
	FOR	6.9%	2.1%	30.9%	13.5%	
	NNF	83.6%	30.0%	66.2%	85.1%	51.4%
NEM	URB	62.8%	23.6%	5.3%	3.2%	
	AGR	1.9%	68.1%	0.9%	0.7%	
	FOR	7.0%	1.4%	43.3%	5.4%	
	NNF	28.3%	7.0%	50.5%	90.7%	62.5%

The forest classification of GHCs shrubs is even more obvious in the confusion matrices between GHCs and the 25 m European wide Forest Map, leading to low correspondence especially in the Boreal zone (Table 12).

Table 12
Confusion matrices between GHCs habitats and Forest map 25m, year 2006.

ENV. ZONES	**GHC**	**Forest Map 2000**		**Accuracy Rate**
		F	**NF**	
BOR	F	23.8%	19.7%	
	NF	76.2%	80.3%	36.1%
NEM	F	33.8%	7.1%	
	NF	66.2%	92.9%	64.4%

These multi-source and multi-scale results are not surprising and Figure 8 explicitly shows the upscale simplification process of the forest cover from the fine-grained GHCs to the broad scale CLC level in two samples in Austria with two diverse spatial configurations. This supports even more the need for conducting pattern and connectivity assessments at one single observation scale and anticipates a difficult multi-scale integration exercise, when for example studying the correlation between micro and macro-scale patterns and connectivity.

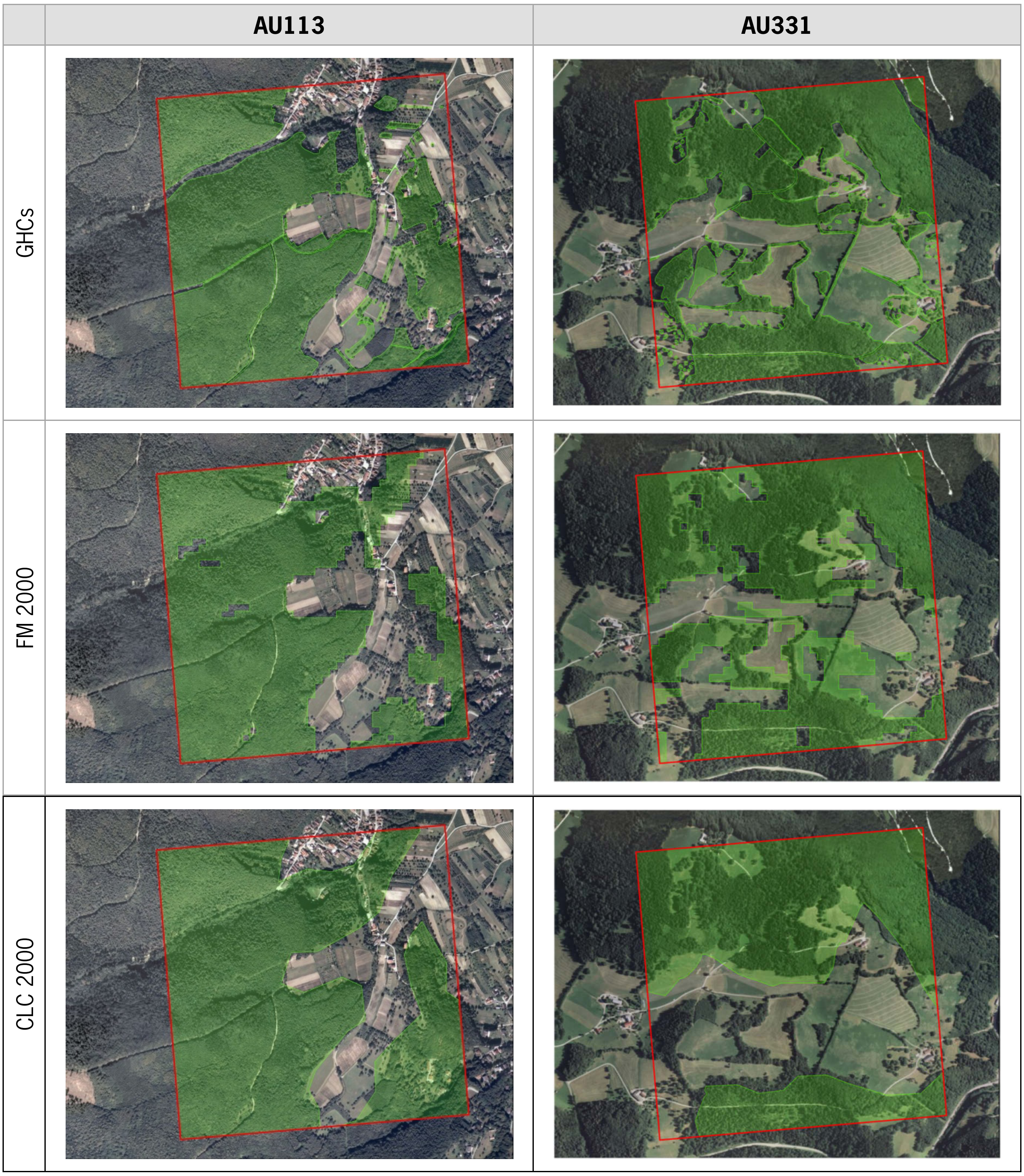


Figure 8
Data sources and scale issues (GHCs habitat map, 25 m forest map and 25 ha CLC forest mask).

4.2 Fine scale habitat pattern measures and products

4.2.1 Local forest habitat pattern characterization

Habitat indicator measures proposed from the three models are summarized in Table 6 and are applied to the focal forest phanerophyte (FPH) GHC habitat in the EBONE database. Analysis units are the 1 km^2 samples which represent the landscape scale. The edge widths in the morphological pattern model as well as the disk radius for the neighbourhood in the landscape mosaic model were set at 25 m.

First for the morphological pattern model, the GHC's vector maps of all available samples were rasterised at 1 m spatial resolution, reclassified into a binary raster layer forest phanerophytes (FPH)-non forest and processed with GUIDOS/MSPA using a narrow forest edge width (*s* equal to 25 m within the 20-120 m forest edge mentioned in Section 1.2.3). The output morphological pattern map has seven FPH habitat pattern classes further simplified into five MORPH classes as described in section III.2 and illustrated for two samples in Figure 9a top. Their forest shares were calculated (IFP, BOP, BRP, COP, ISP as listed in Table 6 and presented in Figure 10a). Also the forest share in linear features (LIP) was calculated. In alternative, the local morphology of the FPH habitat cover was also mapped according to 4 main MORPH pattern classes (Figure10c): core, boundary (aggregation of edges of core, perforation and branch), connector (aggregation of bridge and loop) and islet. Their forest share was also calculated (Figure 10c).

Second for the landscape mosaic pattern model, the GHCs raster maps were re-classified into three main habitat types used as proxies of land use intensity, namely natural/semi-natural (trees/shrubs categories as FPH, TPH, MPH, LPH, SCH; herbaceous HER, sparsely vegetated SPV), cultivated (CUL categories) and urban/artificial types (URB categories). The landscape mosaic pattern model was implemented in ESRI ArcGIS 10.0 and automated with Python scripting to derive the forest landscape mosaic pattern map (Figure 9b). The immediate neighbourhood (disk radius of 25 m for an area of nearly 0.2 ha) around each square metre of land was characterised according to the fifteen mosaic classes. Aside to the share of natural/semi-natural habitats in the sample (NP), the dominant landscape mosaic type was reported. The landscape context of the FPH habitats was obtained by masking the non-FPH classes and the fifteen mosaic classes were aggregated into four main mosaic pattern types ('core natural' NN, 'mainly natural' N, 'mixed natural' MN, or 'some natural' SN) as described in Section III.3 and illustrated in Figure 9b. This forest mosaic pattern map enables to visualize and characterize FPH -non forest interfaces according to the types and proportion of adjacent habitat types in the immediate neighbourhood. Natural/semi-natural forest interfaces (NN at edges) are discriminated from mixed forest interface (MN) where urban/cultivated habitats have a significant proportion in a still predominant natural context. Forestlands when embedded in cultivated and/or urban habitats are identified by the SM mosaic class. Their forest shares were calculated as described in Table 6 and presented for two samples in Figure 10b.

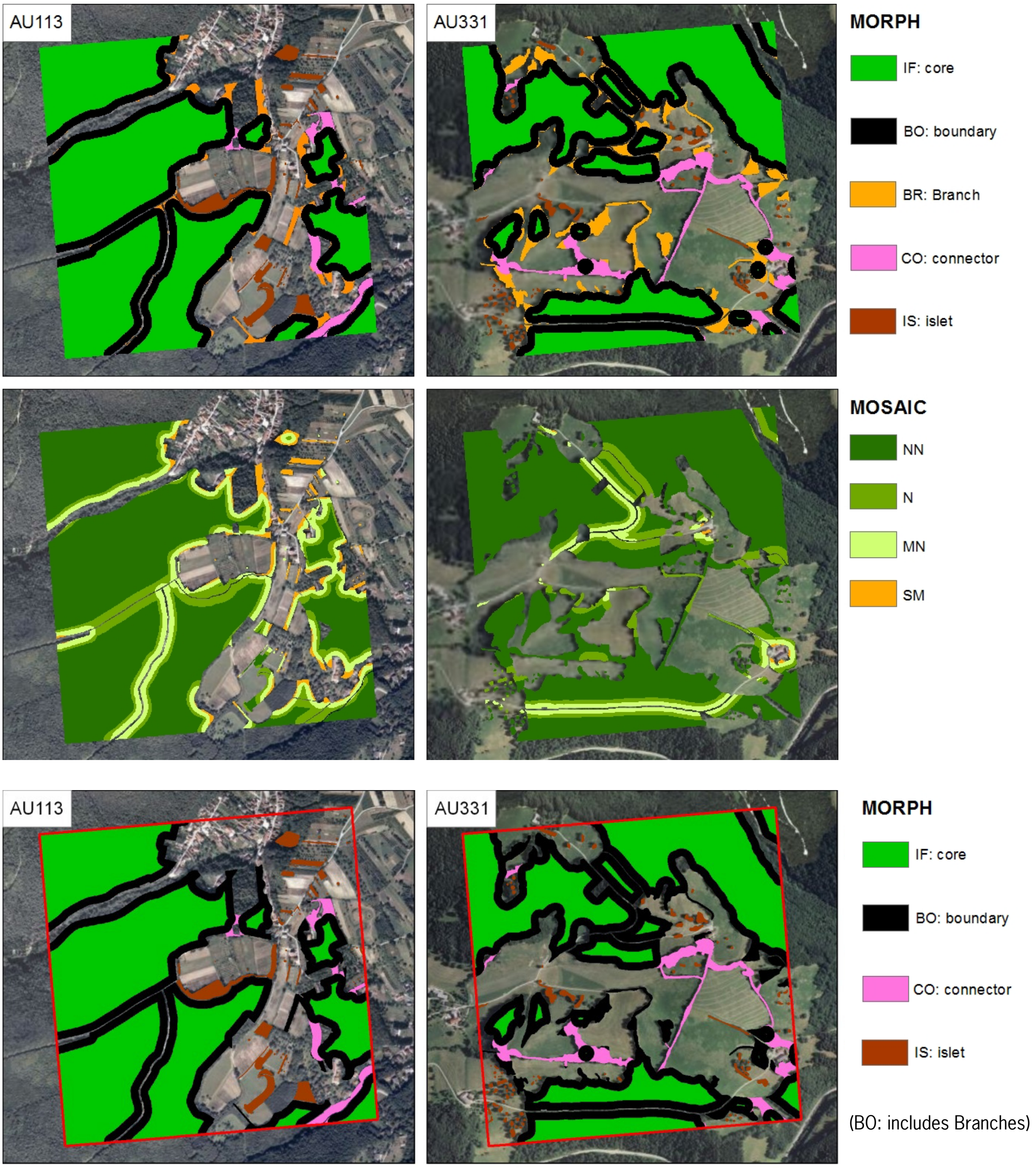


Figure 9
Morphological (top: five MORPH classes, and bottom: alternative MORPH class aggregation into four classes) and landscape mosaic (middle) pattern maps for forest phanerophytes (continental zone, Austria, squares codes: AU113 and AU331).

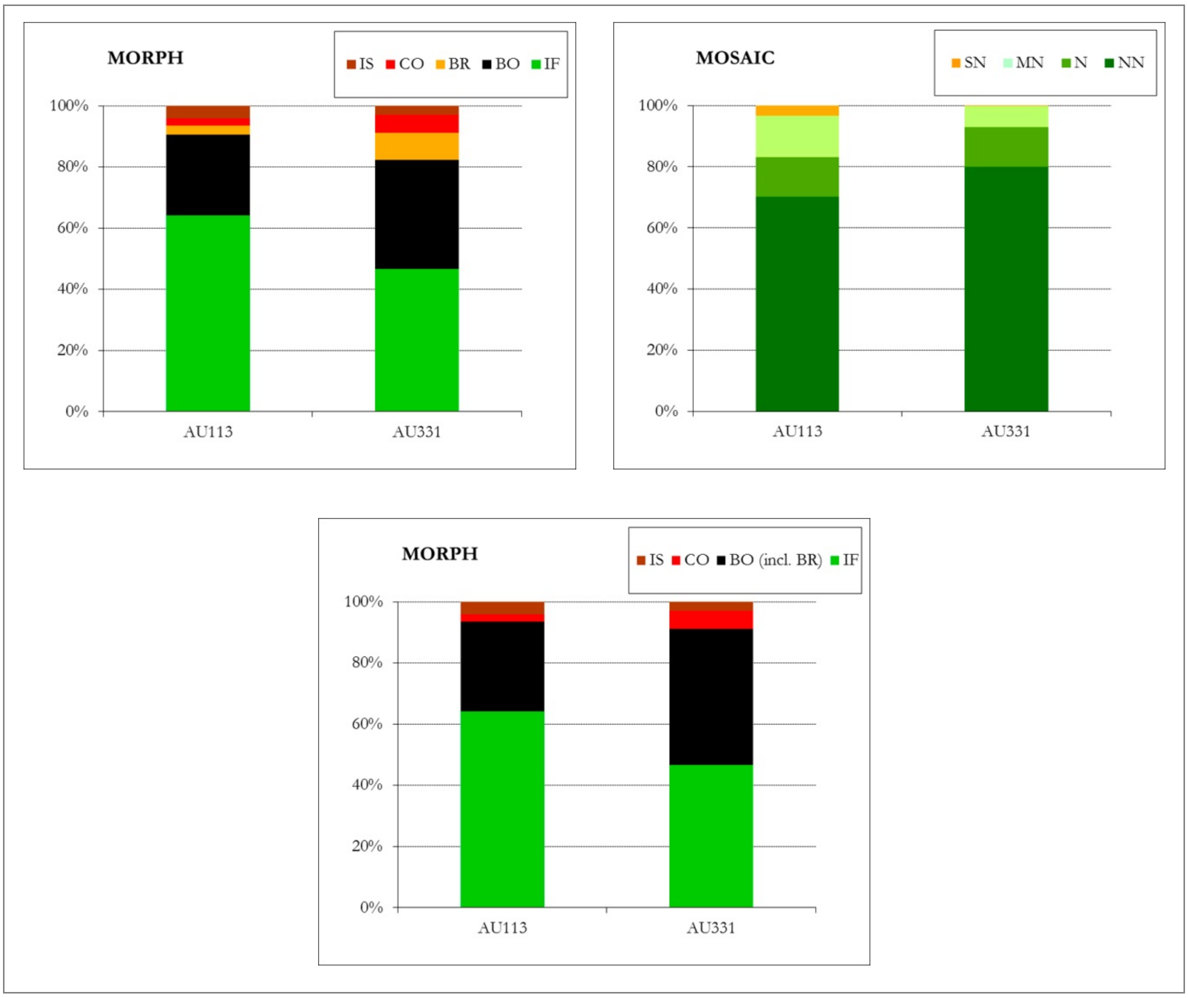


Figure 10

Pattern characterization for two squares in Austria.

Forest proportion in each MORPH class (left and alternative MORPH class aggregation at bottom) and in each MOSAIC class (right)

Finally, the pattern maps derived from the morphological and mosaic models were overlaid to account for the landscape context of each MORPH class, to apply the similarity index and derive the measures listed in Table 6. Results are presented in Table 13 for interior forest and islets, and in Figure 11 for boundaries, branches, connectors and islets. The two samples have similar forest proportion but different forest distributions and non-forest landscape matrix (the dominant mosaic type MMOSAIC are N and NUA). They illustrate well the benefit of combining the two landscape models, which is to characterise simultaneously the structure and context of the patches. 'Interior forest' is compared in patch number and size when identified solely by the MORPH Interior (IF) and when delineated by the model combination with the same fixed edge width except when along natural habitats (IF*). Also, islets (IS) are identified in patch number and size and the proportion of islets in natural context are obtained from IS_{NN}. In our examples, the AU113 sample has a higher interior forest amount distributed in few large patches than AU331, the differences between IFP and IFP* the surroundings of patches is however more natural in AU331 (IF* is significantly much higher than IF). Similarly islets are larger in AU113 but their number and their proportion in natural context are lower when compared to AU331. Figure 11 also shows the more natural landscape context of each non-core MORPH pattern classes in AU331 i.e. the connectors (CO), forest edges (BO) and islets (IS). To conclude, AU331 has a more fragmented forest landscape (more connectors and branches for a total share of linear features of 14.8%, 35.7% of edges, smaller patches) but offers a more natural/semi-natural landscape in general (97.7% share of natural/semi-natural habitat in sample (NP) and a dominant mosaic type N ('MMOSAIC')) that is particularly verified in the surroundings of all forest pattern types (SN shares very low in Figure 11 (right)).

Table 13
Interior forest and islets measures for the FPH habitat in two samples in Austria (Continental zone squares codes: AU113 and AU331)

Samples Id FPH share in sample	FPH pattern	pattern measure	Patch number			Patch size (m^2)	
			Patch <1ha	Patch >5ha	Total	Mean	Median
AU113 FP: 62.7%	IF	IFP = 63.9%	4	4	9	44,590	23,321
	IF*	IFP* = 69.2%	3	4	9	48,304	28,390
	IS	ISP = 4.5%	52	0	52	548	38.5
	IS_{NN}	SI-IS_{NN} = 8.0%	4	0	4	568	535
AU331 FP: 56.7%	IF	IFP =46.6%	16	2	17	15,566	1,744
	IF*	IFP* = 68.7%	11	3	17	22,967	3,627
	IS	ISP = 2.8%	86	0	86	188	121
	IS_{NN}	SI-IS_{NN} = 50.4%	66	0	66	123	90

The Similarity Index (Figure 11 and Table 13) further enabled to characterise and quantify the proportion of different landscape mosaic contexts for each non-core pattern classes. The proportion of boundaries/edges along natural lands (SI-BO_{NN}) is much lower in AU113 than in AU331 (20% and 62% respectively); in AU113, forest edges are more exposed to a mosaic of natural and anthropogenic habitats in a 25 m radius (36% compared to 13% for SI-BO_{MN}). More than half of forest branches which often represent protrusions at edges, are along anthropogenic land in AU113 (47% for SI-BR_{SN}, while only 1% in AU331).

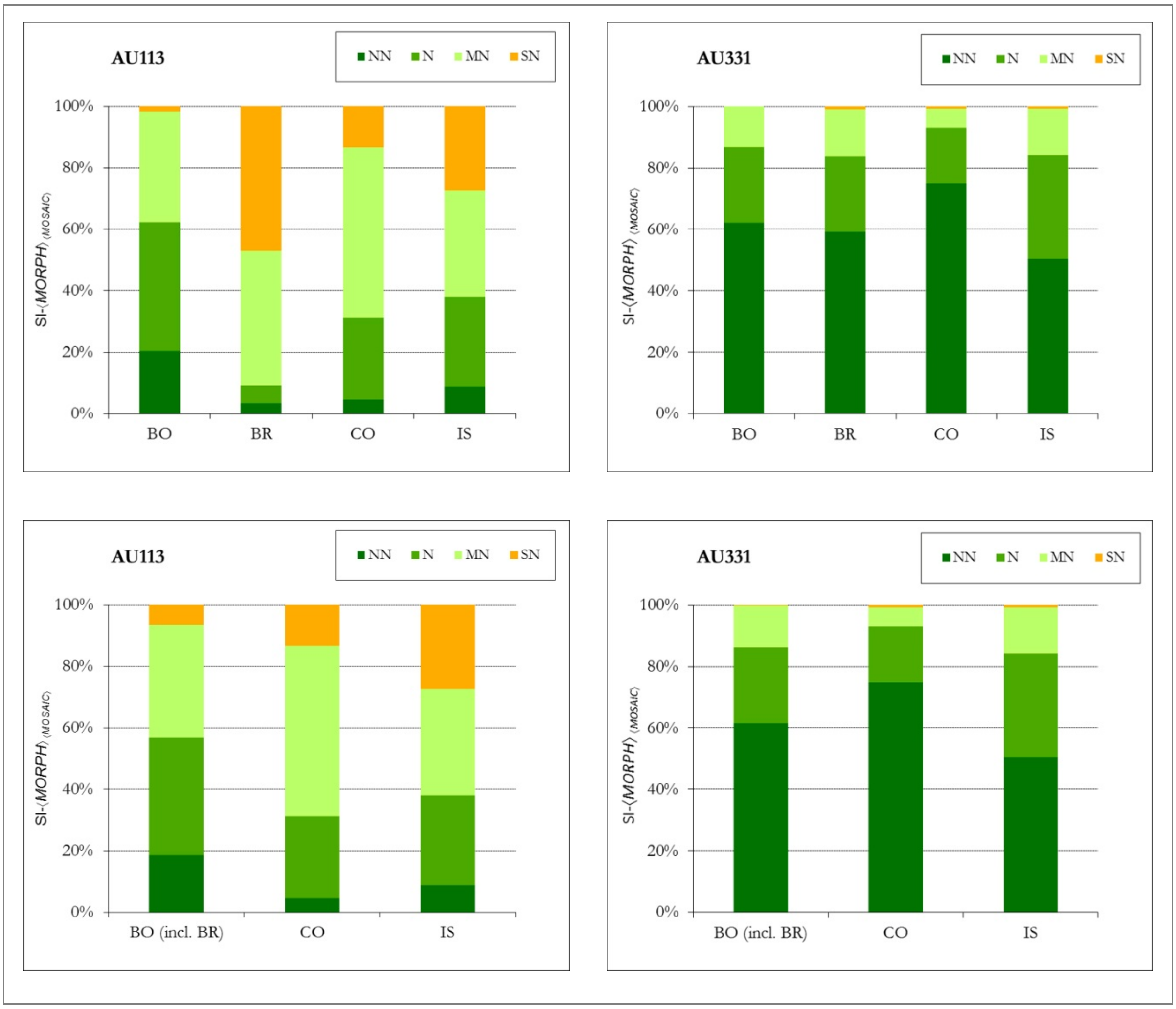


Figure 11
(top) Landscape context on the non-core 4 MORPH classes for the two samples in Austria. (bottom) Idem for the alternative pattern characterisation with 3 non-core MORPH classes.

4.2.2 Local forest habitat connectivity

Connectivity indices PC, RPC and IsoSi were calculated with inter-patch effective distances for species dispersing at 500 m and 250 m (not shown) average dispersal distances. As said in section III.5, costs of movement (friction) were assigned to every habitat types using a logarithmic increment values from FPH and TPH (lowest friction 1) to urban habitats (highest friction 10.000) (Table 14). The parameter $cost_{d50\%}$ was 50.000 for a 500 m dispersal distance.

Table 14
Friction values applied to the GHCs habitat classes.

GHC CODE	FRICTION VALUE	GHC CODE	FRICTION VALUE
URB/ART	10.000	HER/CRY	10
URB/VEG	5.000	HER/HEL	10
URB/GRA	5.000	HER/THE	10
URB/TRE	5.000	TRS/SCH	10
URB/NON	1.000	TPS/LPH	10
CUL/CRO	200	TRS/MPH	10
CUL/SPA	200	SPV/AQU	10
CUL/WOC	100	SPV/TER	10
HER/LHE	10	TPS/TPH	1
HER/CHE	10	TPS/FPH	1

Higher connectivity values in analysis units with the same habitat amount means that the habitat is similarly abundant but better connected for the species. Better connected depend on the inter-patch distance and the non-habitat landscape permeability.

The connectivity of the forest landscape was calculated with the Conefor Sensinode and ArcGIS software, using the original habitat vector maps, a fixed average dispersal distance of 500 m and 250 m (results not shown) for an average friction of 100, habitat friction values as input and detailed in Table 14. Connectivity indices PC, RPC, APC and IsoSi were calculated (see Table 15 with fewer nodes and a less natural matrix in AU113 than in AU331). RPC and IsoSi are compared to forest proportion (FP), IsoSi is always lower than RPC, because only the arrival patch area is accounted per pair of patches (intra-patch) and not the two patches' areas like in the RPC index. Consequently IsoSi is more sensitive to the inter-patch landscape matrix permeability, possible barrier effects and gives more focused on the probability of species movement. In contrast PC and RPC react better to habitat availability (its intra and inter-connectivity).

Table 15
Connectivity indices applied to two samples in Austria (squares codes: AU113 and AU331)

INDICES	AU113	AU331
FP	0.627	0.567
Nodes	33	85
NP	0.737	0.977
MMOSAIC	NUA	N
PC	0.349	0.313
RPC	0.591	0.559
IsoSi	0.499	0.549
APC	0.784	0.967

The APC index does not account for the forest availability but its configuration and the matrix permeability. Differences in the APC values across the two samples are clearly highlighted. In AU331 the APC is very close to one, which represents a matrix without movement costs.

Table 16 shows the correlation matrix for the set of connectivity indices and the forest proportion. As expected, PC and RPC are highly correlated with FP due to the weight of habitat availability; IsoSi has a lower correlation while APC can be considered as not correlated with any of the indices. On the basis of those results, we could suggest to select one of the three indices depending on users' needs. When inter-patch connectivity and species movement between patches are at focus, APC may be more appropriate. When fluxes of species (as proxy, species amount depends on patch size) in between patches is as important as the feasibility of movement, IsoSi may be more suited. When intra-patch connectivity is more important than inter-patch connectivity, PC or RPC may be preferred.

Table 16
Correlation matrix between connectivity indices and forest proportion.

VARIABLES	FP	PC	RPC	IsoSi	APC
FP	1				
PC	0.95239	1			
RPC	0.99330	0.95070	1		
IsoSi	0.85364	0.81119	0.89697	1	
APC	0.13359	0.10828	0.20980	0.50732	1

This research exercise brings the concern on the sensitivity of a connectivity index to the matrix permeability and if a single connectivity index is enough to capture simultaneously habitat connectivity and landscape permeability.

4.3 Reporting habitat pattern per Environmental Zones

4.3.1 Forest habitat pattern per Environmental Zones

The morphological spatial pattern of forest phanerophyte habitats are reported for all the samples available in each environmental zone (see Annex 1a, and Figures 12 and 13). Differences among the in-situ samples in an environmental zone are noticeable on the proportion of forest habitats, core habitat versus edge habitat, proportion of small isolated elements (islets), and proportion of connecting elements (connectors between core patches). This may be used to guide the selection of other samples depending on the type of habitat (interior, edge or linear features) the user is interested in to further study pattern-process relationships.

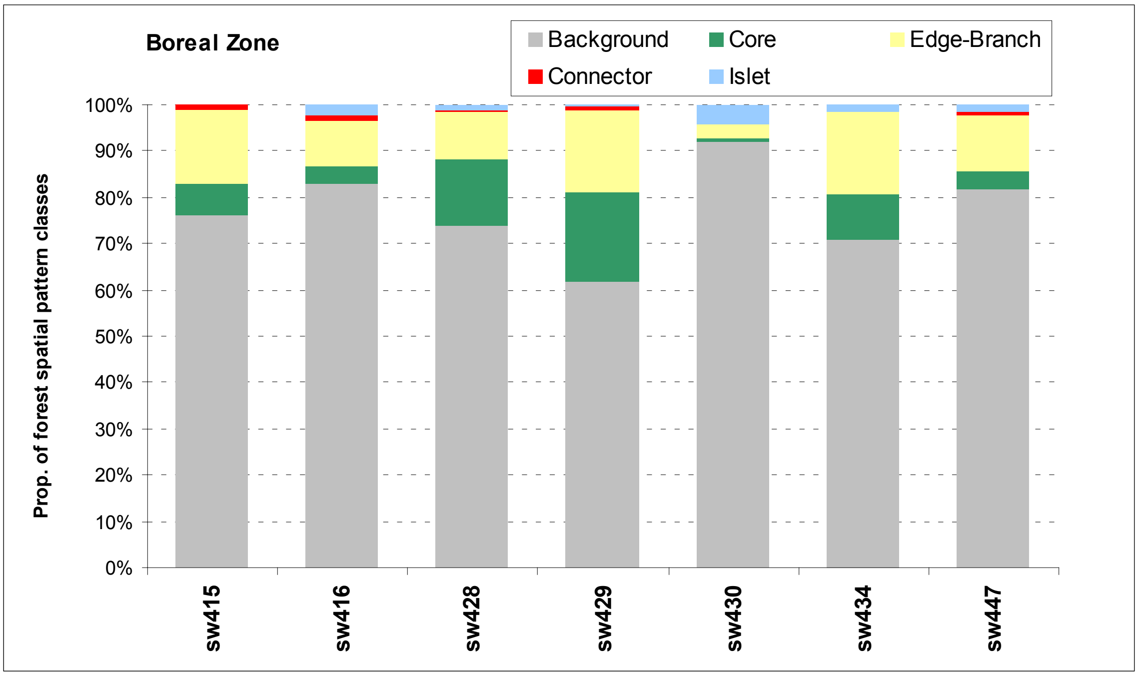


Figure 12
Forest morphological pattern for the Boreal zone (FPH MORPH five classes).

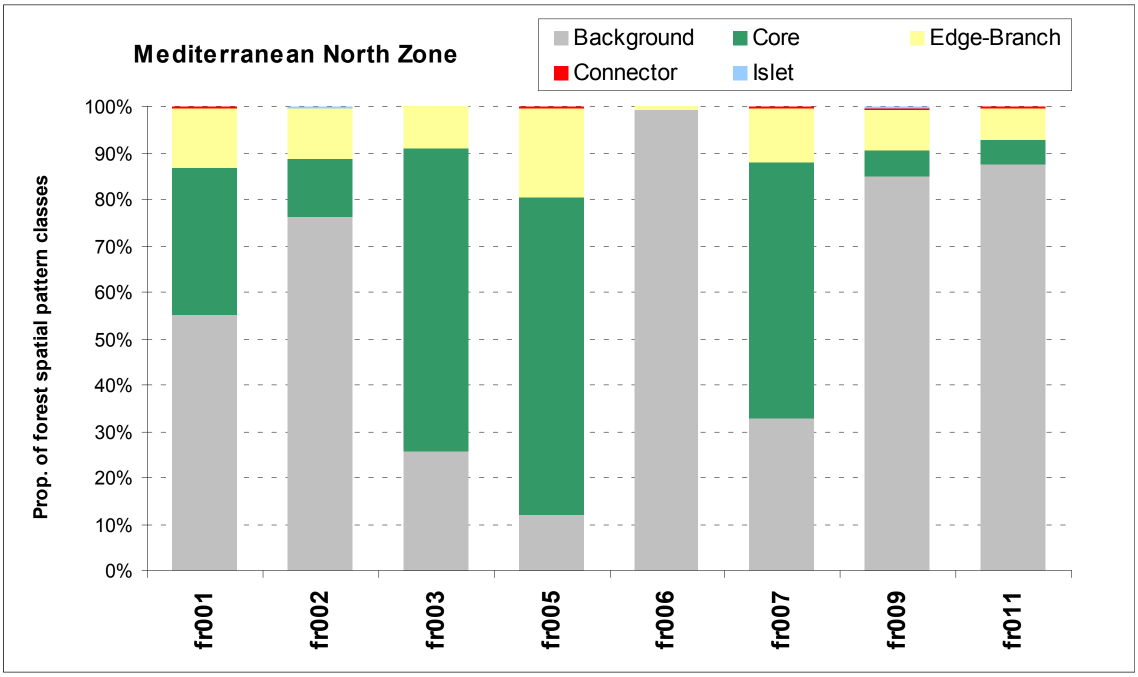


Figure 13
Forest spatial pattern for the Mediterranean North zone (FPH MORPH five classes).

The proportion of forest edges bordering natural habitats ($SI\text{-}BO_{NN}$) was addressed for all samples per environmental zone (Annex 1b and Figure 14 and 15). Forest edge communities are possibly influenced by their adjacent non forested habitats, which 'similarity' to forest tells about the permeability of interfaces. Forests fragmented by natural habitats (like herbaceous), therefore with a high proportion of forest edges in a natural context (NN) are intuitively less vulnerable to further fragmentation than forests fragmented by anthropogenic sources (cultivated and urban habitats). The proportion of forest edges in natural context varies significantly among samples from the same environmental zone in all zones. In the current sample set, highest shares were observed for the nemoral, boreal and Mediterranean North zones.

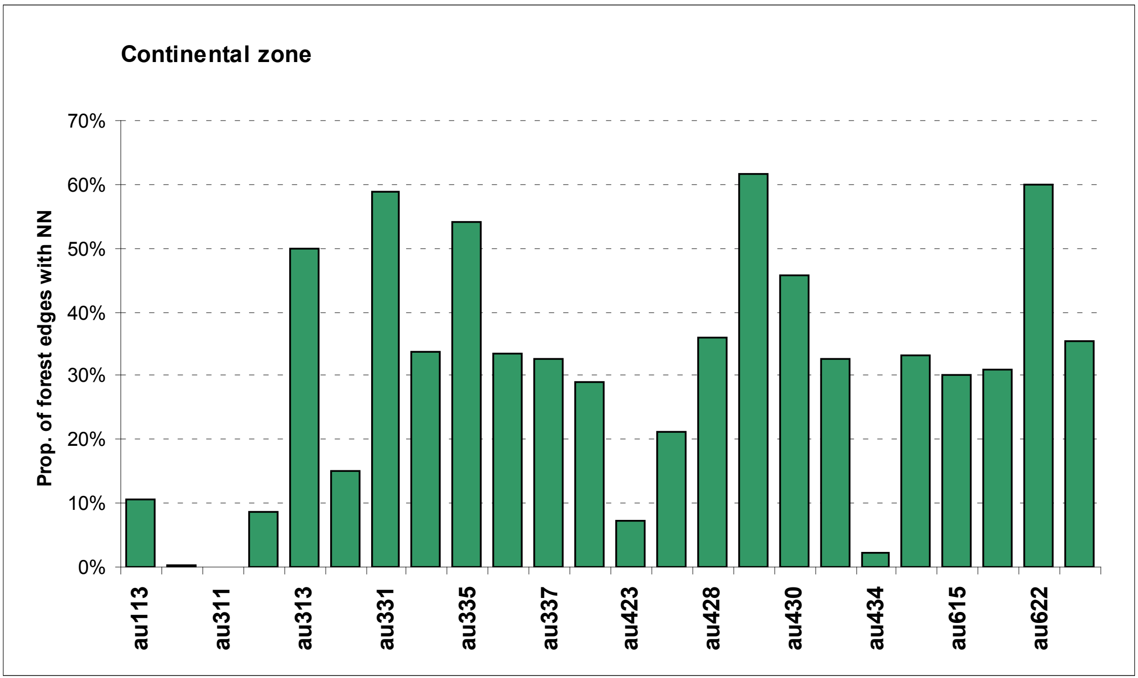


Figure 14
Natural forest edges in continental zone ($SI\text{-}BO_{NN}$).

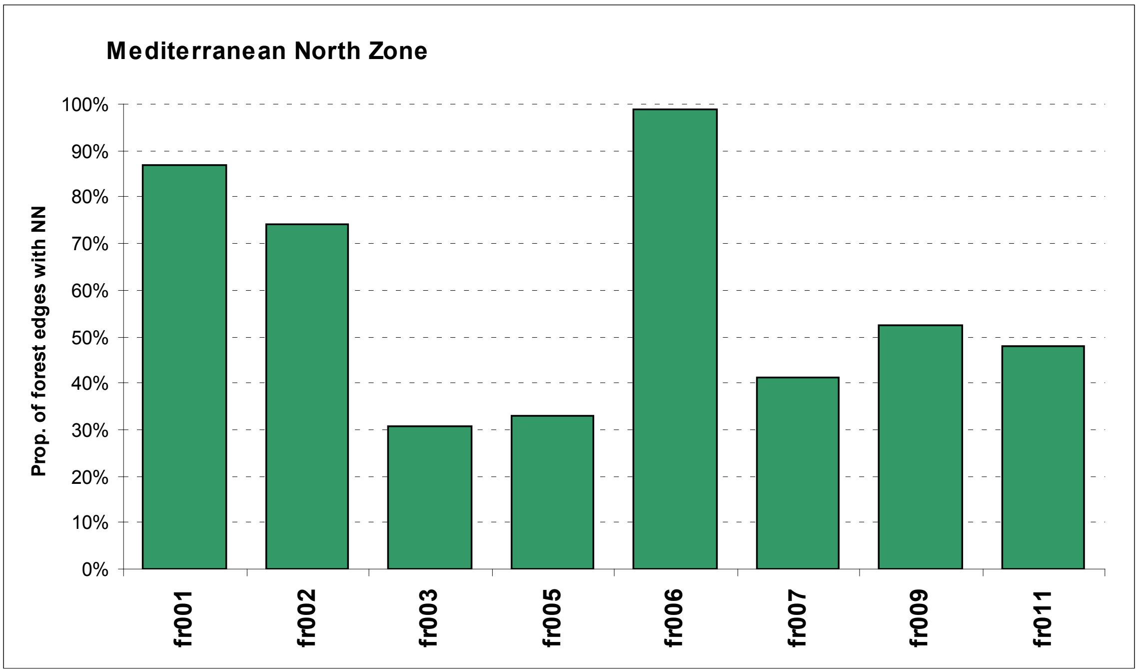


Figure 15
Natural forest edges in Mediterranean north zone ($SI\text{-}BO_{NN}$).

4.3.2 Forest habitat connectivity per environmental zones

Connectivity indices RPC and IsoSi were calculated for species dispersing at 500 m average dispersal distance for all samples per environmental zone (Annex 1c and Figures 16 and 17). In the sample set available, connectivity values varied greatly among samples within and across environmental zones. Highest connectivity values were found in the continental zone. Further IsoSi had in some samples much lower value than RPC meaning that the non-forested landscape does not particularly favors the inter-patch dispersion; this was particularly the case in four samples located in the Mediterranean zone.

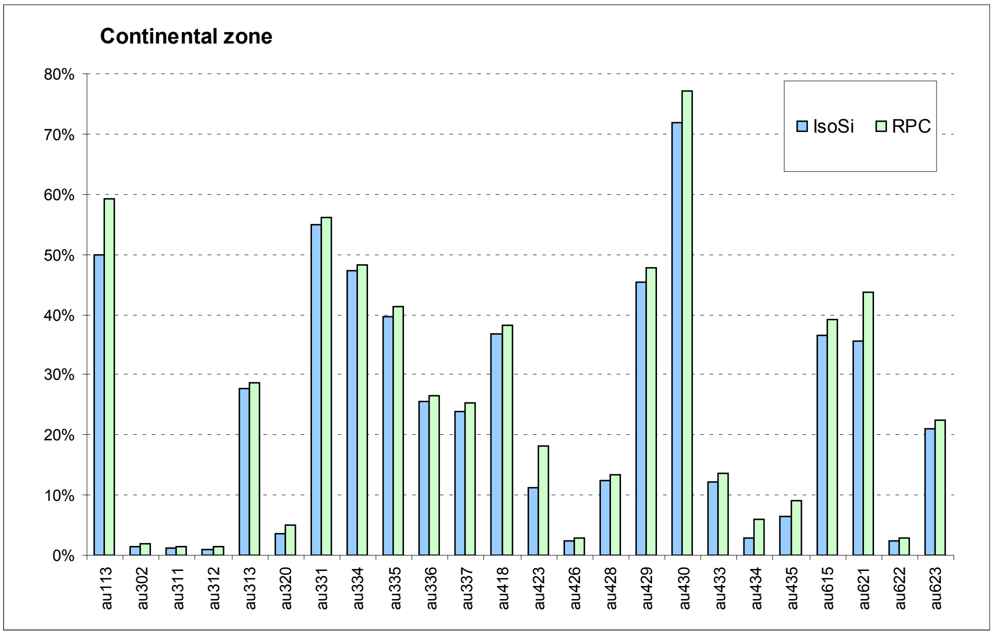


Figure 16
Forest connectivity in the Continental zone.

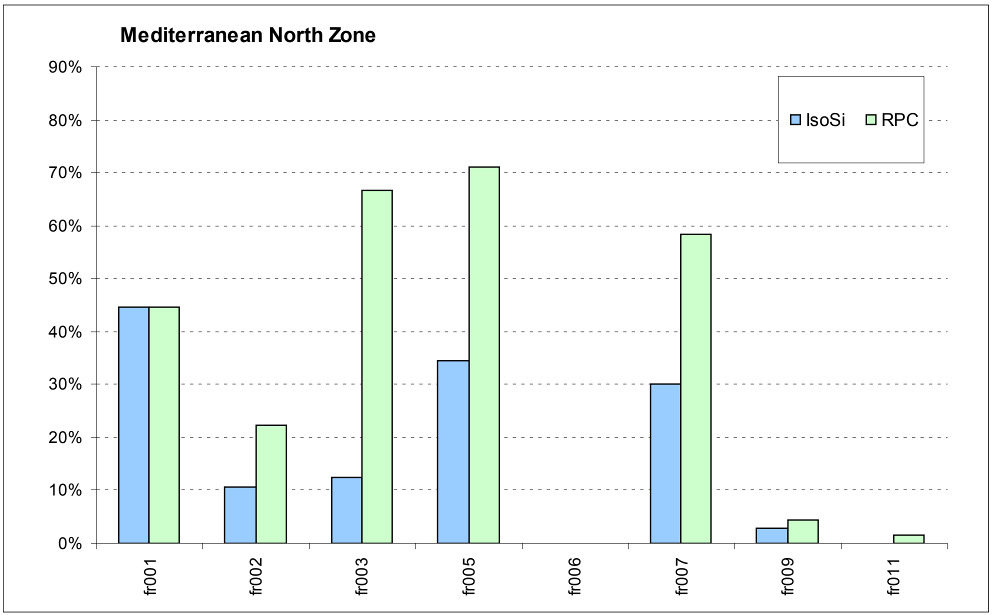


Figure 17
Forest connectivity in the Mediterranean North zone.

4.4 Medium and broad scale land cover pattern measures

4.4.1 Forest land cover morphological and mosaic pattern

Medium (regional) and broad (European-wide) scale CLC based land cover maps were automatically processed for the pattern analysis. For the morphological pattern analysis of the forest cover, the land cover data were reclassified into forest (classes 3.1.1, 3.1.2 and 3.1.3 respectively broadleaves, coniferous and mixed standing forest) and non-forest. The transitional woodlands (CLC 3.2.4) where most the spatial temporary forest dynamics due to the forest management is, was considered in the non-forest class. Table 17 provides for the PACA French region the share of the forest pattern classes when observed at medium scale with one pixel edge width (25m). Figure 18 illustrates the differences of the forest morphological pattern maps derived from the broad (edge size 100 m) and medium scale (edge size 25 m) land cover maps.

Table 17
Forest proportion of the four pattern classes (edge size 25 m, CLC 1ha, year 2006).

Forest morphological pattern class	Forest shares
Core	84.2%
Boundary	15.6%
Connector	0.2%
Islet	0.1%

For the landscape mosaic model, the land cover map was reclassified into three main classes, CLC class 1 (urban and artificial surfaces), CLC class 2 (agricultural lands) and CLC classes 3 and 4 (natural/semi-natural lands). Landscape mosaic pattern types were calculated using two different neighborhoods i.e. immediate surroundings with a window of 3x3 pixels and larger neighborhoods with a 7x7 window. Tables 18 illustrates the land proportion of the mosaic types and the forest proportion of the mosaic pattern types for the PACA region at medium scale with windows of 0.5 ha (3x3 pixels) and 3 ha (7x7 pixels). Land fragmentation processes are depicted by the proportion of mixed classes (MixU, MixA, MN, Mix), the proportions of which are more significant with 3 ha window. The differences of the broad and medium scale landscape forest mosaic pattern maps (3x3 window) are shown in Figure 18.

Table18

(Top) Land proportion of landscape mosaic pattern types and (bottom) forest proportion of forest landscape mosaic types in the French PACA region.

Predominant mosaic type	**Mosaic pattern class**	**Mosaic pattern class**	
		3 x 3 pixels	**7 x 7 pixels**
Predominantly artificial	U	3.5%	2.3%
	Mix U	1.4%	1.9%
Predominantly cultivated	A	12.2%	9.5%
	Mix A	2.5%	4.3%
Predominantly natural	NN	76.1%	71.4%
	N	0.0%	1.8%
	MN	2.6%	4.5%
Mixed	Mix	1.7%	4.2%
Predominant mosaic type	**Mosaic pattern class**	**Neighborhood window sizes**	
		3 x 3 pixels	**7 x 7 pixels**
Predominantly natural	NN	95.1%	87.6%
	N	0.0%	3.1%
	MN	3.9%	6.7%
Others	SN	1.0%	2.6%

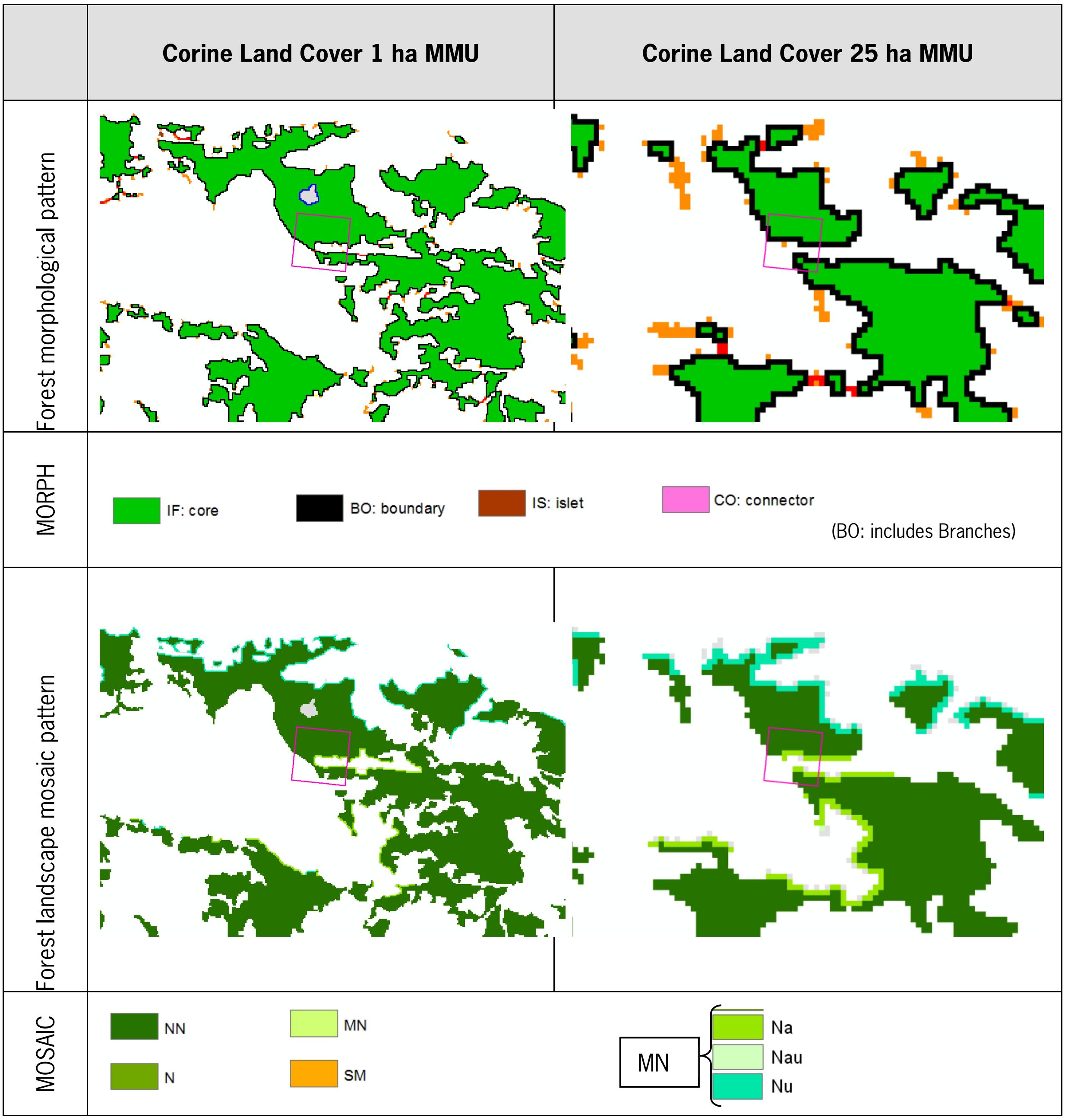


Figure18

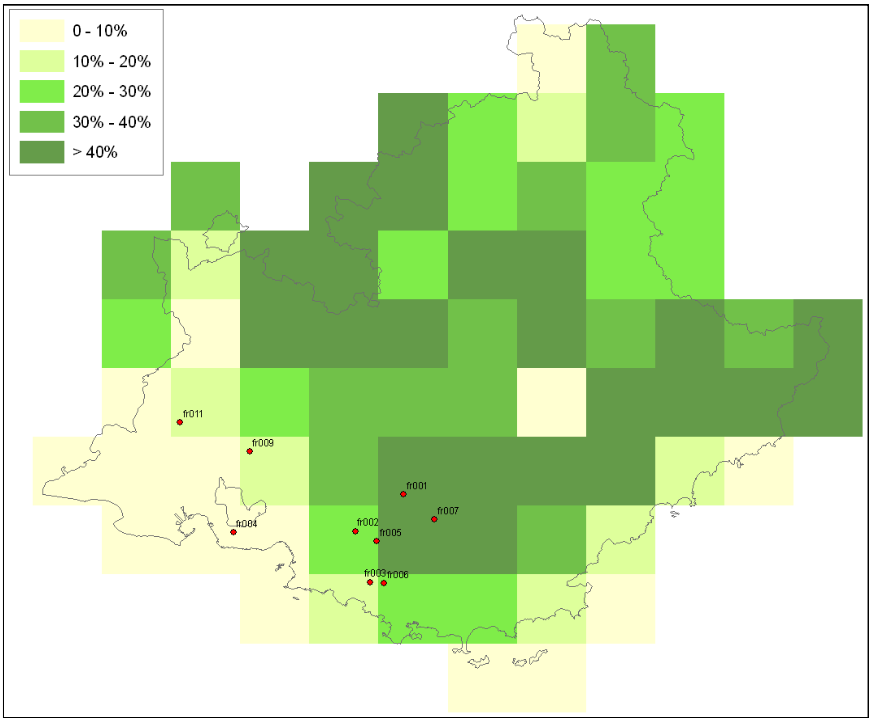
(Top) Forest morphological pattern (MORPH four classes) and (bottom) forest landscape mosaic map from CLC 1 ha and CLC 25 ha land cover maps in Mediterranean South zone of the French PACA region (the pink square overlay is the sample Fr004).

4.4.2 Forest land cover connectivity

The computation of connectivity indices (connectivity index RPC and isolation sensitive index IsoSi) used effective distances and 1 and 5 km average dispersal distances. It was conducted per 25x25km^2 analysis unit over the broad scale CLC 25 ha map of year 2006 (Figures 19a and b) and the medium scale CLC 1ha map available for the PACA region. Friction values are given in Table 19. This broad and medium scale observation of connectivity can be considered as a macro-connectivity level of information. The macro-connectivity context for each habitat sample is thus known (Figure 19). For example, the sample code fr004 is located in a forest landscape context with a low macro-connectivity. The frequency of tiles per ranges of macro-connectivity is given for the French region on the basis of the two indices in Figure 19. The higher frequency is found for medium to high macro-connectivity (above 40%)

Table 19
Friction values per CLC classes.

CORINE CODE	DESCRIPTION	FRICTION
111	Continuous urban fabric	10000
112	Discontinuous urban fabric	10000
121	Industrial or commercial units	10000
122	Road and rail networks and associated land	10000
123	Port areas	10000
124	Airports	10000
131	Mineral extraction sites	10000
132	Dump sites	10000
133	Construction sites	10000
141	Green urban areas	5000
142	Sport and leisure facilities	5000
211	Non-irrigated arable land	200
212	Permanently irrigated land	200
213	Rice fields	200
221	Vineyards	100
222	Fruit trees and berry plantations	100
223	Olive groves	100
231	Pastures	10
241	Annual crops associated with permanent crops	100
242	Complex cultivation patterns	200
243	Land occupied by agriculture, with some of nat. veg.	50
244	Agro-forestry areas	50
311	Broad-leaved forest	1
312	Coniferous forest	1
313	Mixed forest	1
321	Natural grasslands	10
322	Moors and heathland	10
323	Sclerophyllous vegetation	5
324	Transitional woodland-shrub	1
331	Beaches, dunes, sands	10
332	Bare rocks	10
333	Sparsely vegetated areas	10
334	Burnt areas	10
335	Glaciers and perpetual snow	10
411	Inland marshes	10
412	Peat bogs	10
421	Salt marshes	10
422	Salines	10
423	Intertidal flats	10
511	Water courses	5000
512	Water bodies	5000
521	Coastal lagoons	5000
522	Estuaries	5000



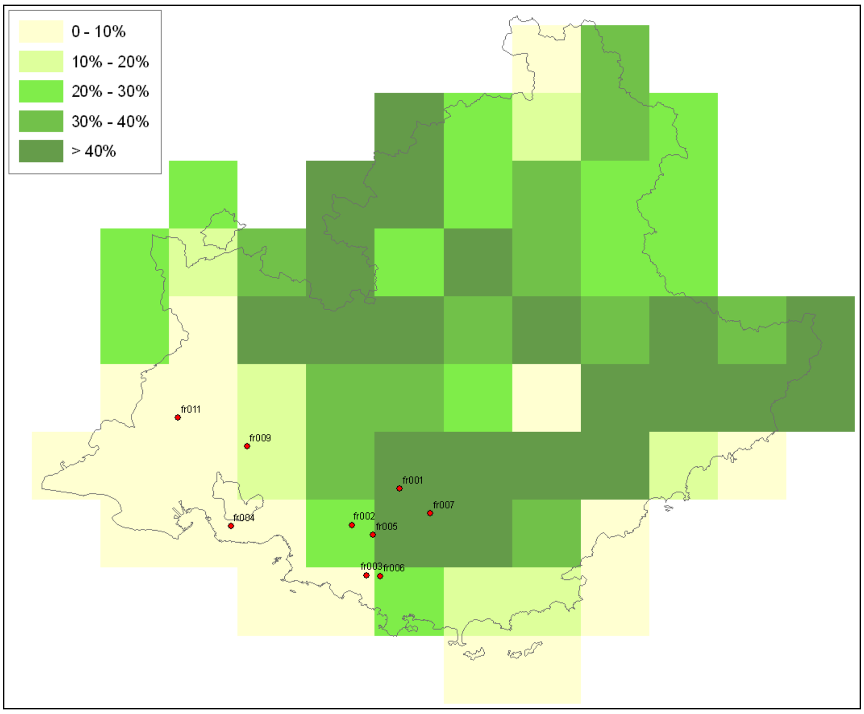


Figure 19
(Top) Connectivity index RPC and (bottom) isolation sensitive index IsoSi (25 x25 km^2 analysis unit, CLC 25 ha 2006).

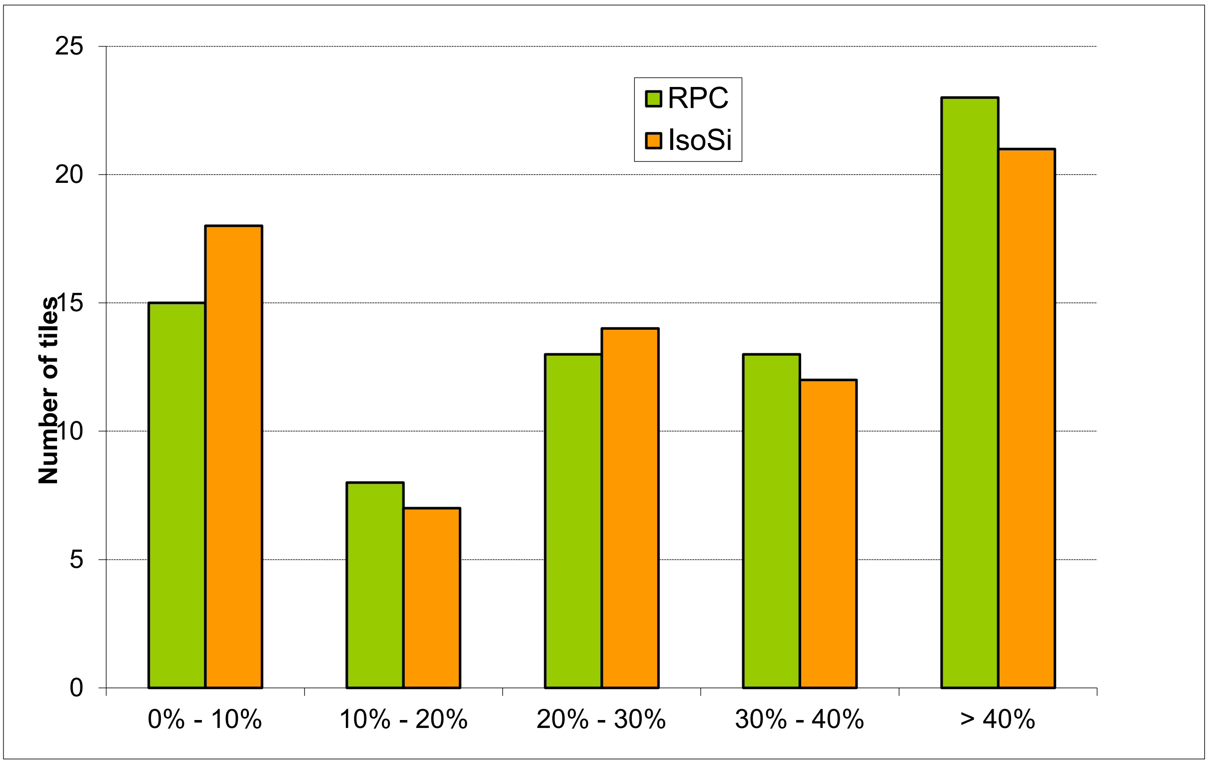


Figure 20
Frequency of 25x25 km² tiles per ranges of connectivity.

4.5 Multi-scale land cover and habitat pattern comparison

Pattern characterization and connectivity are scale dependent and this is illustrated by the connectivity PC index that was reported for three samples in Austria (Figure 21). The sample size of 1 km2 for which habitat fine scale maps are available is however too small to conduct a proper multi-scale connectivity comparison with the broad and medium scale maps.

The connectivity index values based on the 25m European Forest map (FM) is always higher than the ones based on GHCs habitat map, this is mostly explained by the raster based mapping and automatic classification process that generate many isolated (or small cluster of) pixels, thus the tendency to increase the connectivity measure. Broad scale products like CLC tend to overestimate the connectivity measure when the forest is rather compact and distributed in few large patches like in Au113. The occurrence of small and thin features widely distributed in between large patches explained the underestimation of the connectivity value when compared to the GHCs based measure like in the case of the Au331 sample.

No significant behavioral differences in the connectivity index values were noticeable for the two dispersal distances 250 m and 500 m; connectivity was slightly higher across the three scales for species dispersing 500 m in average. Generally speaking, species that have short dispersal distance are more sensitive to habitat area (intra-patch connectivity) than inter-patch connectivity; the contrary is true for species with higher dispersal ability. Species with high dispersal ability are more concerned by the overall habitat availability in the region, regardless of its spatial configuration.

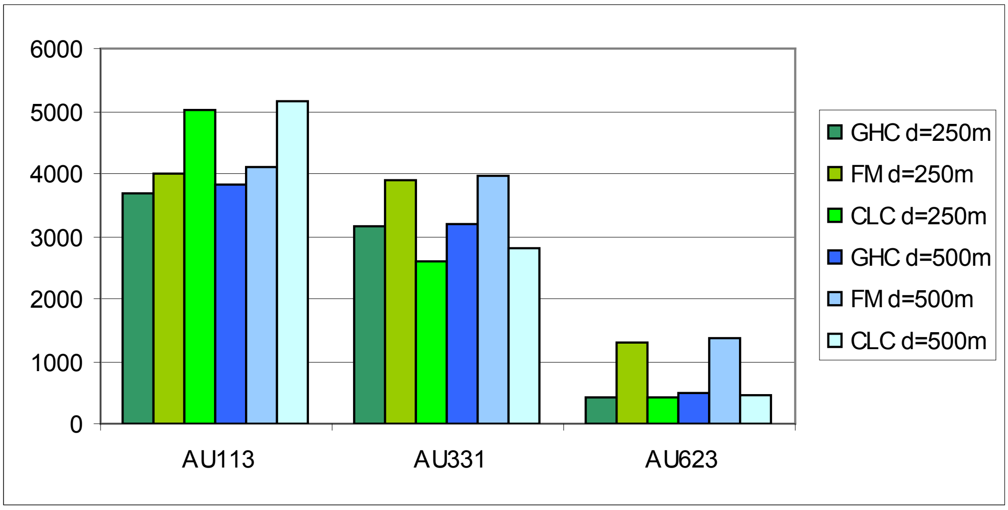


Figure 21

Impact of multi-source and multi-scale data on the connectivity index.

The PC index is calculated for two different dispersal distances (250 m and 500 m), input data are from the 'GHC' habitat map (fine scale), 'FM' JRC Forest map (~ 1ha) and 'CLC' (25 ha)

Due to the lack of habitat maps over larger extent, we thus proposed to simply illustrate in Figure 22 one benefit in having multi-scale standardized connectivity assessments. The macro-connectivity context of the 1 km^2 samples is reported and, in turn each sample is informed by its micro-connectivity characteristics.

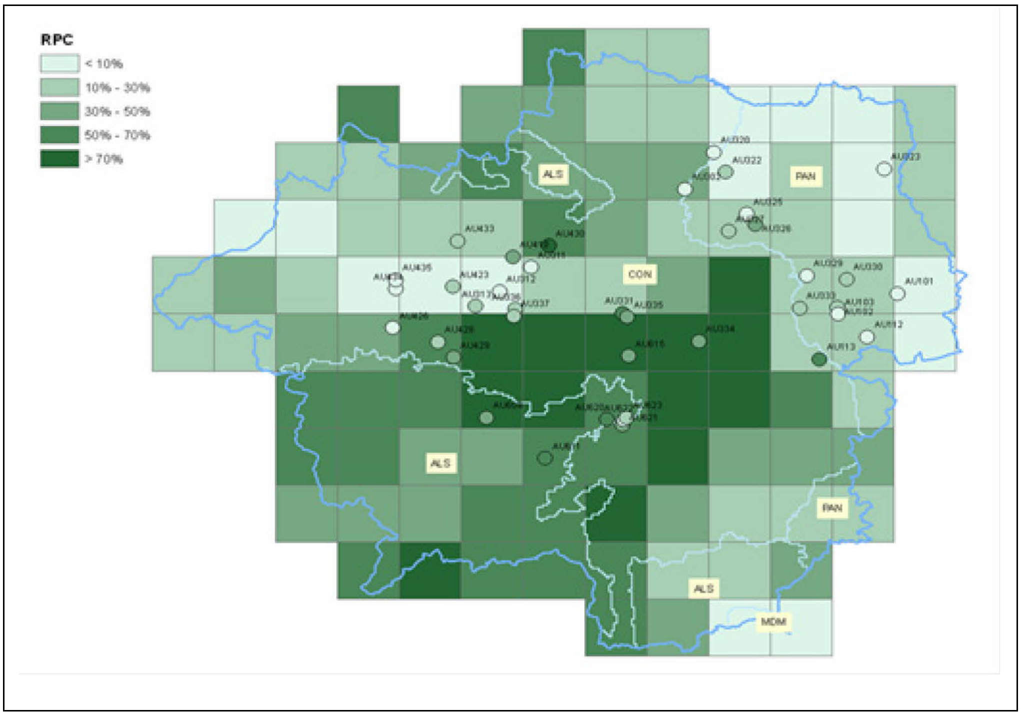


Figure 22

Forest FPH macro and micro-connectivity in Austria.

Macro-connectivity is derived from the RPC index per 25 x25 km^2 analysis unit. Micro-connectivity from the same RPC index is available for each 1km^2 sample (circles shades according to their RPC values).

5 Dissemination and conclusions

The current study was presented in several frames (listed below) and proceedings of conferences, poster and flyer were prepared (see Annexes).

- 25th – 27th March 09, Prague (Czech Republic), International conference 'Towards eEnvironment. O-portunities of SEIS and SISE: Integrating Environmental knowledge in Europe' (http://www.e-envi2009.org). Poster and flyer (Estreguil et al., 2009, see Annex 2)
- 8th June 2009, Prague (Czech Republic). Nature Directors meeting. Poster and flyer (Estreguil et al., 2009, see Annex 3)
- 1st - 4th June 2010, Brussels (Belgium). Green week. DG Research stand. Flyer (Estreguil and Caudullo, 2010a, see Annex 4)
- 21st - 27th September, 2010 – Bragança (Portugal). Proceedings of the Landscape Ecology / IUFRO 2010 International Conference, and slide presentation. (Estreguil and Caudullo, 2010b, see Annex 4).
- 26th - 28th January 2010, Ispra (Italy) for the second meeting of the UNECE/FAO Team of Specialists on 'Monitoring of sustainable forest management'.
- 14th June 2011, Brussels (Belgium). EBONE presentation at DG-ENV B2 at Brussels
- 30th June 2011, Ispra (Italy.: EBONE-EUROGEOSS meeting at JRC Ispra

In order to address the need for a common reporting on habitat and make progress on the data presentation component of habitat layers available in the project, a prototype web-based mapping client (http://forest.jrc.ec.europa.eu/ebone) was also developed to view and query the habitat map and pattern map layers. The map viewer (Figure 23) allows the user to view the location of EBONE field based samples, to view habitat maps, to query the presence and extent (area) of habitats per sample and per environmental zones (Figure 24), to view habitat pattern maps and related indices on pattern and connectivity (Figure 25).

From a technical point of view, the spatial layers and their associated data were prepared in a common ESRI Shapefile format for all samples. They were sent to the web client using the OGC WMS standard, which were published through MapServer. The background to the viewer uses the bing maps published by Microsoft. The application has been developed and managed primarily using Free, Open-Source Software and runs on Linux based operating systems. The mapping client has been written as a component of Joomla. This is a PHP based Content Management System that uses MySQL as a database. Although the prototype client has been developed as a component of the Joomla CMS, this is not a necessity. It could be standalone, or as a component of another CMS depending on requirements. The viewer uses the following software and licensing should be referred to: MapServer, Joomla , PHP, OpenLayers, Jquery. OpenLayers, and JQuery javascript, allow the user to interact with the spatial layers.
To make updates to the layers access to the data directory would be needed. This is where MapServer accesses the data currently stored as a Shape File. Alternatively a spatial database could be used such as PostGIS, for maintaining the data. The client would also need to be updated for the inclusion of further layers. Skills in Openlayers, CSS, HTML, Jquery would be necessary to achieve this. Again other technologies could be considered such as GeoEXT.

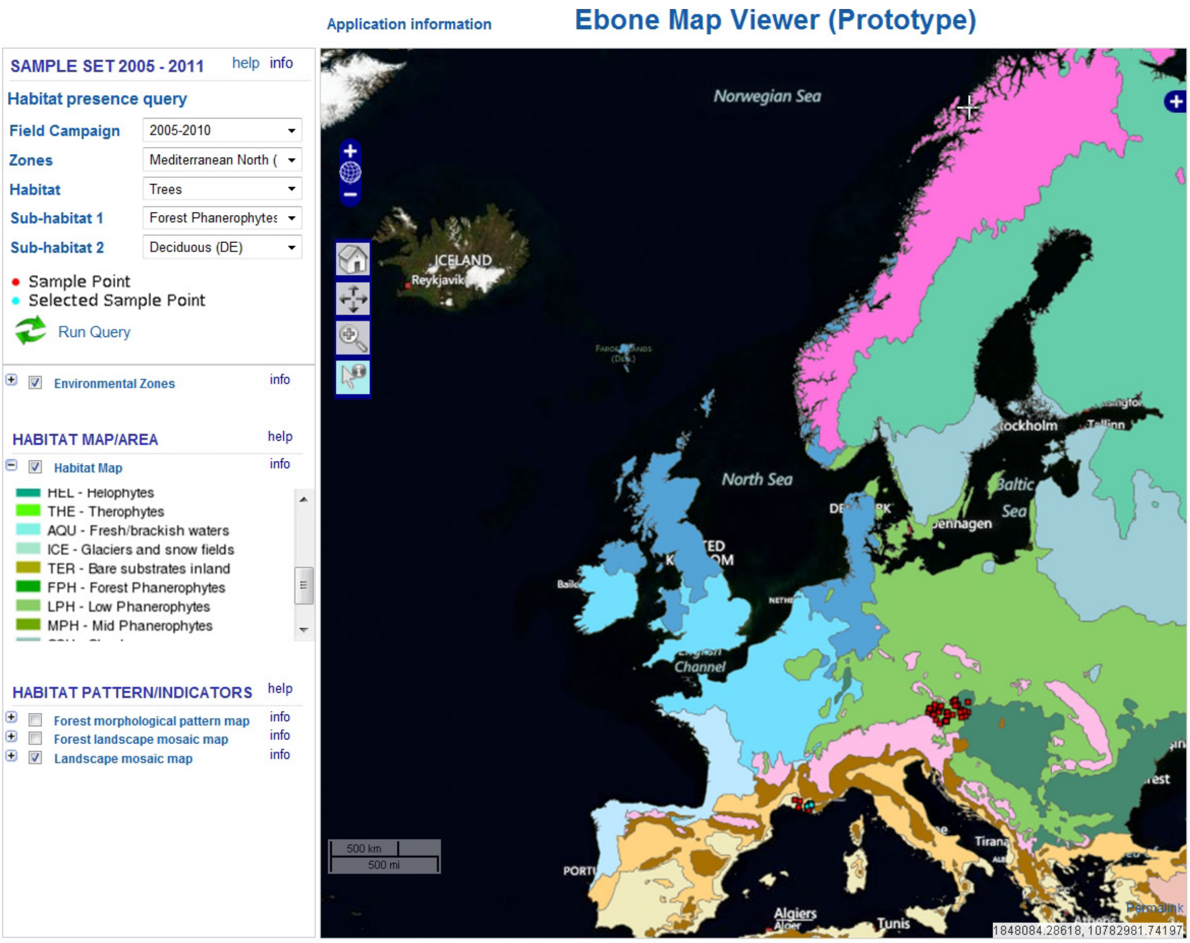


Figure 23

Interface page of the prototype web-based mapping client.

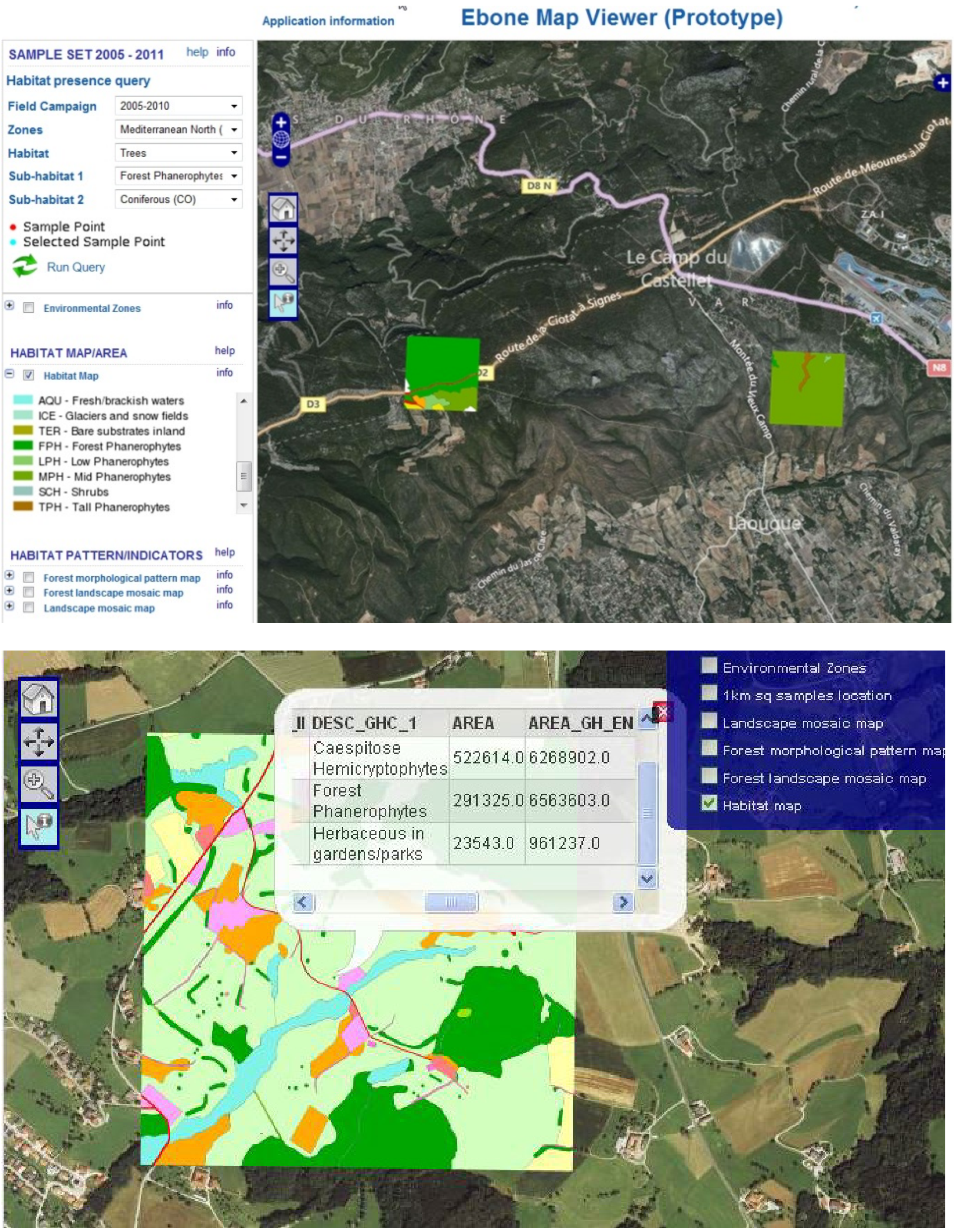


Figure 24

(Top) Habitat query in the continental zone and view of two samples in Austria, (Bottom) Zoom in one sample (Au113) habitat maps, and query of FPH habitat.

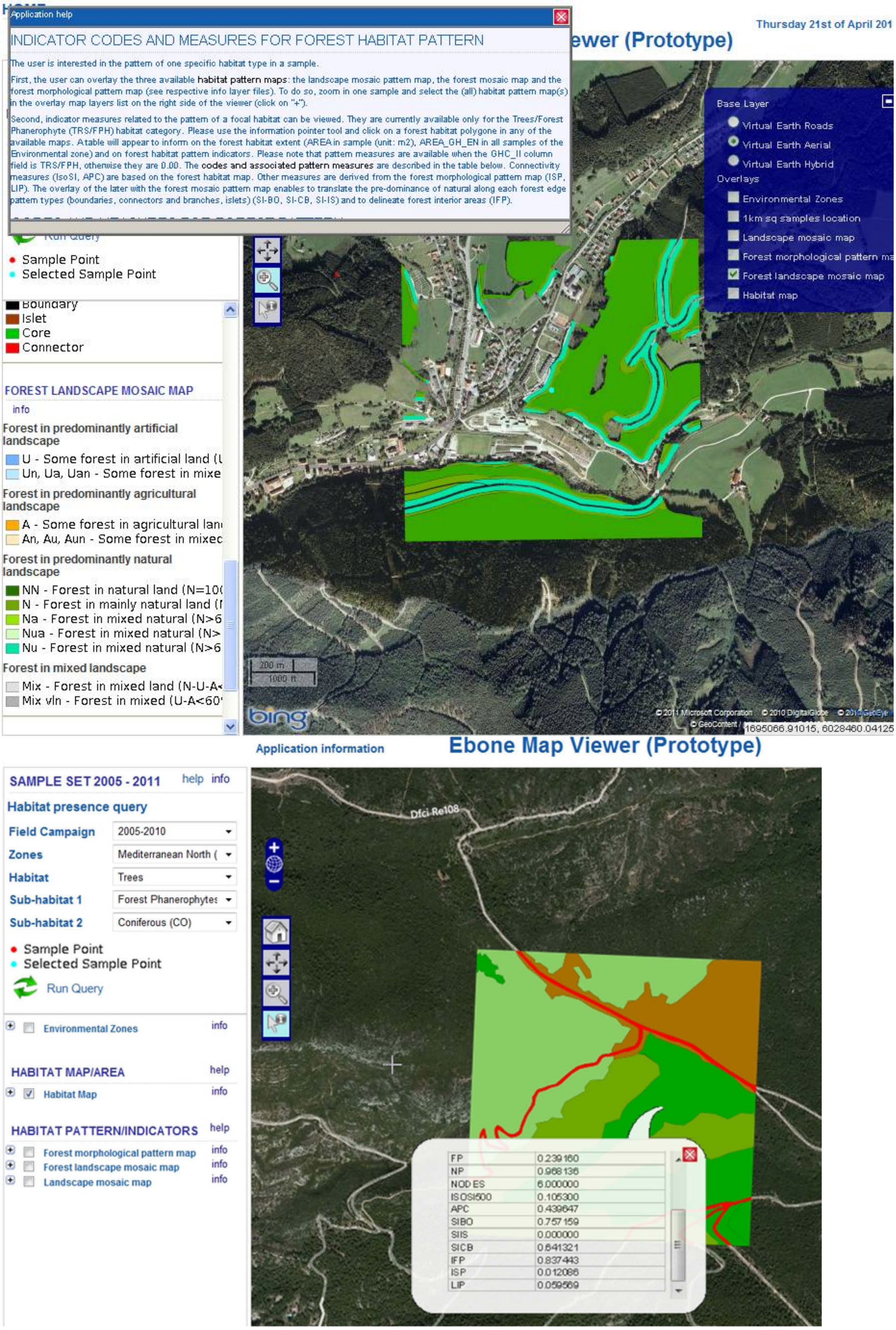


Figure 25

(Top) view of the forest landscape mosaic pattern layer with overlaid the information file layer for indices; (Bottom) Habitat query on indices for the FPH habitat.

To conclude, this study was framed in the landscape ecology research field which is based on the premise that there are strong links between patterns, functions and processes. A number of studies have explored the utility of spatial metrics in landscape analysis since the 1980s and as a result, the number of pattern related indices has proliferated. Nowadays, the potential (non-expert) user, either from landscape planning or environmental local, regional or national agencies or from international agencies, who is looking for one measure of pattern, is left alone in front of this plethora of indices. This study was an attempt to respond to this need of guidelines and standardization to measure pattern. The hypothesis made about user information requirements were about the landscape share of anthropogenic versus more natural habitats, the availability of interior habitat and connecting linear features, the presence of isolated features, the mosaic interface context at edges and the habitat connectivity at landscape level. Focal habitat of interest was arbitrarily decided as forest phanerophyte (FPH).

It is now commonly agreed that no single metric will fully capture the complexity of the spatial arrangement of patches. On the other hand, the combination of multiple components of a pattern into a single value (Bogaert et al., 2000) or the reduction of the number of indices using factor analysis failed in rendering the ecological meaning of the metric to the analyst (Herzog et al., 2001). That's why this study proposed available and well selected pattern models and focused on their customisation, integration and automation for large data processing. Its final aim is to derive a system of standardised ecologically meaningful characterisation of pattern. The three models presented (GUIDOS/MSPA, Landscape mosaic and connectivity models) were revisited to present new indices; they were partly combined and integrated in a common standardised frame. They are spatially explicit; and thus represent both landscape composition and configuration. The landscape level is addressed with focus on the natural -or anthropogenic- dominance of habitats and the proportion of the selected focal habitat. An insight on the morphology of the focal habitat is given and completed by the interface mosaic context of morphological pattern types. The landscape mosaic perspective of landscape pattern is reflected in the connectivity analysis since the matrix is accounted for.

The proposed system of pattern characterisation refers to morphology, interface mosaic context and connectivity. It was successfully applied to the sixty samples available in the EBONE project; each sample was thus easily and quickly characterised in a standardised manner for the forest phanerophyte habitat. The methods could easily be applied to other focal habitat types (herbaceous, cultivated, etc…). The sensitivity of connectivity measures to the matrix permeability (proxy) was pointed out and would require further investigations on how the new indices are affected by the designation of a matrix element. Due to the mono-temporal set of samples, the behavior or response of indices to spatio-temporal variations in landscape pattern could not be checked. Nevertheless, the system of characterization was demonstrated to compare sample based patterns within each available Environmental Zone. Gaps in pattern specific features (e.g. lack of linear features or of natural mosaic context at edges) among the available sample set could easily be identified to further guide the selection of new habitat samples

The methods and system of pattern characterisation here proposed was easily repeated over available Earth Observation based land cover maps to prepare the integration of EO based and in situ habitat pattern assessment. Due to insufficient sample size (1 km^2) and sample population for certain environmental zones, a proper multi-scale and multi-source data assessment could not be done and only an illustration of the scale dependency of the results was provided over few samples. Connectivity analyses were implemented using 25 km x 25 km analysis units providing macro-connectivity information context to the available habitat samples, which in turn were characterized by their micro-connectivity level.

Quantifying spatial pattern is not an end itself, rather it should be the first step to understanding ecological processes. Spatial pattern analysis is of limited value if not used to explain structural changes in landscapes and predict how they influence ecological processes (Li and Wu, 2004). The spatial and temporal dimensions as well as field recording of ecological condition of habitats should be integrated in monitoring programs to increase our understanding of pattern-process relationship. This standardised pattern characterisation will probably ease to conduct such studies (too often restricted to basic patch area measures such as in Krauss et al., 2010) and to compare pattern processes across regions.

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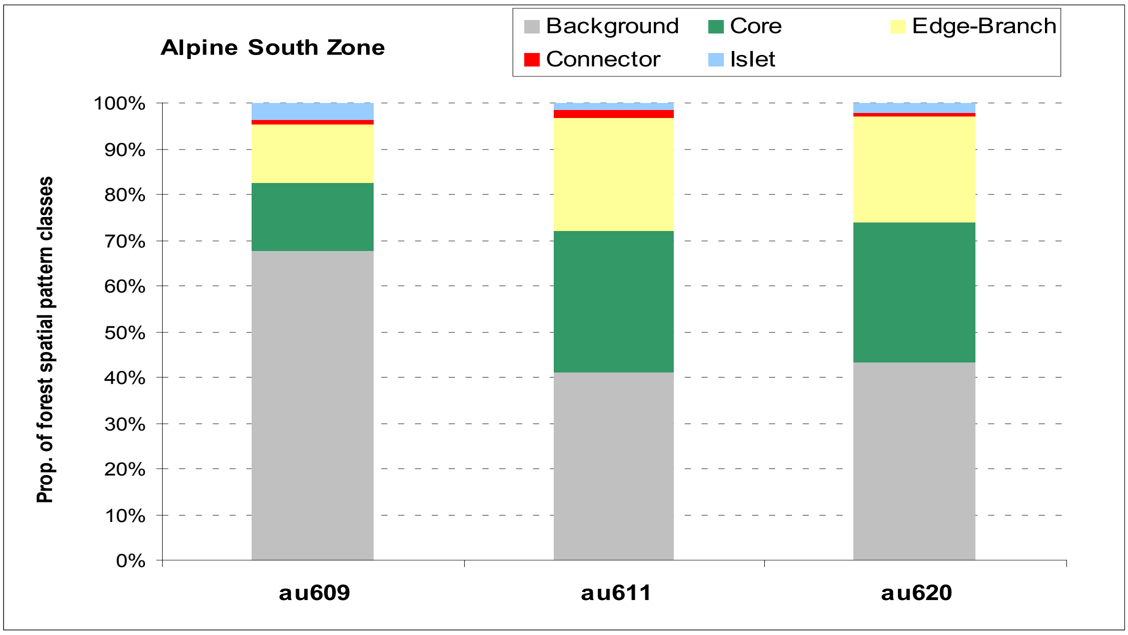
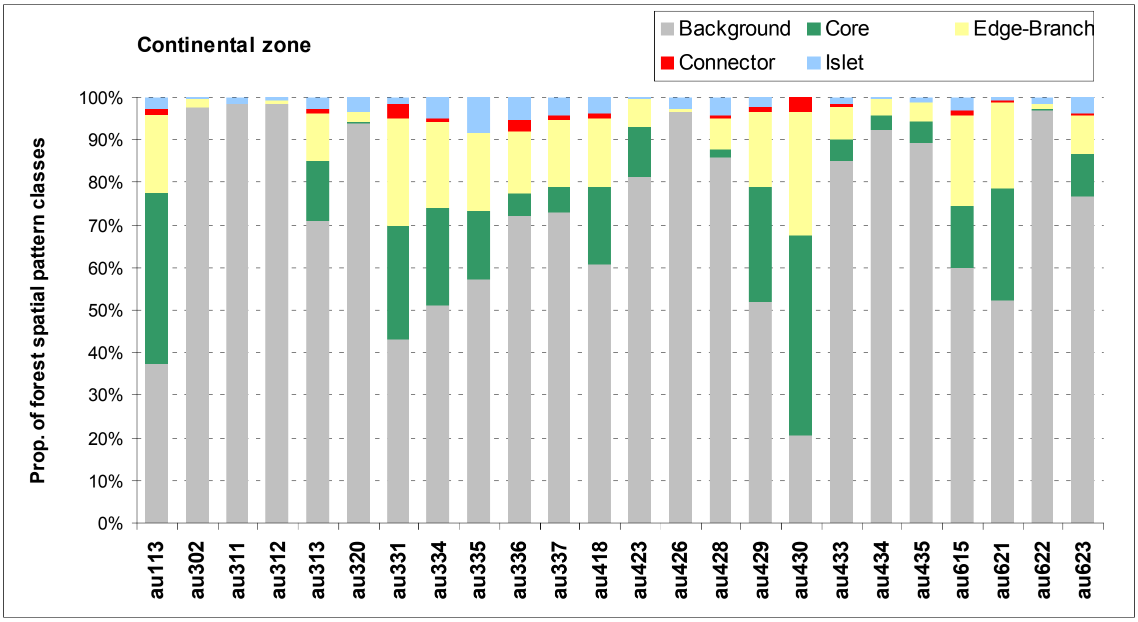
7 Annexes

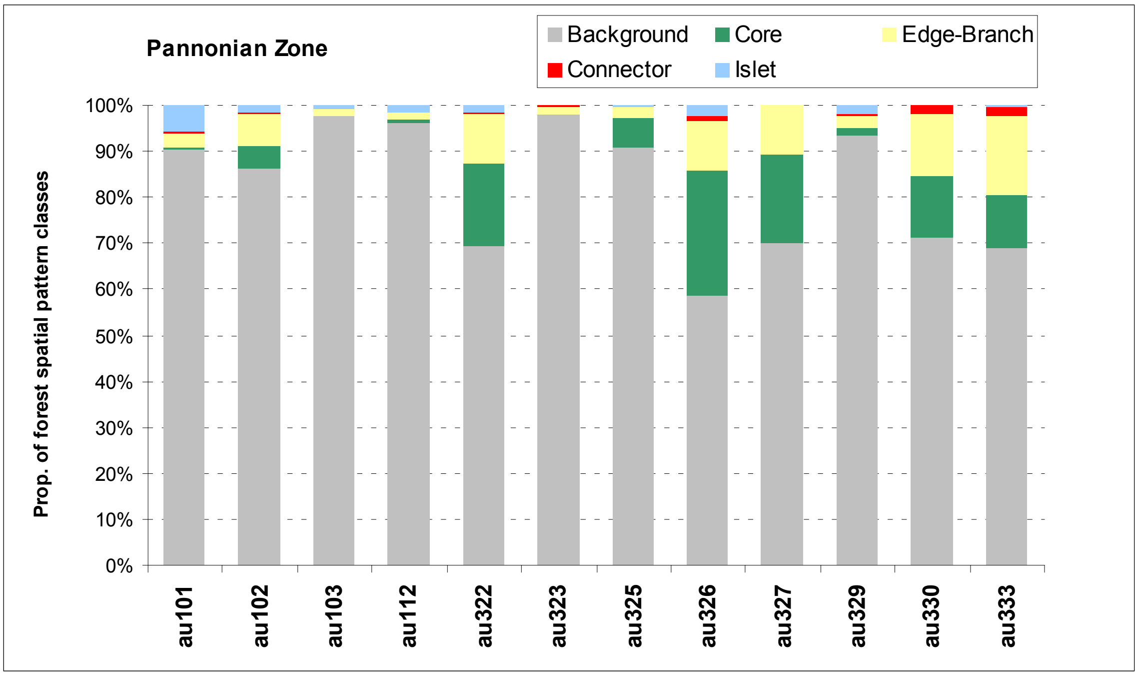
7.1 Annex 1 FPH habitat patterns per environnemental zones

<u>Annexe 1a Morphological pattern of the forest FPH habitat per environmental zones</u>

The charts present for each sample the land proportion other than the FPH habitat (background) and describe the FPH cover share into the four MORPH spatial pattern morphological types






Pannonian Zone
Background
Core
Edge-Branch
Connector
Islet
Prop. of forest spatial pattern classes
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
au101
au102
au103
au112
au322
au323
au325
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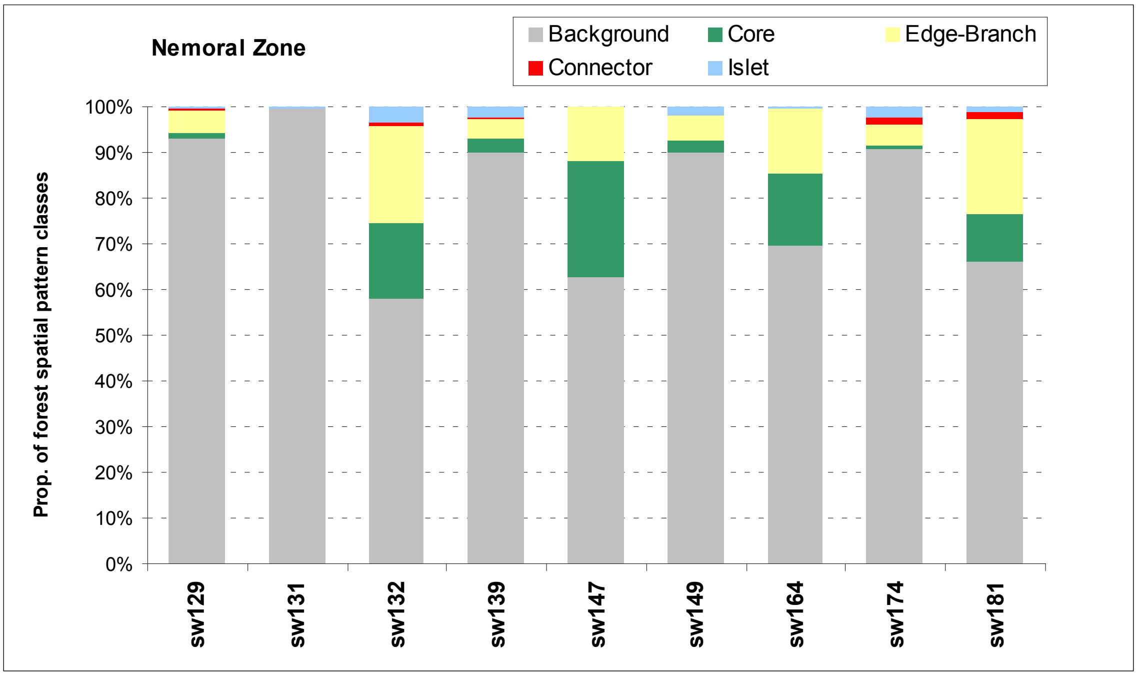
au327
au329
au330
au333


Nemoral Zone
Background
Core
Edge-Branch
Connector
Islet
Prop. of forest spatial pattern classes
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
sw129
sw131
sw132
sw139
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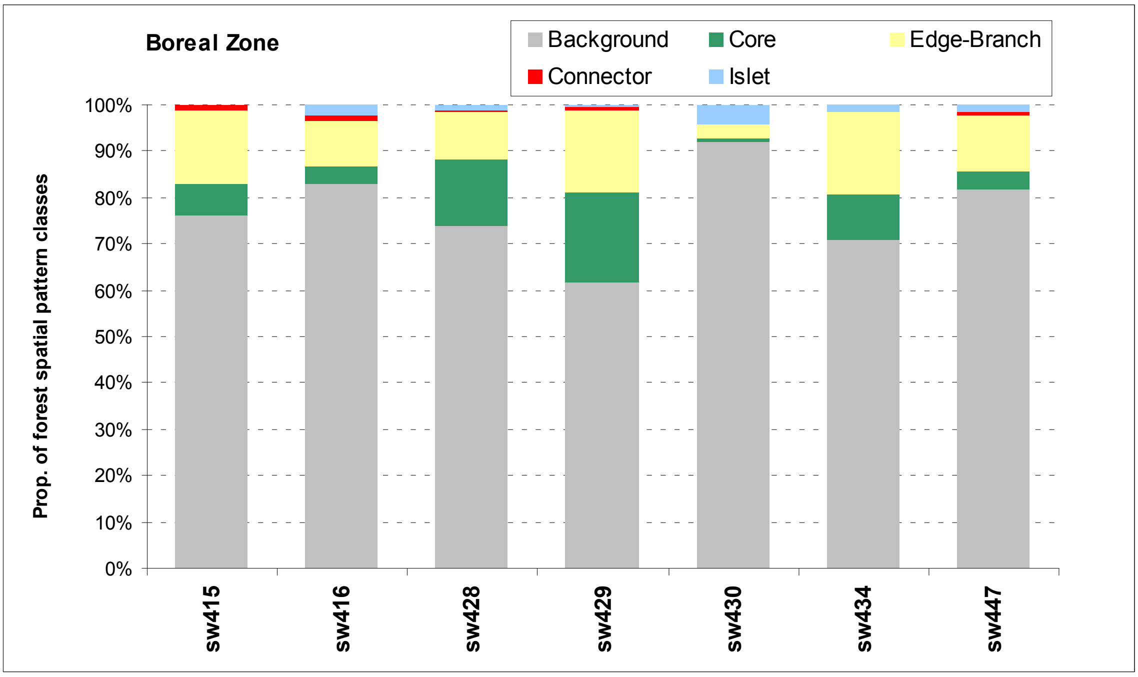
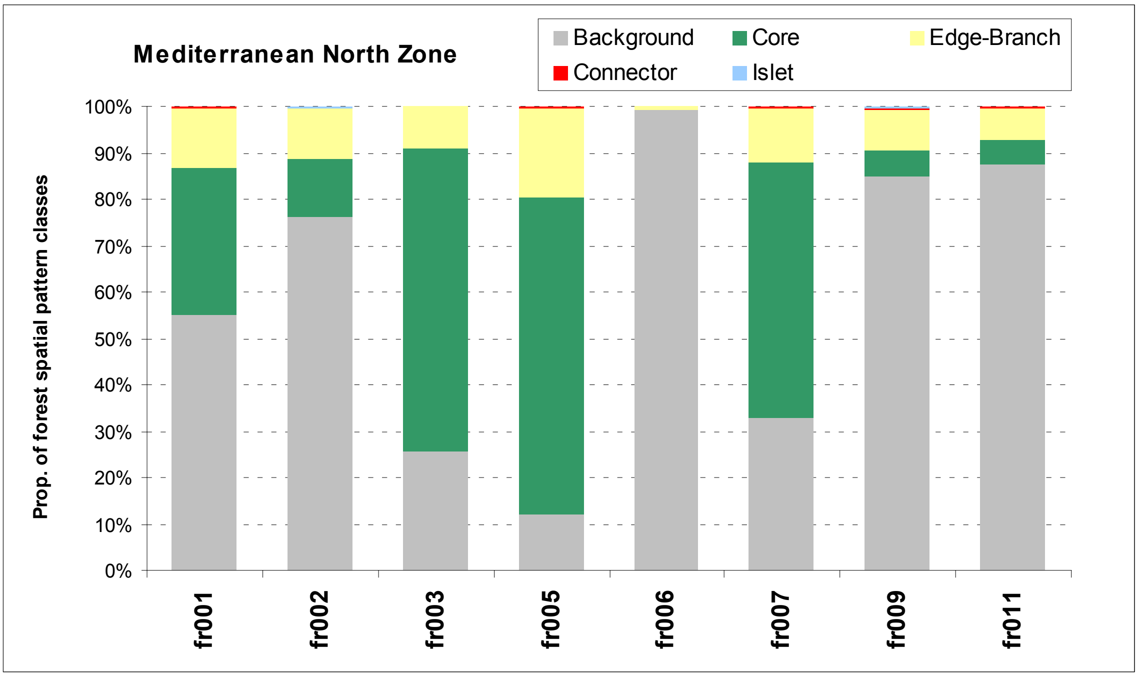
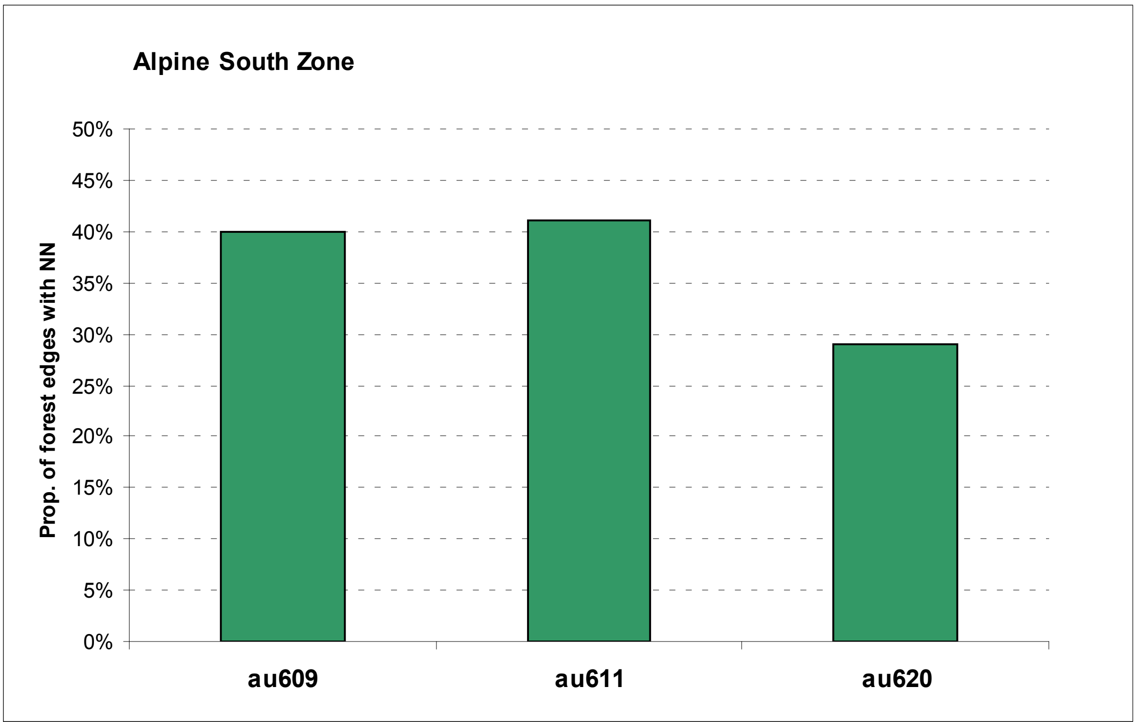
sw149
sw164
sw174
sw181

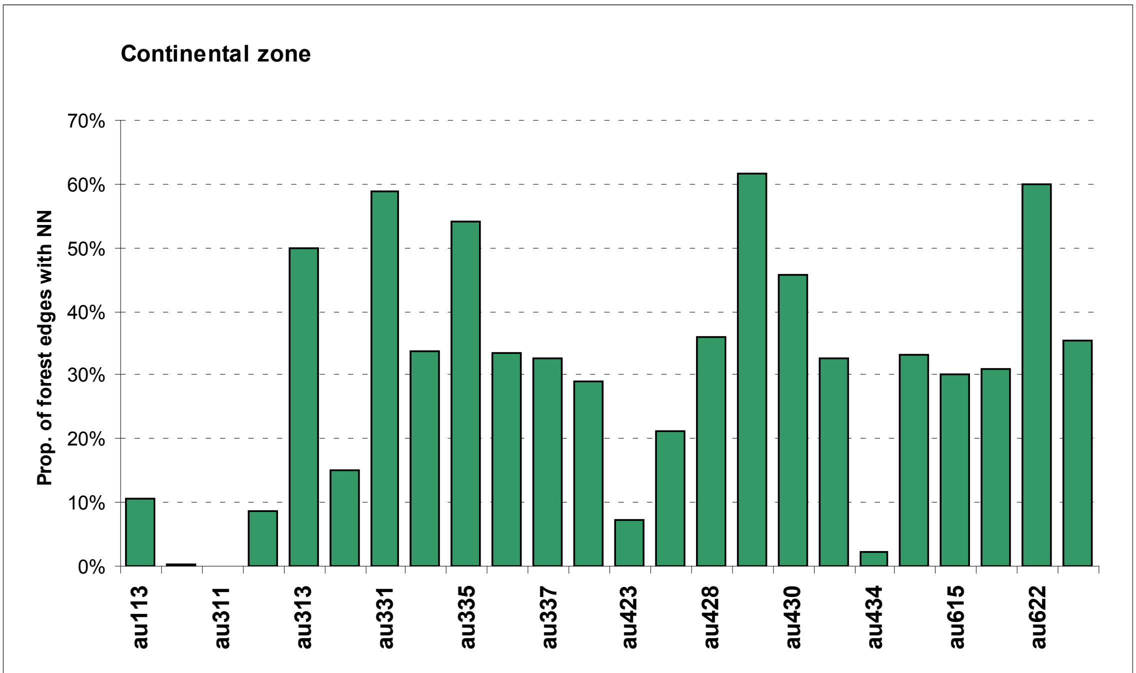

Boreal Zone
Background
Core
Edge-Branch
Connector
Islet
Prop. of forest spatial pattern classes
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
sw415
sw416
sw428
sw429
sw430
sw434
sw447

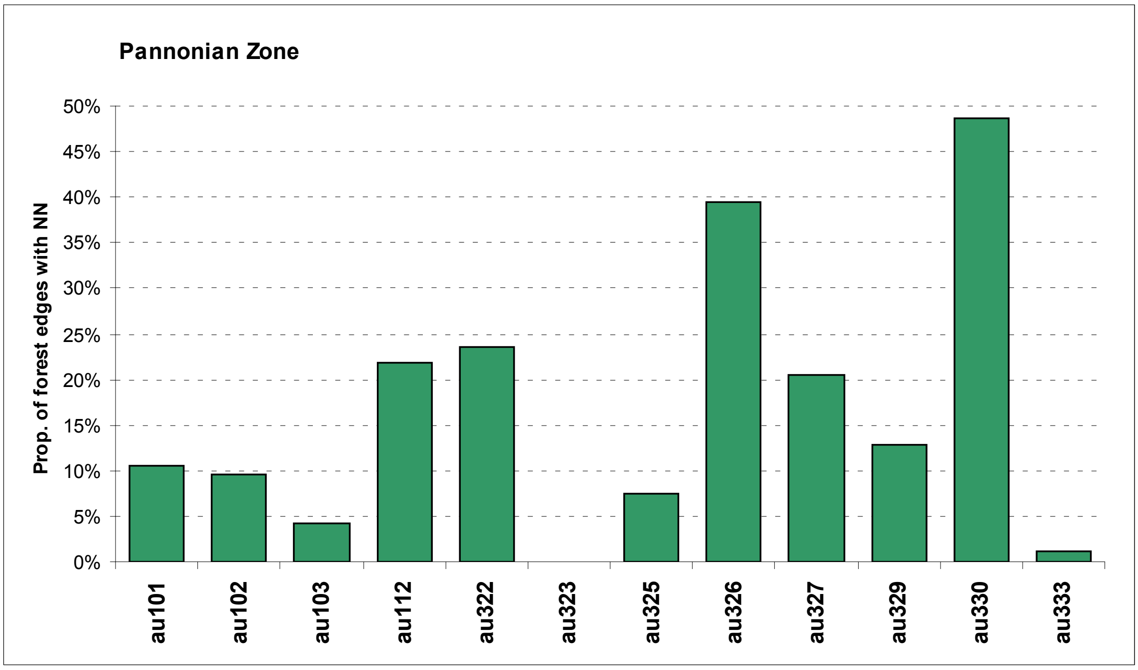

Mediterranean North Zone
Background
Core
Edge-Branch
Connector
Islet
Prop. of forest spatial pattern classes
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
fr001
fr002
fr003
fr005
fr006
fr007
fr009
fr011

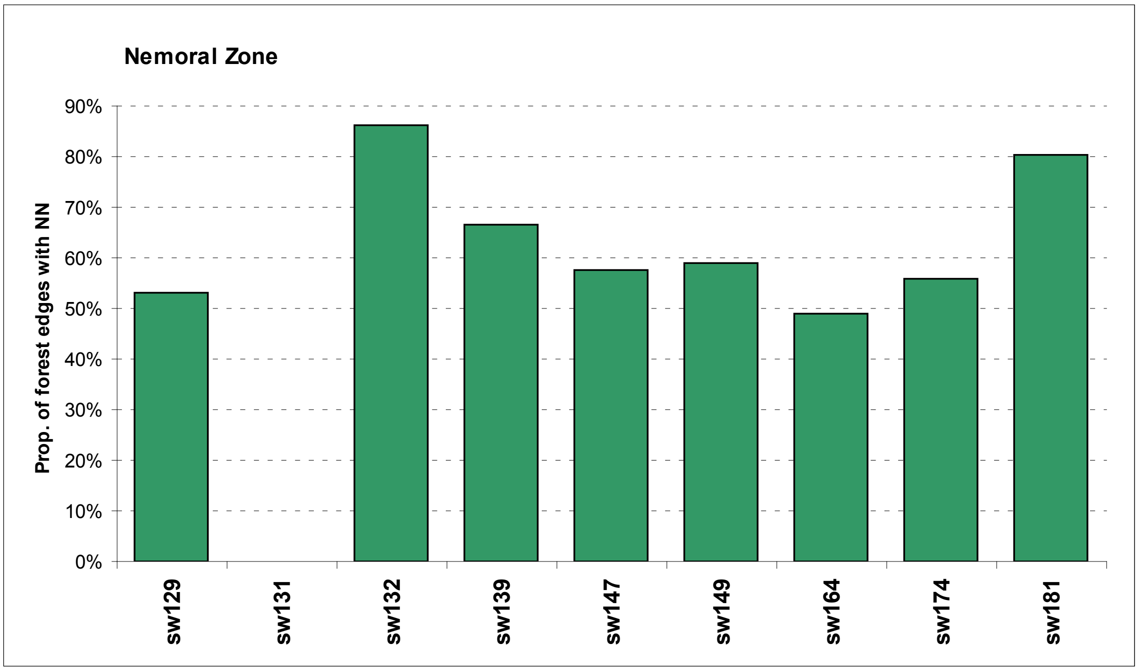
Annexe 1b Forest FPH habitat 'natural' edges types per environmental zones

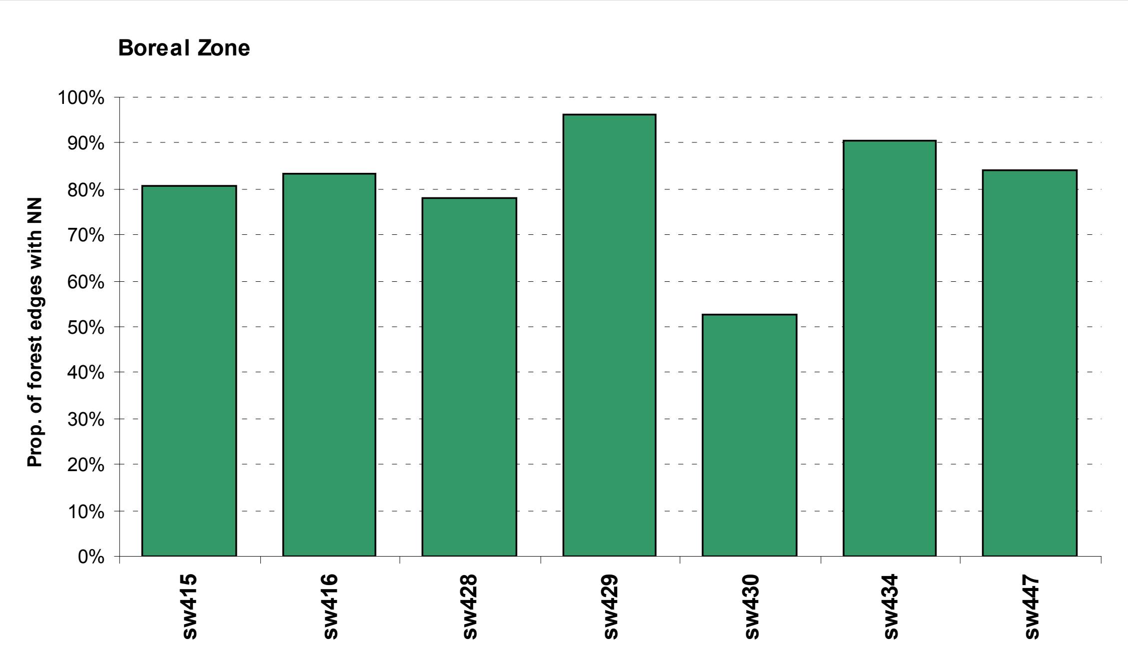
The charts show the proportion of FPH habitat edges which are always adjacent to natural/semi-natural non-FPH habitats (NN). The analysis method is based on the combination of the morphological and mosaic pattern map layers and on the computation of the index $SI\text{-}BO_{NN}$.

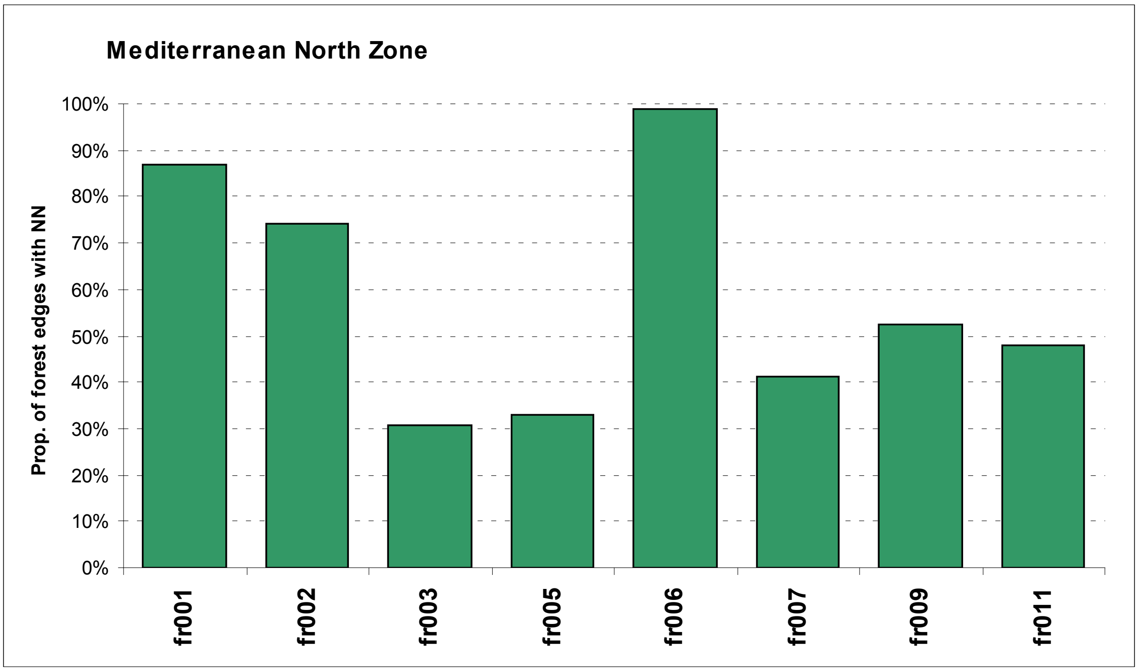





Pannonian Zone
Prop. of forest edges with NN
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
au101
au102
au103
au112
au322
au323
au325
au326
au327
au329
au330
au333

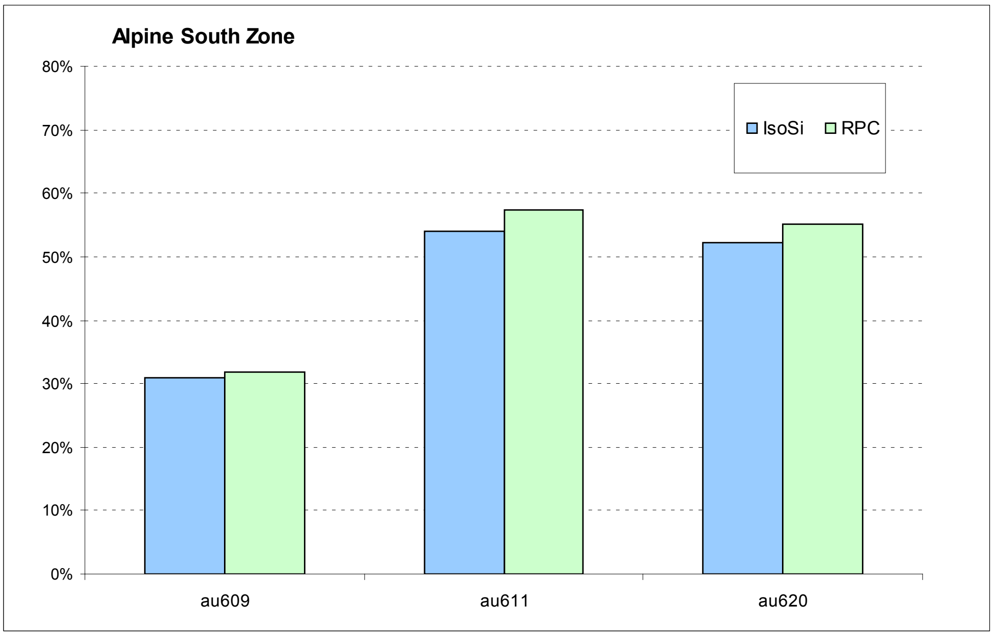

Nemoral Zone
Prop. of forest edges with NN
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
sw129
sw131
sw132
sw139
sw147
sw149
sw164
sw174
sw181

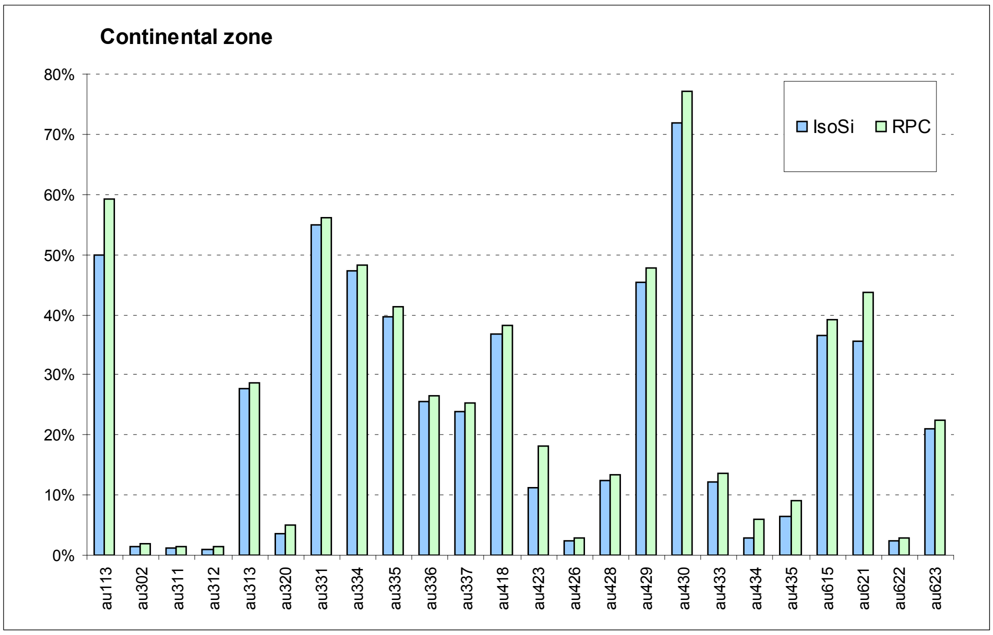

Boreal Zone
Prop. of forest edges with NN
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
sw415
sw416
sw428
sw429
sw430
sw434
sw447

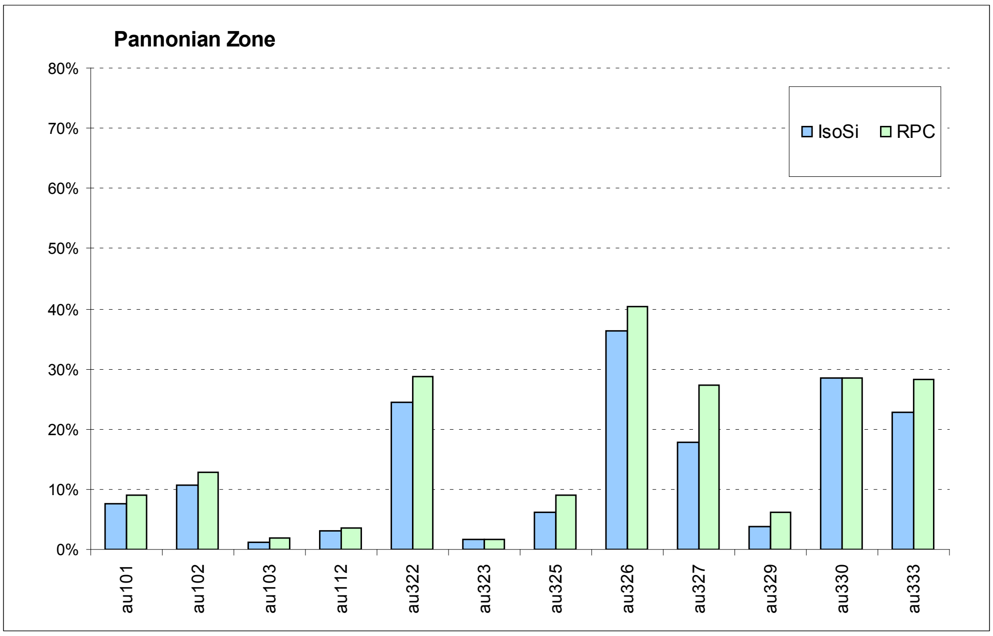

Mediterranean North Zone
Prop. of forest edges with NN
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
fr001
fr002
fr003
fr005
fr006
fr007
fr009
fr011

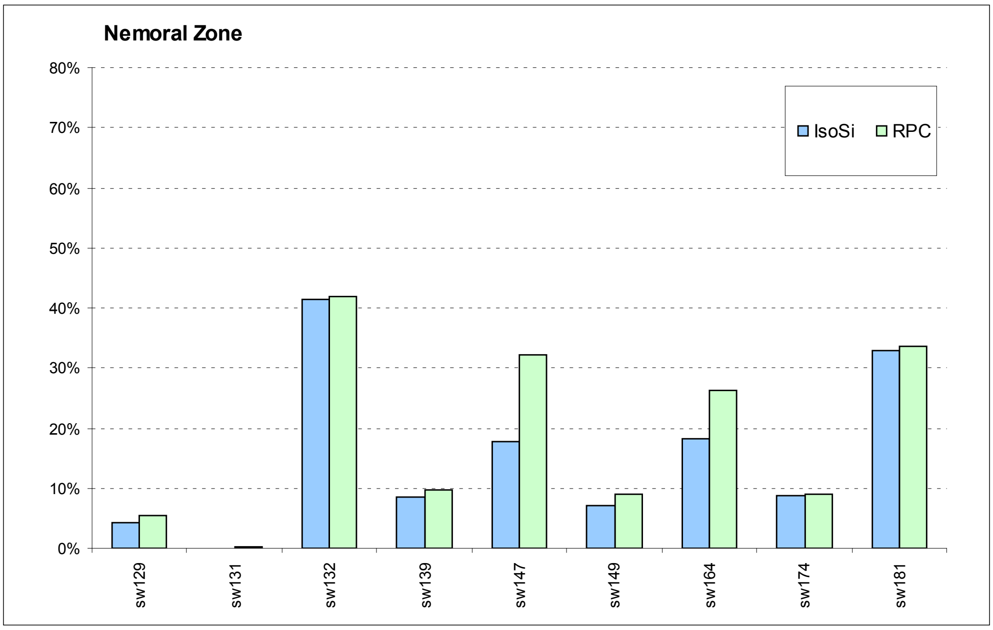
Annex 1c Habitat connectivity per environmental zones

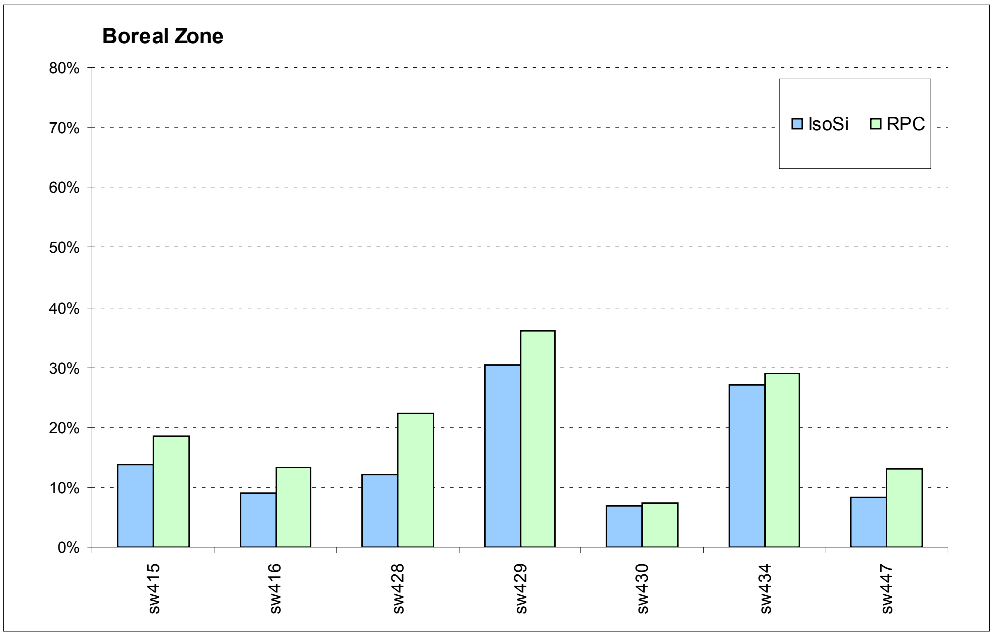
The charts show two connectivity indices (RPC and Isolation sensitive IsoSi indices). Both indices ranges from 0% to 100% (maximally connected).

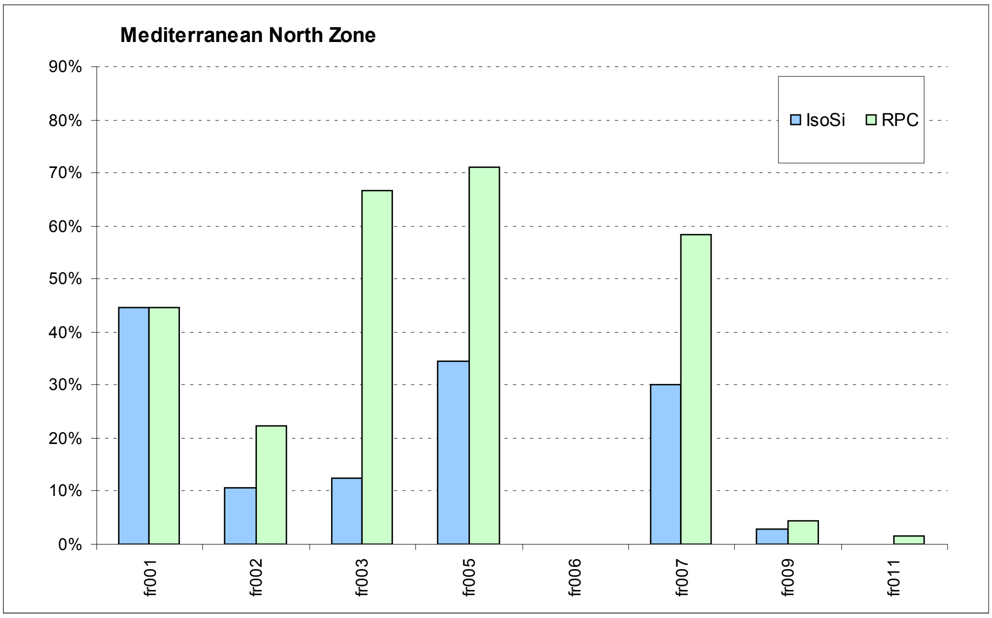





Pannonian Zone
80%
70%
60%
50%
40%
30%
20%
10%
0%
IsoSi
RPC
au101
au102
au103
au112
au322
au323
au325
au326
au327
au329
au330
au333

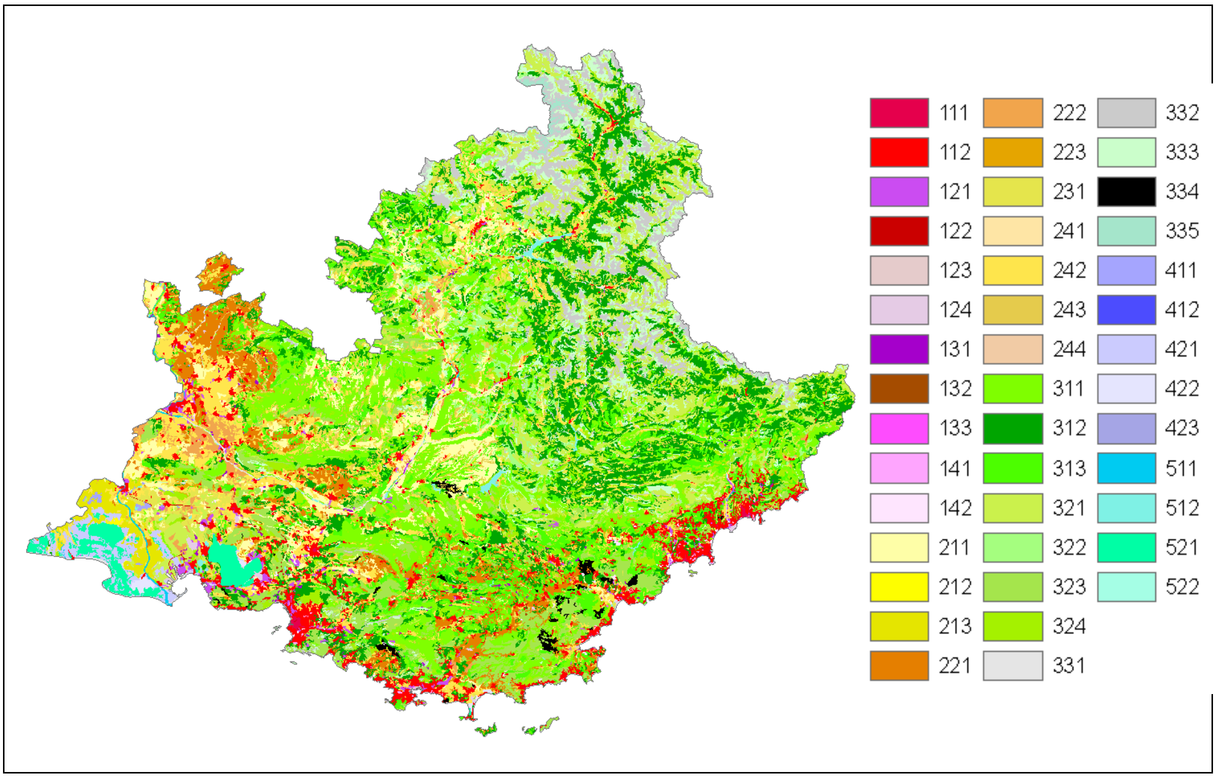

Nemoral Zone
80%
70%
60%
50%
40%
30%
20%
10%
0%
IsoSi
RPC
sw129
sw131
sw132
sw139
sw147
sw149
sw164
sw174
sw181


Boreal Zone
80%
70%
60%
50%
40%
30%
20%
10%
0%
IsoSi
RPC
sw415
sw416
sw428
sw429
sw430
sw434
sw447


Mediterranean North Zone
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
IsoSi
RPC
fr001
fr002
fr003
fr005
fr006
fr007
fr009
fr011

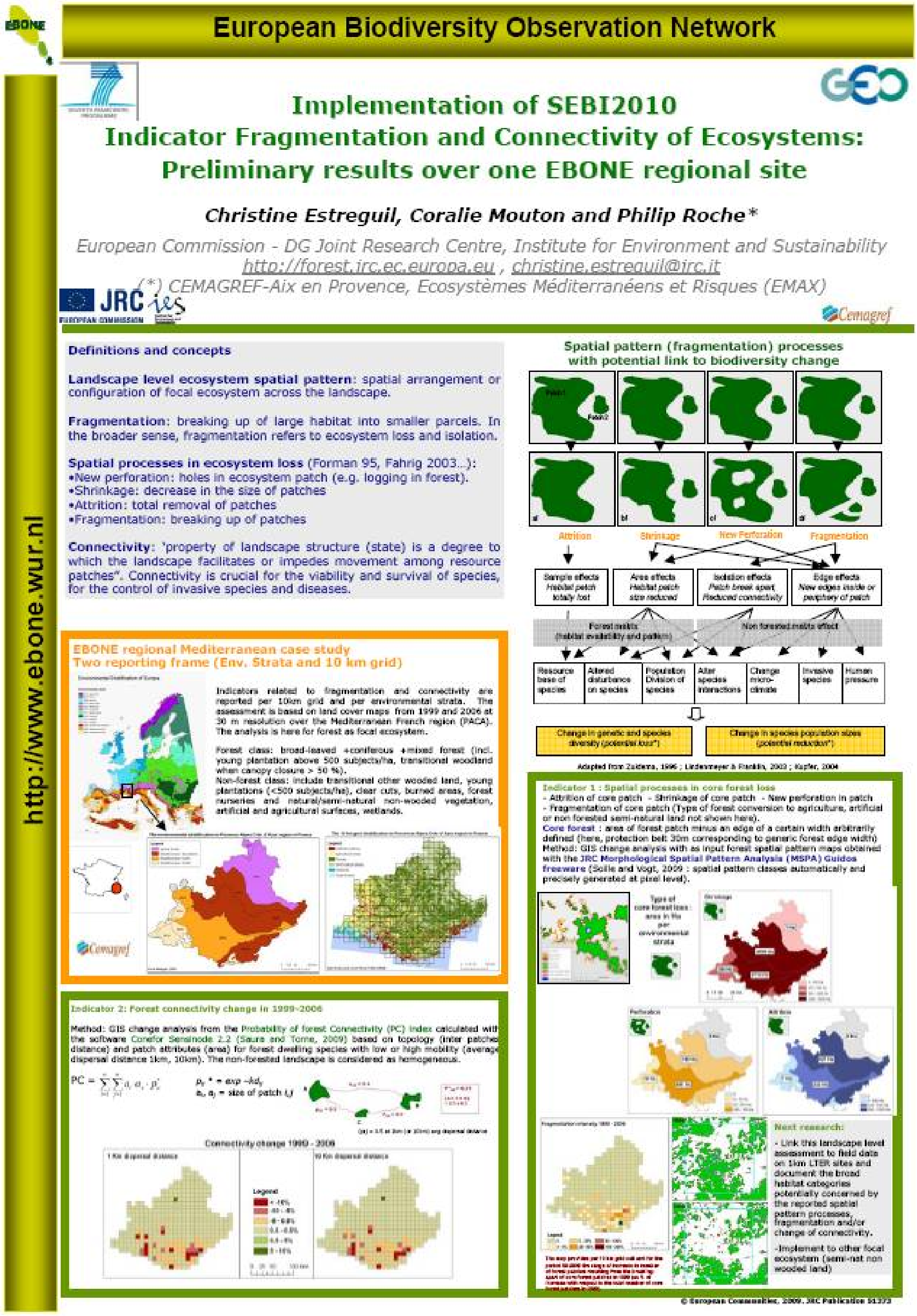
7.2 Annex 2 Medium scale (1ha MMU) Land cover map

CLC based land cover map over the French PACA region (CRIGE PACA land cover map, 2007)



CORINE CODE	DESCRIPTION	FRICTION VALUE
111	Continuous urban fabric	10000
112	Discontinuous urban fabric	10000
121	Industrial or commercial units	10000
122	Road and rail networks and associated land	10000
123	Port areas	10000
124	Airports	10000
131	Mineral extraction sites	10000
132	Dump sites	10000
133	Construction sites	10000
141	Green urban areas	5000
142	Sport and leisure facilities	5000
211	Non-irrigated arable land	200
212	Permanently irrigated land	200
213	Rice fields	200
221	Vineyards	100
222	Fruit trees and berry plantations	100
223	Olive groves	100
231	Pastures	10
241	Annual crops associated with permanent crops	100
242	Complex cultivation patterns	200
243	Land principally occupied by agriculture, with significant areas of natural vegetation	50
244	Agro-forestry areas	50
311	Broad-leaved forest	1
312	Coniferous forest	1
313	Mixed forest	1
321	Natural grasslands	10
322	Moors and heathland	10
323	Sclerophyllous vegetation	5
324	Transitional woodland-shrub	1
331	Beaches, dunes, sands	10
332	Bare rocks	10
333	Sparsely vegetated areas	10
334	Burnt areas	10
335	Glaciers and perpetual snow	10
411	Inland marshes	10
412	Peat bogs	10
421	Salt marshes	10
422	Salines	10
423	Intertidal flats	10
511	Water courses	5000
512	Water bodies	5000
521	Coastal lagoons	5000
522	Estuaries	5000

7.3 Annexes 3 and 4 EBONE related flyer/posters



EBONE

European Biodiversity Observation Network

http://www.ebone.wur.nl

Habitat level implementation of the SEBI2010 Indicator Fragmentation and Connectivity of Ecosystems

Christine Estreguil, Giovanni Caudullo

European Commission - DG Joint Research Centre, Institute for Environment and Sustainability
http://forest.jrc.ec.europa.eu/forest-pattern , christine.estreguil@jrc.ec.europa.eu

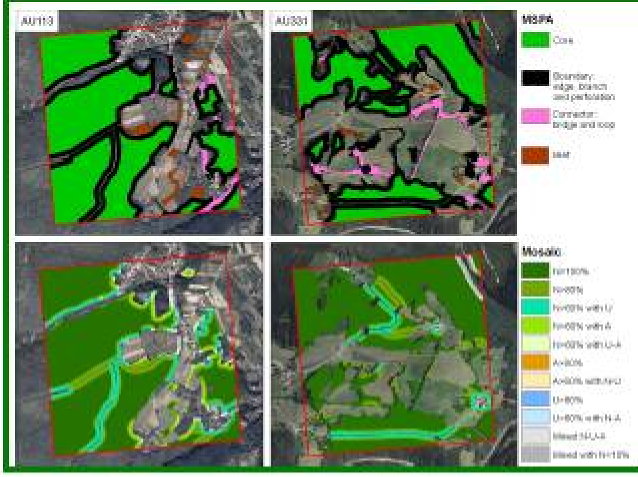
The EBONE project aims at European-wide habitat mapping to deliver area estimates and characterize habitat pattern, fragmentation and connectivity. Methodologies should be standardized and easily repeatable across scales. Reporting is expected by using the European Environmental Stratification. Automatic mapping and assessment of spatial pattern and connectivity are demonstrated for forest phanerophytes from the EBONE 1 km² in-situ samples, which offer harmonized General Habitat Categories maps.

Landscape level spatial pattern: spatial arrangement of a focal habitat across the landscape. Interior and edge habitats with their landscape context are important to discriminate.

Fragmentation refers to loss of habitat area and connectivity (increased isolation). Shift of land uses at the edges of certain habitat types also relate to fragmentation.

Connectivity is the "degree to which the landscape facilitates or impedes species movement among resource patches". It depends on habitat availability (area) and topology (inter-patch distance), species' dispersal abilities and landscape matrix permeability. Connectivity is crucial for the viability and survival of species, for the control of invasive species and diseases.

General Habitat Categories maps (400 m² Minimum Mapping Unit): 'Urban', 'Cultivated', natural 'Sparsely Vegetated' (vegetation cover below 30%), 'Herbaceous', 'Trees/Shrubs', further described according to 16 life forms based on plant characteristics (height and leaf retention division). The 4 Trees/phanerophytes classes are forest (>5 m), tall, mid, low.



Tools and products

- Forest phanerophytes cover detailed into 4 pattern classes using the mathematical morphology spatial pattern analysis (MSPA) GUIDOS freeware with a 25 m edge width (top 2 maps).
- Forest context mapped using a landscape mosaic index: natural (N), cultivated (A) or urban (U) habitat dominant contexts (25 m radius disk around each forest pixel) (bottom 2 maps)
- Connectivity assessed with two indices (freeware http://www.conefor.org) for forest species with specific dispersal abilities.

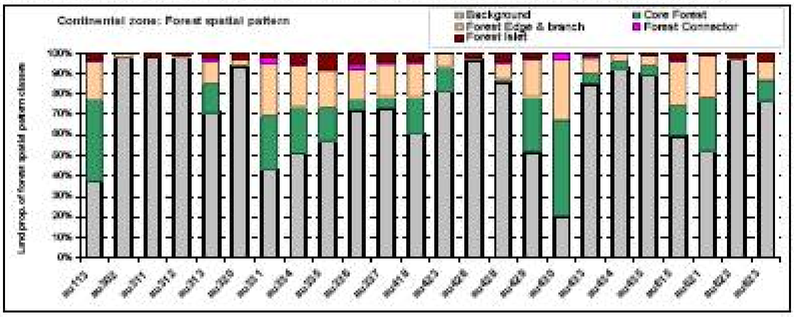
EBONE

European Biodiversity Observation Network

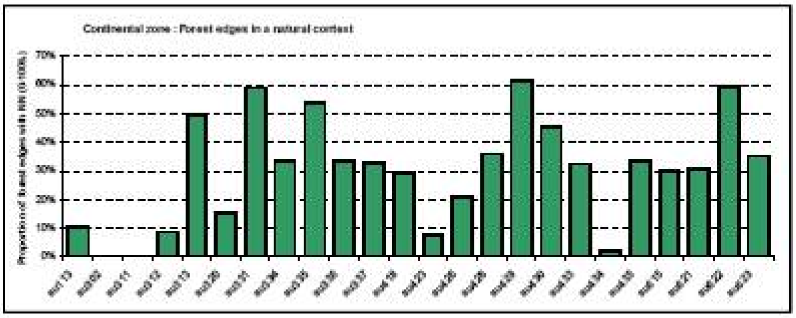
http://www.ebone.wur.nl

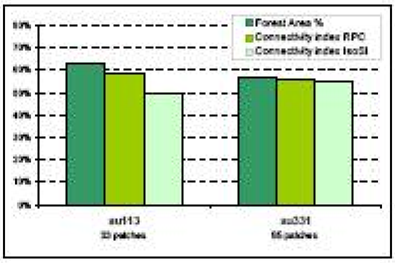
Habitat level implementation of the SEBI2010 Indicator Fragmentation and Connectivity of Ecosystems

Spatial pattern of forest phanerophytes: differences among the in-situ samples in an environmental zone are shown on the proportion of forest habitats, core habitat versus edge habitat, proportion of small isolated elements (islets), proportion of connecting elements (connectors between core patches)



Natural dominance in the surroundings of forest edges: forest edge communities are possibly influenced by their adjacent non forested habitats, which "similarity" to forest tells about the permeability of interfaces. Forests fragmented by natural habitats (like herbaceous), therefore with a high proportion of forest edges in a natural context (NN) are intuitively less vulnerable to further fragmentation than forests fragmented by anthropogenic sources (cultivated and urban habitats).



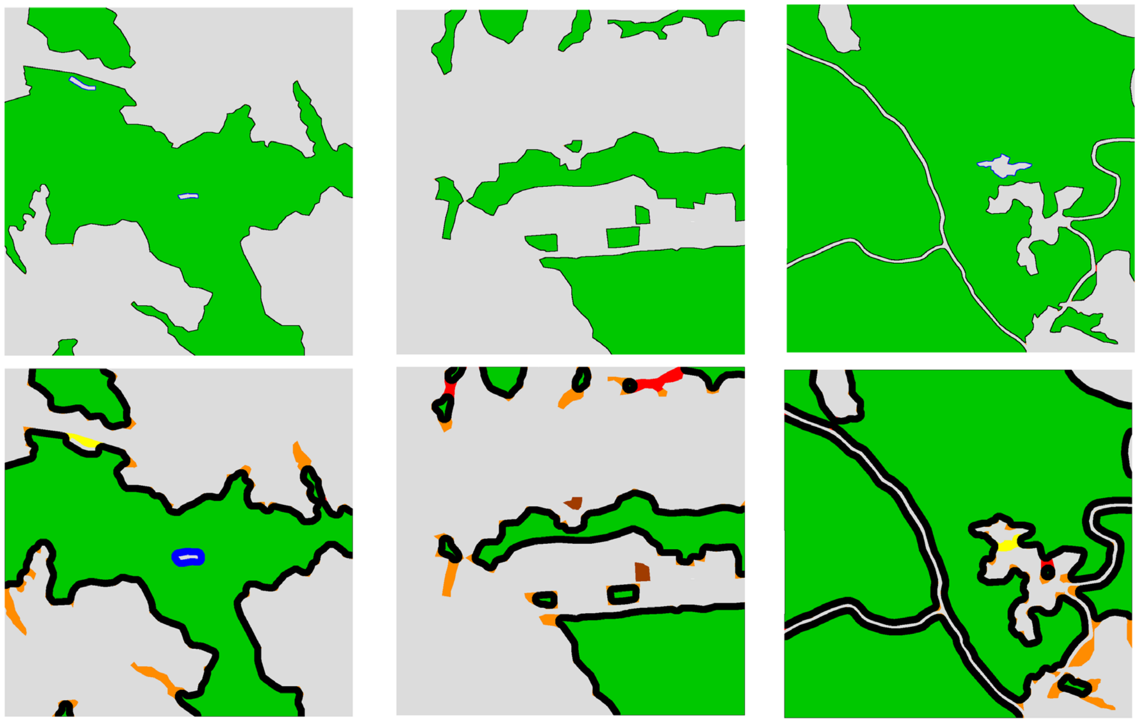


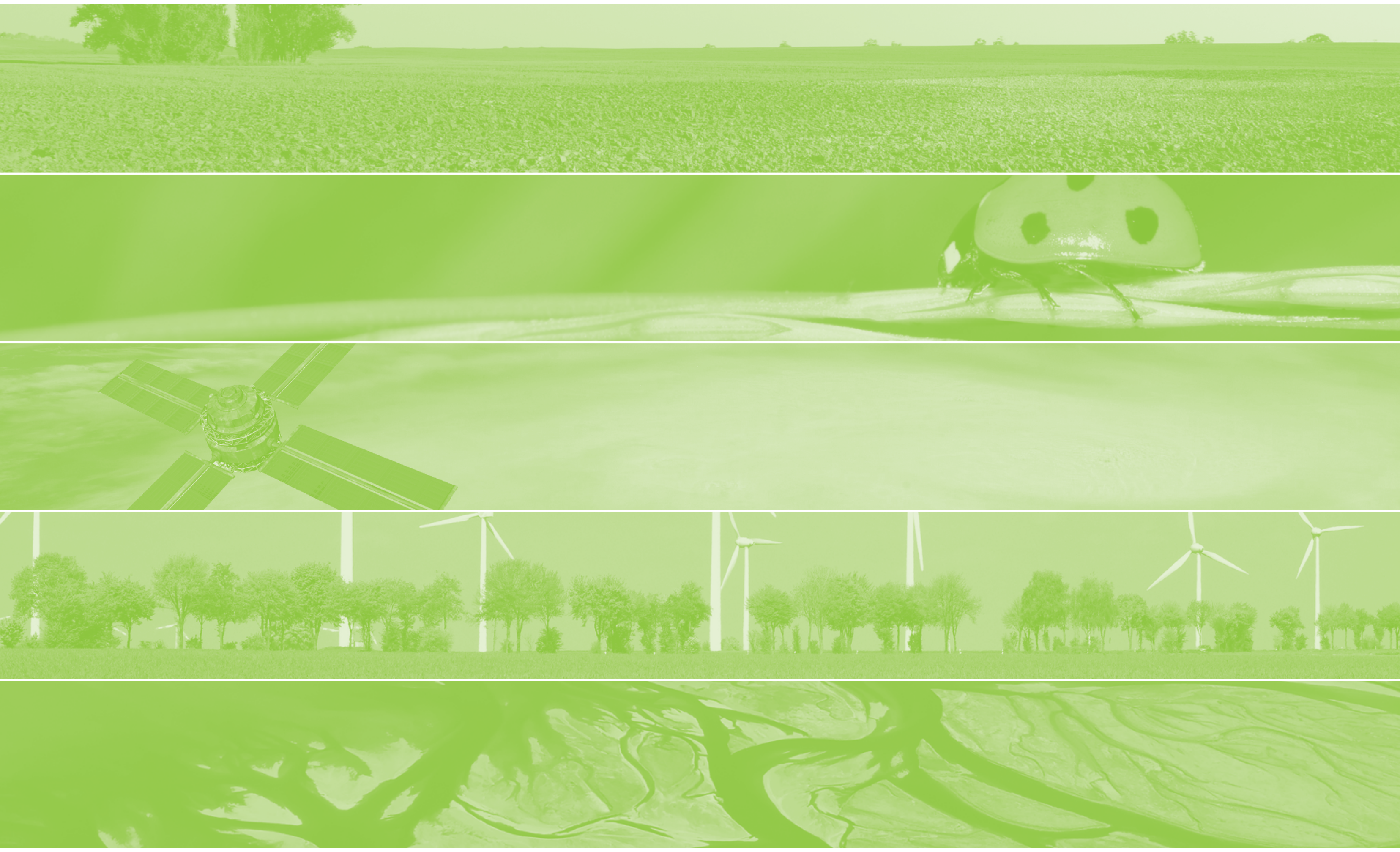
Forest connectivity is calculated for species dispersing in average 500m distance and accounts for the cost of movement through the different habitats between the forest patches.

This chart shows how the two connectivity indices assess different forest spatial patterns and permeability contexts (au113 with fewer and large nodes and a less permeable landscape than the sample au331). IsoSI is more sensitive to the inter-patch landscape permeability and barrier effects while RPC reacts more to forest habitat area and pattern.

7.4 Annex 5 Morphological MSPA analysis with different edge sizes

Edge size MSPA input parameter 1 m (top) and 25 m (bottom) on forest FPH habitat maps





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Alterra is the research institute for our green living environment. We offer a combination of practical and scientific research in a multitude of disciplines related to the green world around us and the sustainable use of our living environment, such as flora and fauna, soil, water, the environment, geo-information and remote sensing, landscape and spatial planning, man and society.

More information: www.alterra.wur.nl/uk